University of Nebraska-Lincoln

2017-2018 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 Midwest High-Power Rocketry Competition. For this challenge, each team must design a rocket that is able to orient itself in an indicated cardinal direction as well as hold a specified orientation for a certain period of time. To measure the rocket's instantaneous roll speed, roll direction, and compass orientation, Husker Rocketry will utilize two onboard inertial measurement units and an accelerometer. A payload consisting of a flywheel attached to a gearbox and motor will roll-orient the rocket using conservation of angular momentum. A motor specifications calculator was used to determine flywheel, DC motor, and gearbox parameters. The flywheel was modeled and tested using SolidWorks Finite Element Analysis (FEA) program. The rest of the rocket was designed with OpenRocket using competition criteria and modeled using SolidWorks. Based on the results given by software and inter-team discussion, a standard 3.9 inch (9.9 cm) body tube diameter was selected with an overall rocket length of 60.2 inches (1.53 m). Specific dimensions regarding the rocket's internal components will be discussed further in the report. Using these dimensions, a design was modeled in OpenRocket that has a predicted apogee of 4803 ft (1464 m). The analysis shows it will remain stable for the entire flight. The payload compartment will be placed above the booster section and main parachute. Recovery will be accomplished using a single-deployment system. This involves one Stratologger firing an ejection charge for the parachute at apogee for recovery with a redundant electronic system and motor ejection charge to ensure parachute deployment. The main propulsion system will be a Cesaroni J760 White Thunder solid motor. One competition motor is requested, with the other being purchased separately. With the motor loaded, the mass of the entire rocket is expected to be 12.5 lbs (5.66 kg).

2 Design Features of Rocket Airframe

The main fuselage of the rocket consists of an ogive nosecone, a body tube for the purpose of housing the electronics related to the flight instrumentation as well as the payload operation, a payload can for housing the active roll control system, a booster tube containing the parachute as well as the motor and its inner phenolic tube housing, a set of three fins, and a tail cone for holding the motor tube and phenolic tube in place. The active roll orientation system is a machined flywheel connected to a DC motor equipped with a gearbox and mounted to a machined bracket affixed to the electronics can.

2.1 Fuselage Specifics and Dimensioning

The ogive nose cone is made of fiberglass and has a length of 15.7 in (40 cm), a base diameter of 4.01 in (10.2 cm), and a wall thickness of 0.04 in (0.102 cm). The electronics body tube is made of wrapped carbon fiber and has a length of 10 in (25.4 cm), an outer diameter of 4.01 (10.2 cm,) and a wall thickness of 0.056 in (0.142 cm). The electronics/payload can is made of machined 6061-T6 aluminum and has a total length of 8.5 in (21.6 cm) (including the exposed and coupler portions). The coupler possesses an outer diameter of 3.9 in (9.91 cm) and a wall thickness of 0.062 in (0.159 cm). The exposed section of the can has a length of 2 in (5.08 cm), an outer diameter of 4.01 in (10.2 cm), and a wall thickness of 0.065 in (0.165 cm). The booster tube is also constructed of wrapped carbon fiber and has a length of 10 in (76.2 cm), an outer diameter of 4.01 in (10.2 cm), and a wall thickness of 0.056 in (0.142 cm). The trapezoidal fin set consists of three custom fiberglass fins, each possessing a root chord of 12 in (30.5 cm), a tip chord of 3.5 in (8.89 cm), a height of 3.5 in (8.89 cm), a sweep length of 6.6 in (16.7 cm), and a sweep angle of 62°. The tail cone is made of 6061-T6 machined aluminum with a length of 2.5 in (6.32 cm) and an initial diameter of 4.01 in (10.2 cm). Two nylon 1010 rail buttons, one at the center of mass and the other centered between the fins at the base will be used. They will be mounted opposite of the camera.

2.2 Internal Components of Booster Section

As previously mentioned in Design Features of the Airframe, the rocket motor casing will be housed in a phenolic tube. The phenolic tube is affixed to centering rings made of 1/8th inch Finnish Birch aircraft plywood. The fins have notches on their bases which interlock with the centering rings. The centering rings, phenolic tube, and fins are all bonded with 635 epoxy resin from U.S. Composites, Inc.

2.3 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 rocket lies 33.3 in (84.5 cm) from the tip of the nose cone, and the center of pressure of the rocket lies 39.1 in (99.3 cm) from the tip of the nose cone.

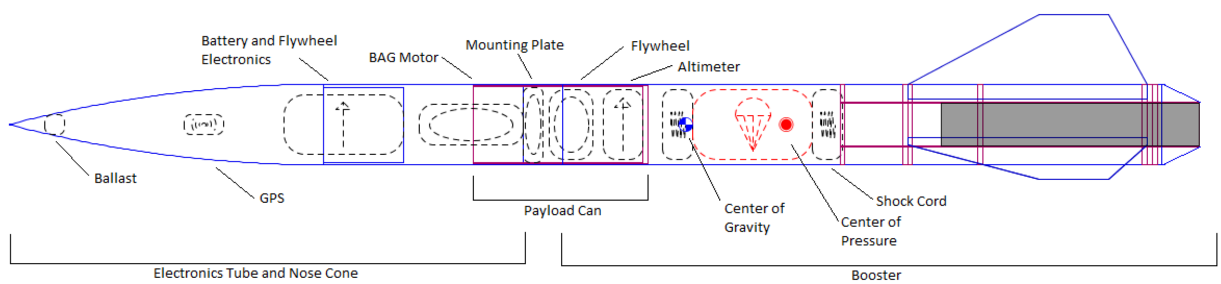


Figure 1: Diagram of the rocket with relevant masses and parachutes.

3 Design Features of the Payload

The payload of the rocket will be composed of the roll orientation system and its electronics, the recovery components, and radio ground telemetry. The rocket's roll orientation is controlled by a flywheel using the principle of conservation of angular momentum.

3.1 Active Roll Orientation System Design

3.1.1 Hardware

The active roll control system utilized by the rocket is composed of a flywheel machined of AISI 1020 steel affixed to a VexPro VersaPlanetary 3:1 Gearbox and its accompanying VersaPlanetary Integrated Encoder. The gearbox and flywheel are driven by a VexPro BAG motor. The entire assembly is attached to a mounting plate made of 6061 T6 aluminum attached to the fuselage. The flywheel is attached to a 0.5 inch (1.27 cm) gearbox hex shaft by two VexPro heavy duty shaft collars, one above and one below.

Components were designed to be lightweight yet strong enough to handle high power rocketry dynamics. The flywheel consists of a central hub and a thin-walled cylinder connected by 6 spokes. The mounting plate is a short disk with a raised outer edge. This outer edge has four threaded holes for mounting to the aluminum payload can. The plate also has four holes for the gearbox screws and a central hole for the shaft.

3.1.2 Finite Element Analysis

Finite Element Analysis (FEA) was done using the built-in simulation feature of SolidWorks. This was especially important for the flywheel, which will be potentially spinning over one thousand rpm and will be experiencing potentially extreme amounts of torque. Of particular concern was the ability of the spokes to handle the torque as a result of the flywheel's high rate of rotation. FEA was therefore conducted as a static study of torque on the system.

To create an accurate simulation of the potential effects of torque on the system, a reasonable value for torque experienced by the flywheel needed to be determined. This was done by determining the moment of inertia of the flywheel itself as well as making an estimate for the acceleration of the flywheel based on the BAG motor specifications. Using values of 2.12 lb·in^2 for the moment of

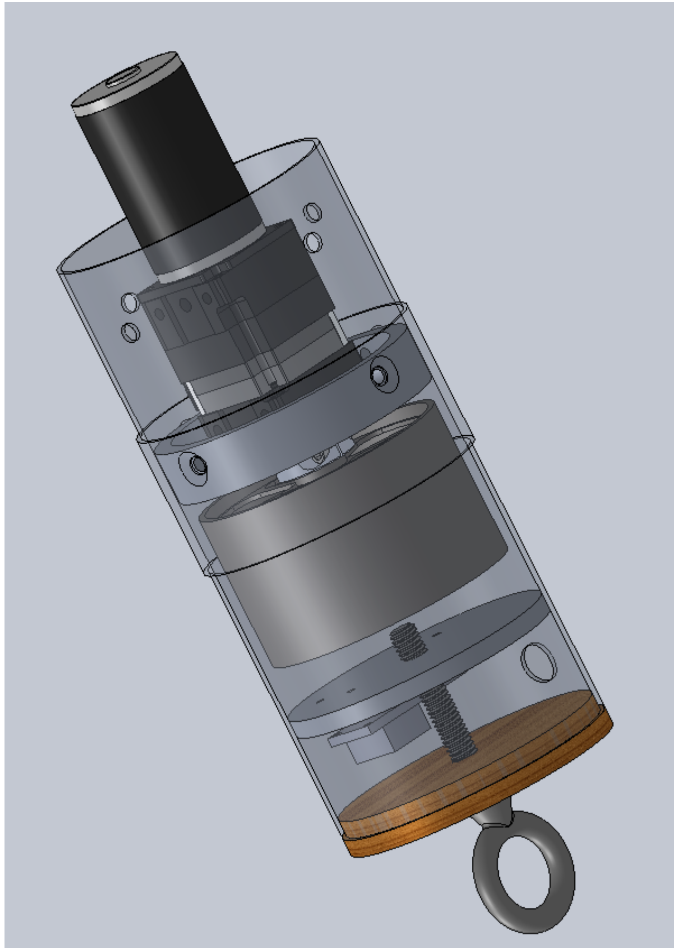


Figure 2: SolidWorks Rendering of Payload Can with Roll Control System

inertia and 104.7198 rad/s^2, the estimated torque on the flywheel due to the motor's spin and the flywheel's mass placement was approximately 0.065 N·m, which is below the value of 0.4 N·m, the stall torque of the BAG motor. This indicated that the motor would still be able to run with the flywheel attached without interference.

Figure 3 showcases the extent to which von Mises stress (an indicator at which a ductile material will yield) acts on the flywheel. The maximum amount of stress acting on the flywheel at any point is 690.2 kPa, which is significantly less than 410 MPa, the minimum yield strength of AISI 1020 hot-rolled steel. This showcases that the material in this orientation and shape is strong enough to withstand the stresses acting upon it during flight operations.

Figure 4 and Figure 5 are visual representations of the resultant displacement and strain, respectively, due to the application of torque on the flywheel. As can be noted from the figures, the amount of deformation experienced by the flywheel is negligible and its stiffness essentially counteracts the strain it experiences. The data gathered from this study was instrumental in the final design of the flywheel and helped to ensure that it would be a stable, strong design.

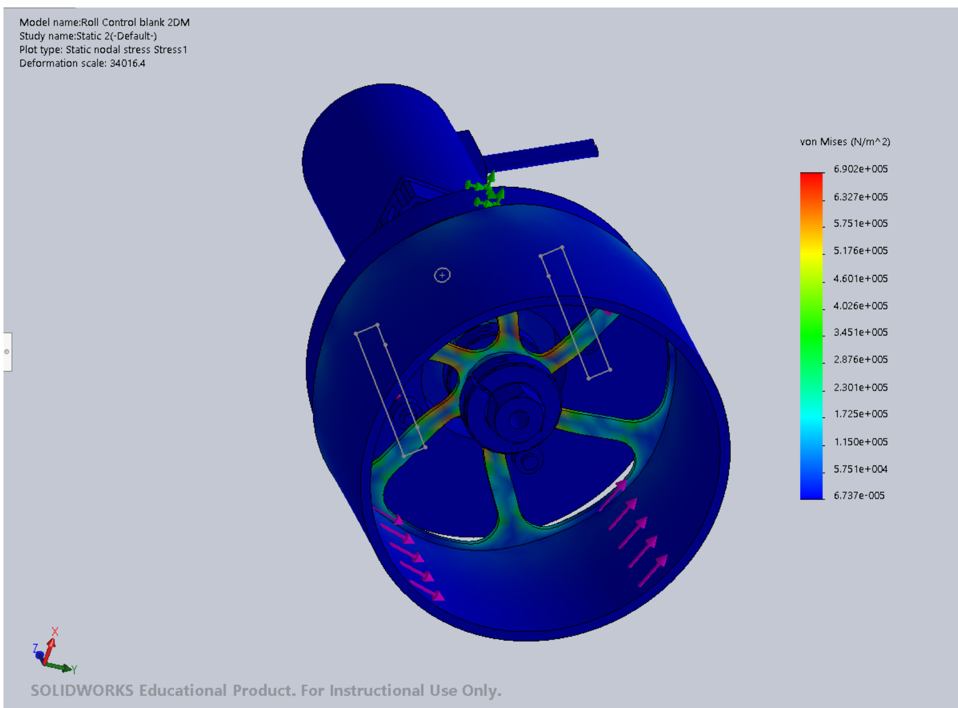


Figure 3: Finite Element Analysis of Von Mises Stress on the Payload Flywheel

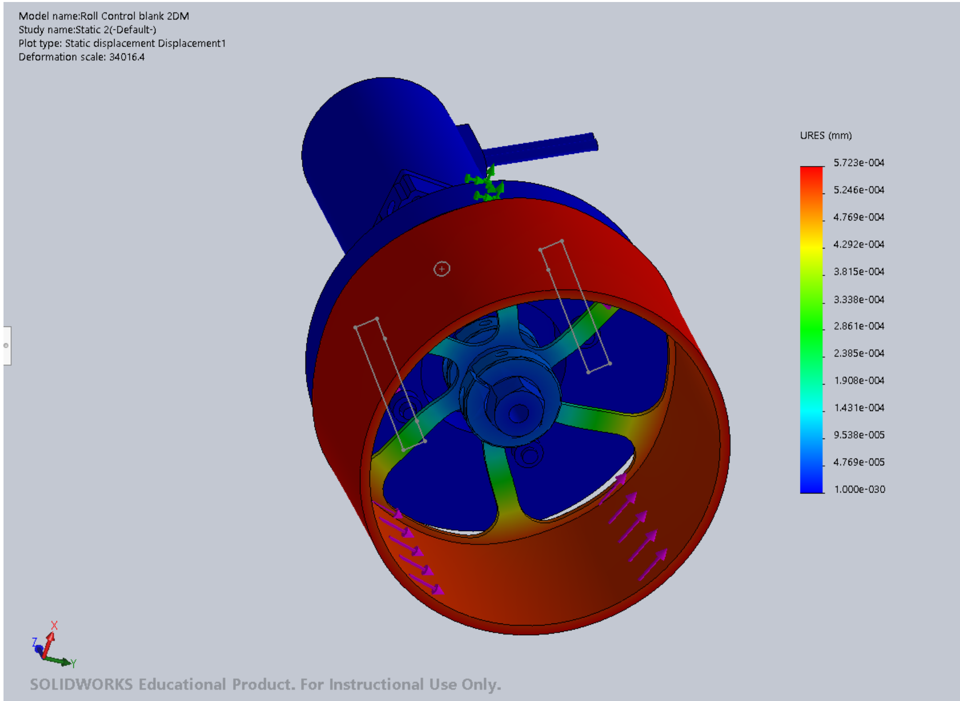


Figure 4: Finite Element Analysis of Overall Displacement of the Flywheel

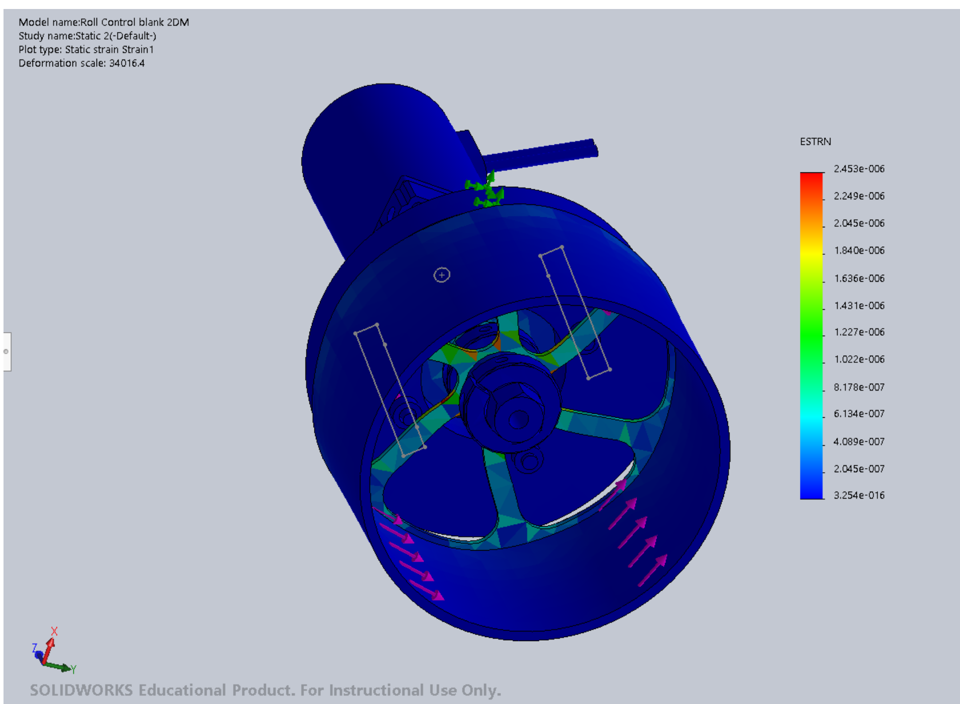


Figure 5: Finite Element Analysis of Overall Strain Experienced by the Flywheel

3.1.3 Flight Avionics

The flight avionics package performs several functions critical to the roll control mechanism and radio telemetry. The flight package is driven by a Teensy 3.6 Microcontroller Unit (MCU), which is powered by a 180 MHz ARM Cortex-M4 microcontroller. 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.

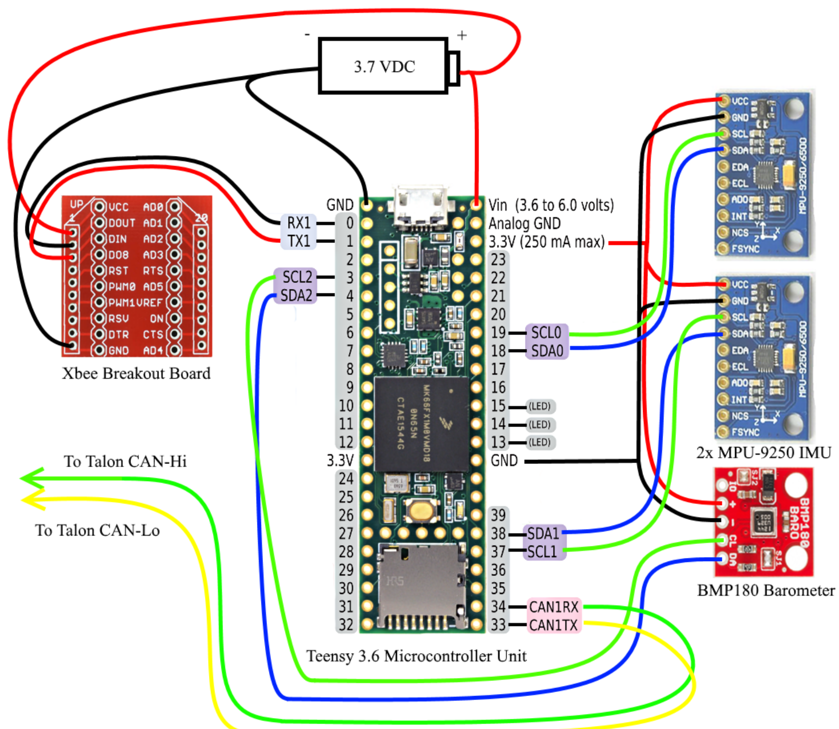


Figure 6: Flight Package Wiring Diagram

To collect roll orientation and angular rate, there are two MPU-9250 Inertial Measurement Units connected to the MCU via the I2C bus. These IMUs will also be used to record linear acceleration, velocity, and overall flight distance, to construct a detailed model of the rocket's flight trajectory. This data will be logged using the onboard SD card reader. The roll orientation data will be used to control the VexPro BAG Motor via a Talon SRX motor controller. This controller will be connected to the Teensy via the CAN bus. The Teensy platform is unique in that it supports the hardware CAN bus, without emulating the protocol. A standalone Wing HD camera will be used to record the flight and view the orientation LEDs, which will be mounted in front of the camera. Two LEDs will be used to denote the roll procedure, with each light indicating a roll direction, and both lights being used to indicate either "orientation hold" or system standby. A BMP180 barometer is also included for recording altitude, temperature, and pressure data to further improve the flight model. These sensors are powered via a common 3.3V line output by the Teensy.

To improve usability and organization of the avionics package, the payload can will be built using an ABS/PLA printed sled. The motor battery is held in an enclosure intended to limit the movement of the battery during flight. The motor controller, camera, and flight controllers are mounted to the outside of this enclosure to minimize the electronics footprint. The MCU, IMUs, XBee module, and barometer are mounted to two development board layers, to minimize the number of wires required. The camera is mounted so that the lens is outside of the rocket fuselage. It will be protected using an ABS/PLA printed aerodynamic shroud.

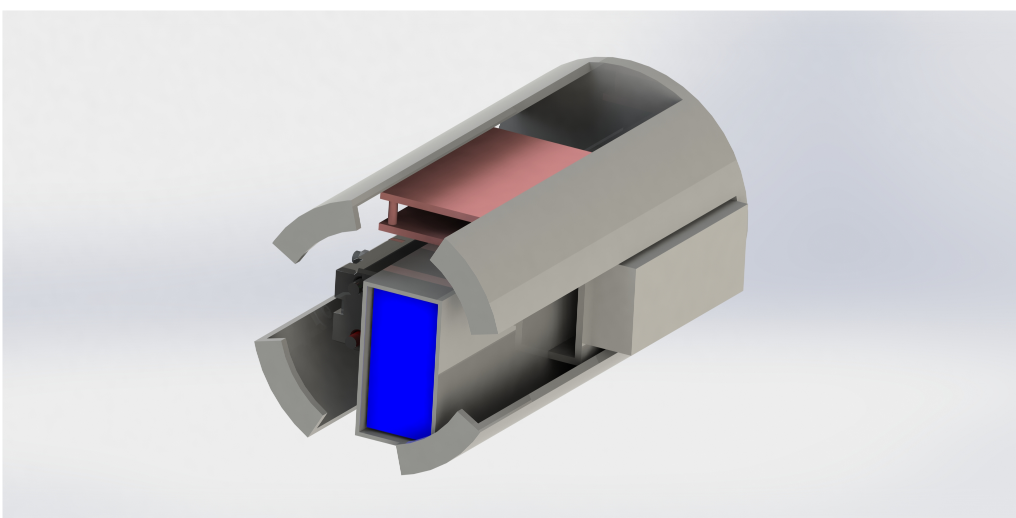


Figure 7: Flight Avionics Layout Design, including battery (Blue), flight controllers (red), motor controller (left), and camera (right)

3.2 Recovery

A single deployment parachute system was used to recover the rocket. This parachute is deployed at apogee by electronically controlled ejection charges as well as a redundant time-based motor ejection charge.

3.2.1 Parachute

To safely recover the rocket at a descent rate of less than 24 ft/sec (7.3 m/s), a Fruity Chutes Iris Ultra Compact 60 inch parachute was selected, having a drag coefficient of 2.2. This parachute is housed in the forward end of the booster section which allows the motor ejection charge to be fully operational. It is attached to the rocket by one body length (5 ft / 1.53 m) of 1/4 in. (6.35mm) flat nylon shock cord. The shock cord is epoxied to the booster on the phenolic tube and is also attached to the payload can of the rocket with an eyebolt. The parachute is deployed at apogee using main and backup black powder ejection charges facing downward. Both the eyebolt and the charges are mounted on a plywood bulkhead at the aft end of the payload can. In addition to the plywood bulkhead, there is an additional aluminum bulkhead separating the flywheel and ejection electronics that is welded to the payload can. The eyebolt is threaded onto this bulkhead.

3.2.2 Electronics

The recovery electronics consist of a StratoLogger SL100 Altimeter, a two-cell lithium polymer battery, a key switch, and an e-match. A second, identical independent recovery system that is programmed to fire after the first is employed as a redundant backup. The altimeter, battery, and key switch are housed in the payload can in the space between the aluminum and plywood bulkheads. The key switch is mounted on the inside edge of the payload can and 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. 1 inch (2.54 cm) copper pipe caps hold the black powder ejection charges. The minimum amount of black powder to be used will be experimentally determined at a later date.

3.3 Radio Telemetry and Tracking

To complete the bonus communication challenge, the flight avionics package includes a 2.4 GHz XBee Pro 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 include roll orientation data, velocity and position, altitude, and the status of the roll control system. During the descent, the system will report useful information about the flight for quick analysis, including maximum altitude, velocity, and other interesting flight data.

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 an Arduino Uno R3, an SD Card shield, an XBee Pro 2.4Ghz RF Module, and a laptop. This will allow ground control to program the rocket commands prior to flight and collect and display telemetry data in real time for in-flight analysis. Data received through telemetry will be logged to the SD card for submission.

3.3.2 Commercial GPS Tracker

A BRB900 GPS TX/RX tracking device 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 Analysis of Basic Flight Performance

Flight performance was analyzed for four scenarios: no wind, mild wind (2 m/s), medium wind (4.47 m/s), and high wind (8.94 m/s). Wind came from due East for each simulation. The high wind scenario corresponds to the maximum wind speed allowed by NAR rules. Wind turbulence was taken at 10% for each scenario (i.e. the wind speed standard deviation was 10% of the average wind speed). OpenRocket was used for flight simulations. The International Standard Atmosphere (ISA) was used for determinations of flight performance.

4.1 Launch Analysis

Velocity off the launch rod was found for each wind condition. The launch rod was assumed to be 8 ft (2.44 m) in length. The results from each simulation can be found in Table 1. The rocket's velocity at launch rod departure is deemed sufficient to maintain a safe stability. See Section 4.4 for more details on stability.

Table 1: Velocity at launch rod departure for each wind condition

Wind Speed	**Velocity at Launch Rod Departure**
0 m/s	26.7 m/s
2 m/s	25.7 m/s
4.47 m/s	26.7 m/s
8.94 m/s	26.7 m/s
Average	26.4 m/s

4.2 Ascent Analysis

Apogee, maximum velocity, maximum acceleration, and time to apogee were determined using OpenRocket simulations for each wind condition. Results of each simulation can be found in Table 2. Plots of altitude, velocity, and acceleration during the entire ascent can be found in Figure 8 on page 17.

Table 2: Ascent parameters for each wind condition

Wind Speed	Apogee	Maximum Velocity	Max. Acceleration	Time to Apogee
0 m/s	1452 m	208 m/s	150 m/s^2	16.5 s
2 m/s	1464 m	209 m/s	154 m/s^2	16.6 s
4.47 m/s	1430 m	208 m/s	150 m/s^2	16.5 s
8.94 m/s	1447 m	208 m/s	150 m/s^2	16.4 s

4.3 Recovery Analysis

Recovery analysis was performed using OpenRocket. Parachute deployment was programmed to occur at apogee. Ground track profile, velocity at deployment, and ground hit velocity for each wind condition were considered for analysis. Values can be found in Table 3.

Table 3: Descent parameters for each wind condition

Wind Speed	Velocity at Deployment	Ground Hit Velocity	Drift Distance
0 m/s	0.844 m/s	4.76 m/s	2 m
2 m/s	2.2 m/s	4.80 m/s	573 m
4.47 m/s	4.97 m/s	4.59 m/s	1274 m
8.94 m/s	7.91 m/s	4.41 m/s	2594 m

Deployment velocity was also considered if the electronic ejection system fails. The motor ejection charge is adjusted to be 0.5 seconds after apogee. The deployment velocities were found to increase slightly: 15 mph (6.7 m/s) for no wind, 13 mph (5.79 m/s) for 4.47 mph (2.0 m/s) wind, 16.2 mph (7.24 m/s) for 4.47 m/s wind, and 27.3 mph (12.2 m/s) for 20 mph (8.94 m/s) wind.

Deployment and ground hit velocities are not considered a cause for concern, and are within competition specifications.

4.4 Stability Analysis

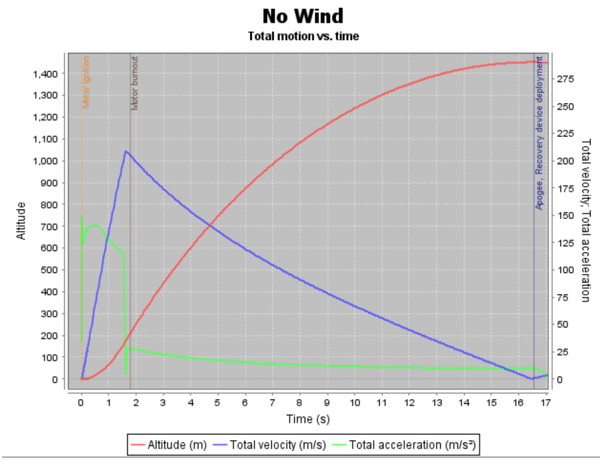
The rocket has a predicted static stability of 1.25 calibers. The center of pressure lies at 38.9 in (98.9 cm) from the tip of the nose cone, with the center of gravity at 33.9 in (86.1 cm). Minimum stability occurs immediately after launch rod clearance, and is predicted to not fall below 1 caliber for all wind conditions simulated. Stability is shown to drop below 1 caliber immediately before apogee, however, this does not represent a concern as this is due to the shifting of the center pressure as the rocket begins to turn as it reaches apogee. Maximum stability occurs immediately after motor burnout and is predicted to attain approximately 1.8 calibers for all wind conditions. See Figure 9 on page 18 for plots of stability versus time for each wind condition. The stability condition is expected to be fulfilled for all points during the flight.

4.5 Environmental Analysis

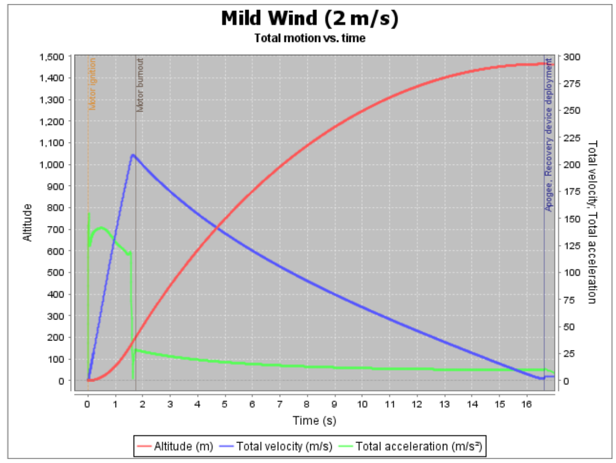
Wind conditions and direction on the launch date are unpredictable at this point in time. However, the range of wind speed tested demonstrates acceptable and safe performance for all expected wind conditions.

The average low temperature on May 19th and 20th in North Branch, Minnesota is 49°F (9.4°C), with an average high temperature of 73°F (22.8°C). Using the average low temperature instead of the ISA, apogee is decreased by approximately 29 ft (12 m). At the average high temperature, apogee is increased by 46 ft (14 m). The air density and viscosity does not change enough within this limited temperature range to have an appreciable impact on other flight parameters.

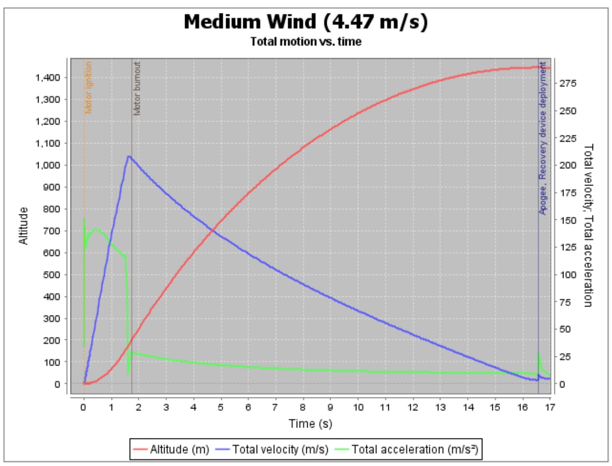
Figure 8: Simulated flight parameters for all wind velocities



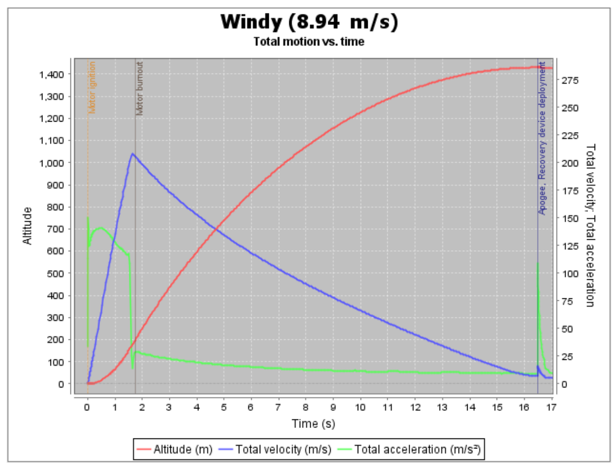
(a) Wind velocity of 0 m/s.



(b) Wind velocity of 2.0 m/s.

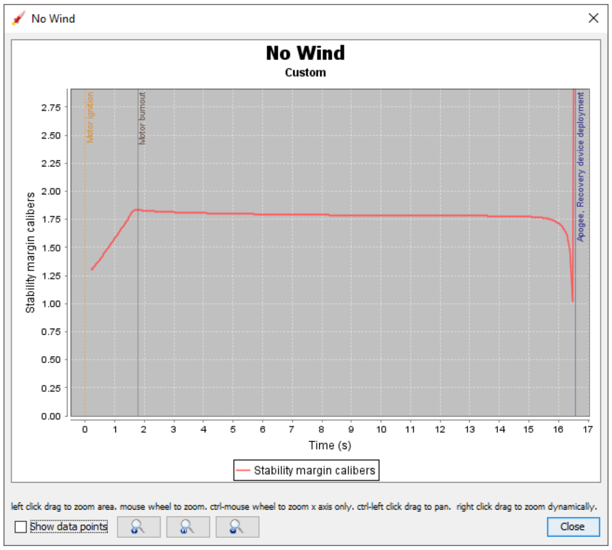


(c) Wind velocity of 4.47 m/s.

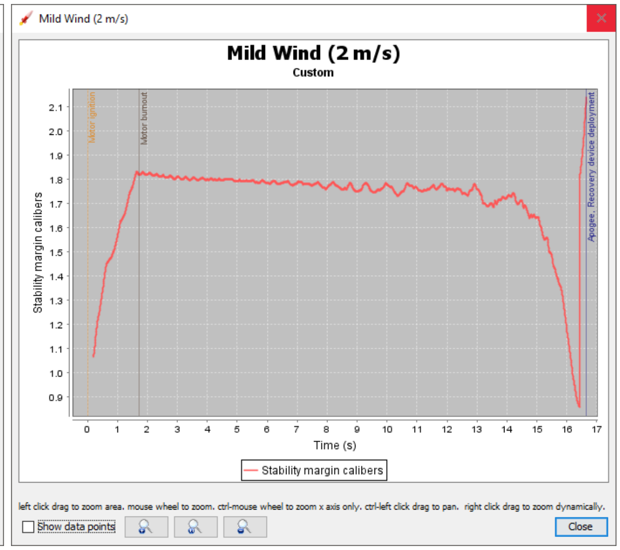


(d) Wind velocity of 8.94 m/s.

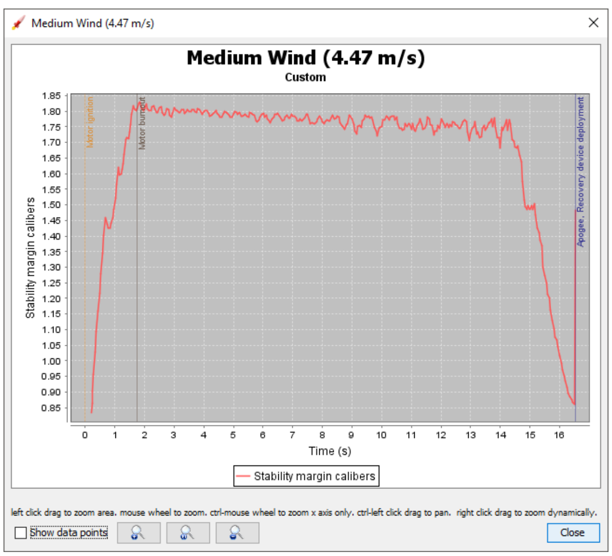
Figure 9: Simulated stabilities for all wind velocities



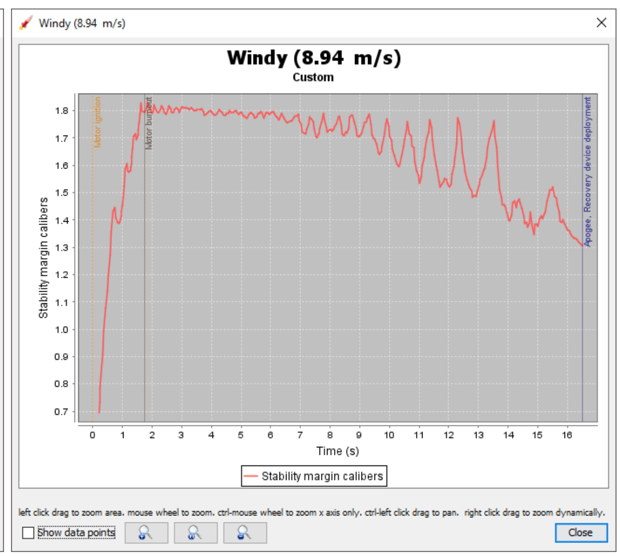
(a) Wind velocity of 0 m/s.



(b) Wind velocity of 2.0 m/s.



(c) Wind velocity of 4.47 m/s.



(d) Wind velocity of 8.94 m/s.

5 Safety

5.1 Model Rocket Demonstration

A U.S. Army Patriot M-104 (Skill Level 1) Estes model rocket was purchased, built, and launched twice to practice and demonstrate proper safety procedures. The model rocket was launched on a day with clear skies and acceptably low winds in a pasture. A two-stage electronic ignition switch was used. The ignition switch required key insertion and button compression to activate the igniter. A launch pad with a launch rod was placed on a large sheet of tin to keep the risk of stray sparks igniting the grass to a minimum and to stabilize the rocket launch pad. A fire extinguisher was kept nearby and bystanders stood an appropriate distance away. There were instances of ignition issues, such as a faulty battery, igniter fuse, and electronic ignition switch. These issues were signaled by first the ignition switch not displaying an auditory warning and second by the rocket motor not igniting. The issues were handled by removing the key from the ignition switch and waiting approximately two minutes. Finally, without standing over or in the way of the rocket, one experienced team member approached the rocket to replace the battery, igniter fuse, and electronic ignition switch. The parachute recovery system worked perfectly both times. The rocket appeared to fly in a stable manner as demonstrated by the rocket not coning, oscillating, or deviating from the parabolic flight path. Both times the rocket was recovered on the ground a few hundred feet away and brought back to the launch area for inspection. No damage was found after each flight upon inspection.

(a) Model rocket before launch

(b) Model rocket after launch

5.2 Pre-flight Checklist

- ☐ 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
  - ☐ Place transmitter in casing and in electronics bay

- ☐ Avionics Bay
  - ☐ Rewire flight computers to key switches
- ☐ Recovery System
  - ☐ Insert Nomex wadding
  - ☐ Prepare main parachute
  - ☐ Fold, place in main parachute tube
  - ☐ Connect main chute to nose cone
  - ☐ Place drogue chute in drogue tube
  - ☐ Gather shock cord in airframe
  - ☐ Position nose cone and insert shear pins
- ☐ Loading 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
- ☐ Launch Procedure
  - ☐ Load vehicle on launch rail
  - ☐ Angle launch rail to vertical
  - ☐ Activate flight computers
  - ☐ Arm deployment charges

- ☐ Clear launch pad
- ☐ Confirm continuity
- ☐ Signal launch readiness

5.3 Post-flight Checklist

- ☐ Visually mark touchdown location
- ☐ If unable to visually determine touchdown location, use GPS tracking.
- ☐ Deploy recovery team
- ☐ Guide recovery team to rocket
- ☐ Confirm recovery

5.4 Hazardous Materials Handling

The 635 epoxy resin is a skin, eye, and respiratory irritant. In addition, the epoxy can cause skin sensitization, an allergic reaction that occurs after repeated exposure. Respiratory sensitization may also occur. To limit skin, eye, and respiratory exposure, the epoxy is only used while wearing eye protection, latex gloves, long sleeves, pants, and closed toed shoes in a well-ventilated area. Hands are washed following use of the resin. Should a member come into accidental contact with the resin and show signs of skin or respiratory irritation, they are prevented from further handling resin to prevent an allergic reaction.

The black powder for the ejection charges is a high explosive. It is only handled well away from sources of heat and sparks. It is stored well away from other flammables in a flame-proof storage cabinet. Only members who have worked with black powder and demonstrate safe handling procedures are permitted to pack the ejection charges for testing. When testing the ejection charges, care is used to start with a minimal amount of black powder with members standing well away. During preparation for flight, the onboard ejection charges are disconnected from the ejection electronics until the rocket is ready for flight on the launch rail.

The rocket motors follow the same handling and storage procedures as the black powder. Only NAR Level Two Certified Members are permitted to load the motor into the motor casing, as well as place the motor igniters.

6 Budget

Table 4: Overall Budget

Category	**Price Per Unit**	**Quantity**	**Cost**
Lodging	$510.33/night	3 nights	$1503.00
Vehicle Rental	$428.15/van	2	$856.30
Gas	$200/van	2	$400.00
Materials	$1858.05	n/a	$1858.05
Registration Fee	$400.00	n/a	$400
Contingency fund	$700.00	n/a	$700
		Total	$5717.35

6.1 Funding sources

The primary source of funding for Husker Rocketry is the University of Nebraska-Lincoln Engineering Student Advisory Board (eSAB), which contributed $4,200 to the project. As well, Husker Rocketry received a grant of $8,000 from NASA Nebraska Space Grant. The Space Grant expired on February 28th, 2018, and access to funds was restricted. A donation of $500 was also made by Sampson Construction.

6.2 Booster

The cost of the booster is estimated to be $1034.97. A itemized list can be found in Table 5.

Table 5: Booster Budget

Item	**Supplier**	**Quantity**	**Cost**
54mm 3-Grain Case	Apogee	1	$69.39
Tailcone	AeroPack	1	$54.00
Pro-54 Delay Adjustment Tool	Apogee	1	$29.37
54mm Standard Rear Closure	Apogee	1	$42.75
Cesaroni J760-19A White Thunder	CS Rocketry	2	$185.90
60" Iris Ultra Parachute	Fruity Chutes	1	$225.00
Chute Release	Jolly Logic	1	$129.95
Eyebolt	McMaster-Carr	1	$ 12.21
54mm phenolic tube	Public Missiles	1	$14.99
Carbon Fiber Tubes	Public Missiles	1	$239.95
Finnish Birch Aircraft Plywood	Aircraft Spruce	1	$56.38
Natural G10 Sheet	ePlastic	1	$71.46
		Total	$1164.36

6.3 Payload

The cost of the payload is estimated to be $505.28. An itemized list can be found in Table 6.

Table 6: Payload Budget

Item	**Supplier**	**Quantity**	**Cost**
HD Wing Camera	Hobby King	1	$31.19
Turnigy 5000mAh LiPo Pack	Hobby King	1	$28.18
VersaPlanetary Integrated Encoder	VEX	1	$49.99
BAG Motor	VEX	1	$24.99
VersaPlanetary Gear Box	VEX	1	$34.99
VersaPlanetary 3:1 Gear Kit	VEX	1	$10.99
High Strength Clamping Collar	VEX	2	$9.98
Talon SRX	VEX	1	$89.99
Talon SRX Encoder Breakout Board	VEX	1	$9.99
Talon SRX Data Cable	VEX	1	$14.99
Machining Costs	UNL Machine Shop	1	$200.00
		Total	$505.28

6.4 Miscellaneous

Other costs are estimated to be $230.02. An itemized list can be found in Table 7

Table 7: Booster Budget

Item	Supplier	Quantity	Cost
Foam Paint Brush	Amazon	1	$12.99
Dust Mask	Amazon	1	$13.99
Nitrile Gloves	Amazon	1	$10.14
Polypropylene Coverall	Amazon	1	$45.95
635 Thin Epoxy System	US Composites	1	$71.00
Nose Cone	Public Missiles	1	$75.95
		Total	$230.02