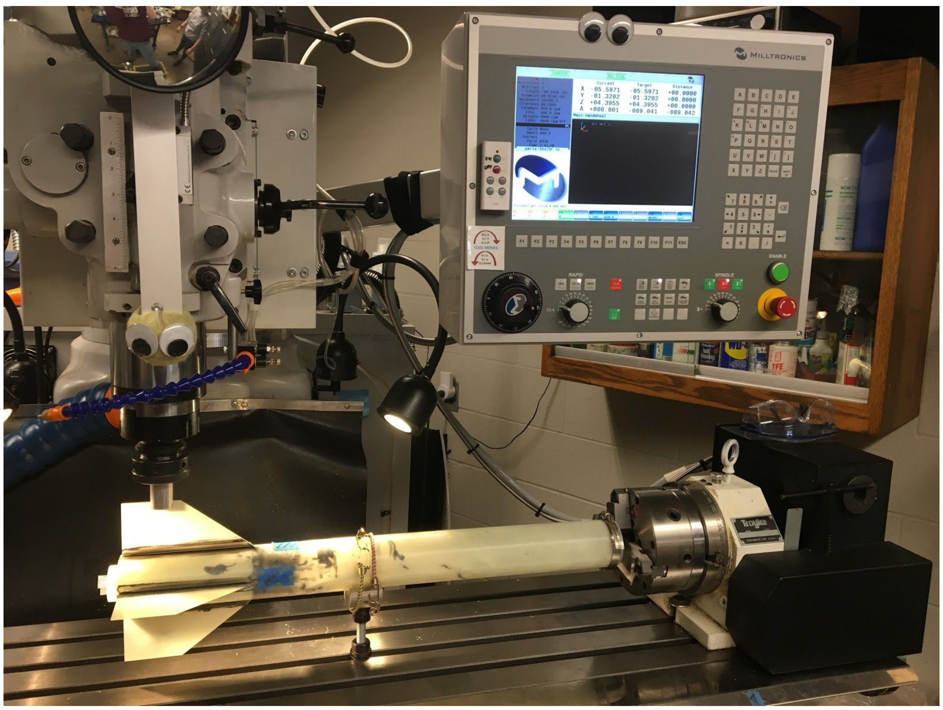
Preliminary Design Report

Macstronauts
Macalester College



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Executive Summary

The 2018 Space Grant Midwest High-Power Rocket competition requires teams to complete two successful launches while implementing different tasks related to roll orientation of the rocket to be evaluated by an exterior camera. The first launch is to reduce all roll to zero and maintain orientation to apogee. The second launch tests the rocket's ability to roll to 4 pre-programmed orientations based on cardinal directions and to repeat that sequence a total of 4 times with different wait times between each orientation. We have designed a stationary flywheel system based on the principle of conservation of angular kinetic energy to control the roll orientation of the rocket. These calculations were done by hand while simulations using OpenRocket informed design choices of the body of the rocket. The rocket has an overall length of 124.7 cm, an outer diameter of 6.6 cm, and a target weight of 2993 grams. The motor controlling the flywheel has a maximum torque of 0.59 Newton-meters. We wanted to minimize the intrinsic roll of the rocket from construction imperfections as well as choosing a rocket with a minimized moment of inertia to make corrections easier to accomplish. Our onboard computer is a Raspberry Pi Zero, which will take gyroscopic data, run it through a program that will control the motor and flywheel. A secondary program will execute the pre-programmed set of commands. We are prepared for the bonus challenge of radio communication by way of an XBee radio chip in the AV bay. The competition guidelines require an on board down-facing camera with LEDs in its sightline to monitor roll while the LEDs indicate an attempt at roll change. We are accomplishing this by using LiquidFyre's Mobius Mini Camera Shroud System to provide minimal asymmetric drag from a camera mount and mounting LEDs through the airframe of the rocket. We are using an Altimeter 3 data logger to track altitude for competition data. At apogee both iterations of the roll control programs will abort and a motor-based ejection charge will fire. Shortly afterwards, a secondary charge controlled from an altimeter in the AV bay will also fire. Propulsion will be provided by the J420R motor which fits in the competition guidelines of any I or J class motor. The motor provides an average thrust of 423 newtons for 1.54 seconds and has a total impulse of 651 newton-seconds (these data taken from the OpenRocket software package). Based on our simulations it is predicted that our rocket will reach an apogee of 1378 meters (4524 feet), above the competition minimum of 914.4 meters (3000 feet).

Airframe Design Features

The current design of our rocket includes components we will integrate that were not part of the kit in order to fulfill the requirements of the competition. These components include a method of taking video and a method to control the roll and orientation of the rocket.

Video

We plan to use the 32 GB microSD Mobius Mini Camera for capturing video from our rocket. This will be mounted using a mount supplied by LiquidFyre Rocketry that is designed to minimize the aerodynamic influence of the camera on the rocket. The camera and mount/shroud system can be seen in Figure 1. We plan to use this specific mounting system, but if we are unable to for one reason to another, we plan to 3D-print a mount to be attached to the exterior of the rocket.

The mount system we plan to order can be found at the following link: https://www.liquidfyre-rocketry.com/index.php?route=product/product&product_id=80

Figure 1. — The Mobius Mini Camera and mount system from LiquidFyre Rocketry.

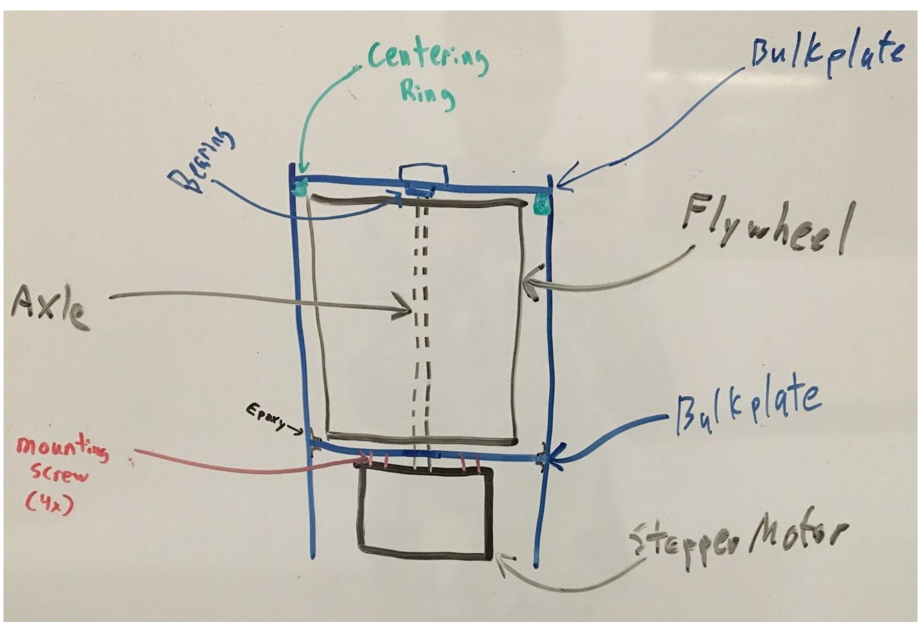
Roll/Orient System

We plan to integrate a stationary flywheel driven by a stepper motor in order to control the roll of our rocket and be able to orient the rocket specifically. Although we have not yet built the flywheel, we plan to create a cylindrical flywheel made out of a heavier metal that is attached to a stepper motor mounted just above our avionics bay (see the model of our rocket on the following pages). This flywheel will be created to optimize maximum moment of inertia while minimizing weight. Additionally, this optimization will take into consideration the maximum angular velocity of the motor. The stepper motor we are using is a Nema 17 Hybrid Stepper Motor with a rated maximum torque of 0.57 Newton-meters.

If the rocket has no natural tendency to roll, we would ideally only have the stepper motor move when we needed to spin the rocket to a specific orientation. However, we expect that there might be some inherent spin because of the inherent imprecision of human construction and the asymmetry of the camera mount, so we will program the stepper motor to receive a detection of natural roll from a gyroscope and correct for it. Additionally, a secondary program will follow pre-programmed instructions to orient to specific cardinal directions following counter-clockwise and clockwise requirements as specified. All iterations of the roll control or orientation programs will have an abort feature when the rocket reaches apogee for safety.

The flywheel system will be installed in the upper airframe as follows. A coupler tube will be secured in the upper airframe using rivets rated with a shear strength of 570 Newtons. Towards the bottom of the coupler tube, a bulk plate will be epoxied in, leaving room for the stepper motor to be mounted below it such that the bottom of the stepper motor is flush with the bottom of the coupler tube. Attached to the moving axle of the stepper motor will be an extended axle that goes through the center of the flywheel and will be attached to a bearing at the other end of the flywheel. This bearing which allows the axle to freely move is mounted on a bulk plate that will be separated from the flywheel by a centering ring. A visual presentation of the configuration can be seen in Figure 2.

Figure 2. — A mock-up diagram of the flywheel cage.



Electronics/Payload Design Features

Our AV bay features 3 seperate LiPo batteries, 2 of which will be powering our onboard computer, all peripheries, and Raven 3 altimeter, while the third is dedicated to the flywheel system. These batteries will be switched out between launches for fresh batteries. Our onboard computer consists of a Raspberry Pi Zero. It will receive data from a magnetometer, gyroscope, altimeter, and radio (Figure 5). It will communicate via a motor driver chip to the stepper motor. Our magnetometer is the HMC5983 magnetometer. Our gyroscope is the I3G4250D using the STEVAL-MKI169V1 adapter board. The altimeter communicating with the Pi (separate from the Raven 3 chip controlling ejection charges) is the MPL3115A2 altimeter. We are using a XBP9B-DMSTB002 XBee radio chip. We have separated our AV bay into two primary components, a Lower AV bay, containing 2 batteries, altimeter, magnetometer, gyroscope, and Raven 3 altimeter (Figures 3 and 4). The 2 sleds will be attached around the batteries using zip ties while the battery holders will be epoxied to one of the bulk plates. An interior threaded tube will be used to secure this section against two inner centering rings in the AV bay coupler tube. The upper section of the AV bay includes a larger sled epoxied on bottom to the bulk plate that is also the upper bulk plate of the lower AV bay. The upper section of the sled is epoxied to a final bulk plate to keep it centered in the AV bay coupler tube. On one side of the sled is the Pi and a third battery. This battery exclusively powers the flywheel system. On the reverse of the sled is the radio, motor driver chip, and a screw switch. The screw switch will not be connected until the rocket is vertical on the launch pad and will provide power to the Raven 3. This is a safety feature to ensure that the secondary explosive charge does not detonate prematurely. Wires run from the lower section to the upper section by way of a hole in the bulk plate that separates the sections. The coupler tube will be riveted into the upper airframe while secured only with a friction fit to the lower airframe.

The flywheel system (Figure 6) will be ‘caged’ by a coupler tube and mounted in the upper airframe using rivets to avoid crushing any section of the AV bay below it during motor burn. It consists of the stepper motor mounted to a bulk plate with an axle running through the flywheel to a bearing, then through a second bulk plate, and secured using a shaft collar. The upper bulk plate will rest against a centering ring inside the coupler tube for stability. The lower bulk plate that the stepper motor is mounted to will be epoxied inside of the coupler tube.

Figure 3. — An image of the Lower AV bay (disassembled).

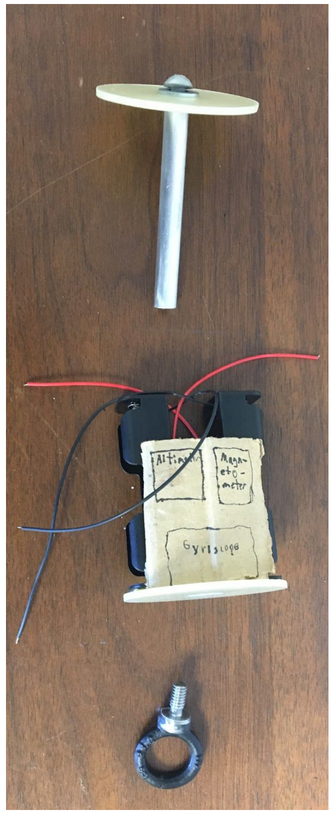


Figure 4. — An image of the Lower AV bay (assembled, reverse).

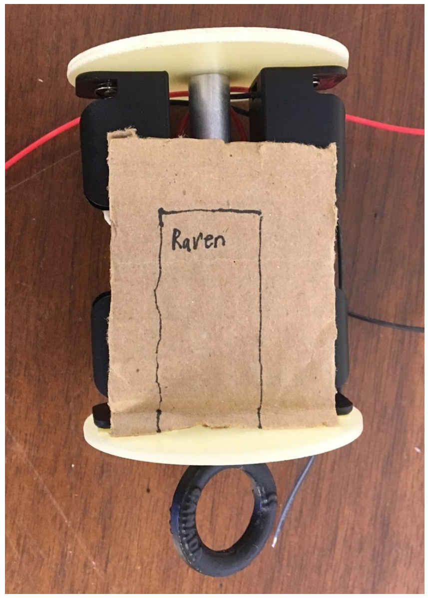


Figure 5. — An schematic of the entire AV bay.

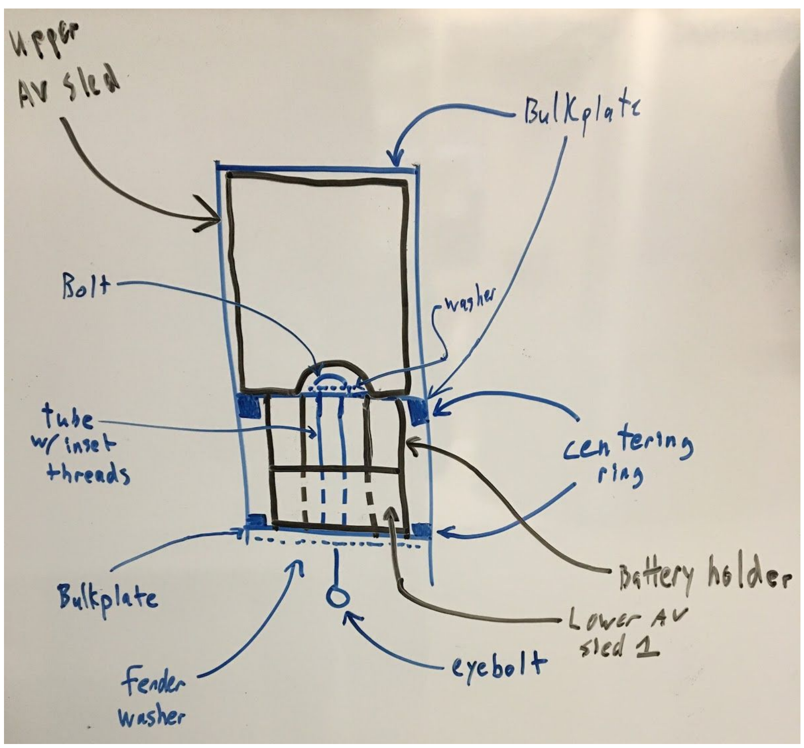


Figure 6. — A schematic of the flywheel 'cage'

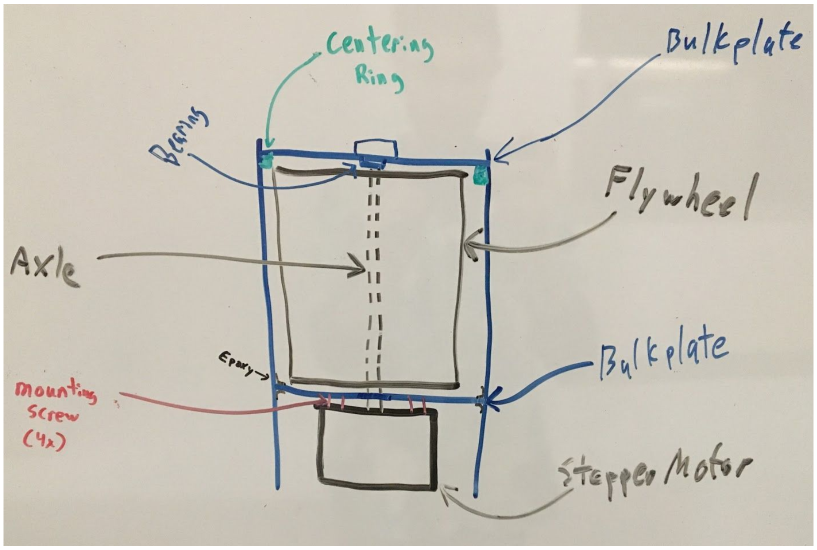
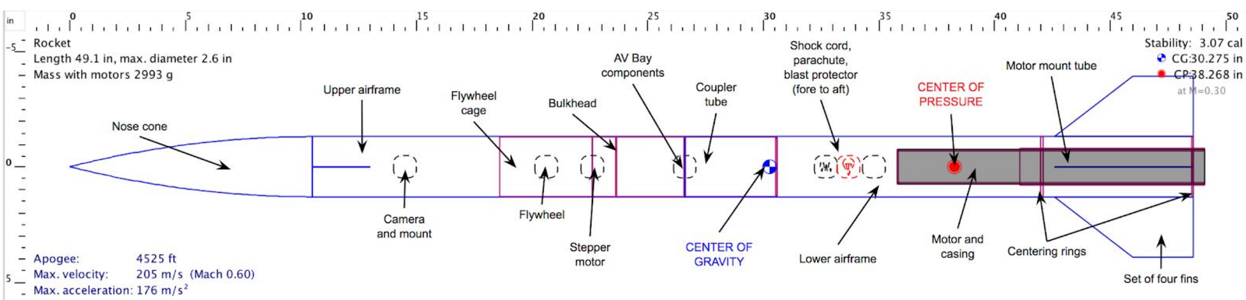

Centering Ring
Bulkplate
Bearing
Flywheel
Axle
Epoxy
Bulkplate
mounting screw (4x)
Stepper Motor

Diagram of Rocket

A diagram of our rocket can be seen in Figure 7 below. The components of the rocket are labeled, as are the center of gravity and the center of pressure. The position of the center of gravity is 30.275 inches from the tip of the nose cone and the center of pressure is 38.268 inches from the tip of the nose cone. The motor included is a J420R from AeroTech, which is 13.3 inches long with a 1.5 inch diameter. This model has a stability of 3.07 calipers, which is within the accepted range of stability levels provided by our mentor. The mass of the rocket including the motor is 2993 g.

Figure 7. — This diagram of our rocket was created using the OpenRocket software package. The components of the rocket are labeled, and the center of gravity and center of pressure are labeled as well, with their positions from the tip of the nose cone listed to the upper right.



Analysis of Anticipated Basic Flight Performance

As previously stated, our rocket was modeled using the OpenRocket software package. As part of this process, simulations can be run to determine likely characteristics of a launch based on all of the data input. These data include the length, mass, and density (in some cases) of each component, the location of each piece with respect to the rest of the rocket, and the motor selected. All of the components of our rocket were measured and massed prior to assembly, and these values were input into open rocket to create the most accurate possible model. Then, simulations were done with several different I and J class motors to determine which motor would allow us to reach the competition minimum altitude with a comfortable margin while reducing the amount of stress placed on the numerous electronics used to implement the roll/orient system. Based on these simulations, we chose the J420R motor from AeroTech.

An example simulated plot of altitude, vertical velocity, and vertical acceleration is shown in Figure 8 on the next page. Below, we will give values we gleaned from this simulation regarding maximum altitude, peak velocity, peak acceleration, and descent speed.

Estimated Maximum Altitude

With the J420R-14 motor, OpenRocket simulates an estimated maximum altitude of 4525 feet in an average wind speed of 2 m/s with a standard deviation of 0.2 m/s.

Estimated Peak Velocity

With the J420R-14 motor, OpenRocket simulates an estimated maximum velocity of 205 m/s (approximately Mach 0.60) in an average wind speed of 2 m/s with a standard deviation of 0.2 m/s.

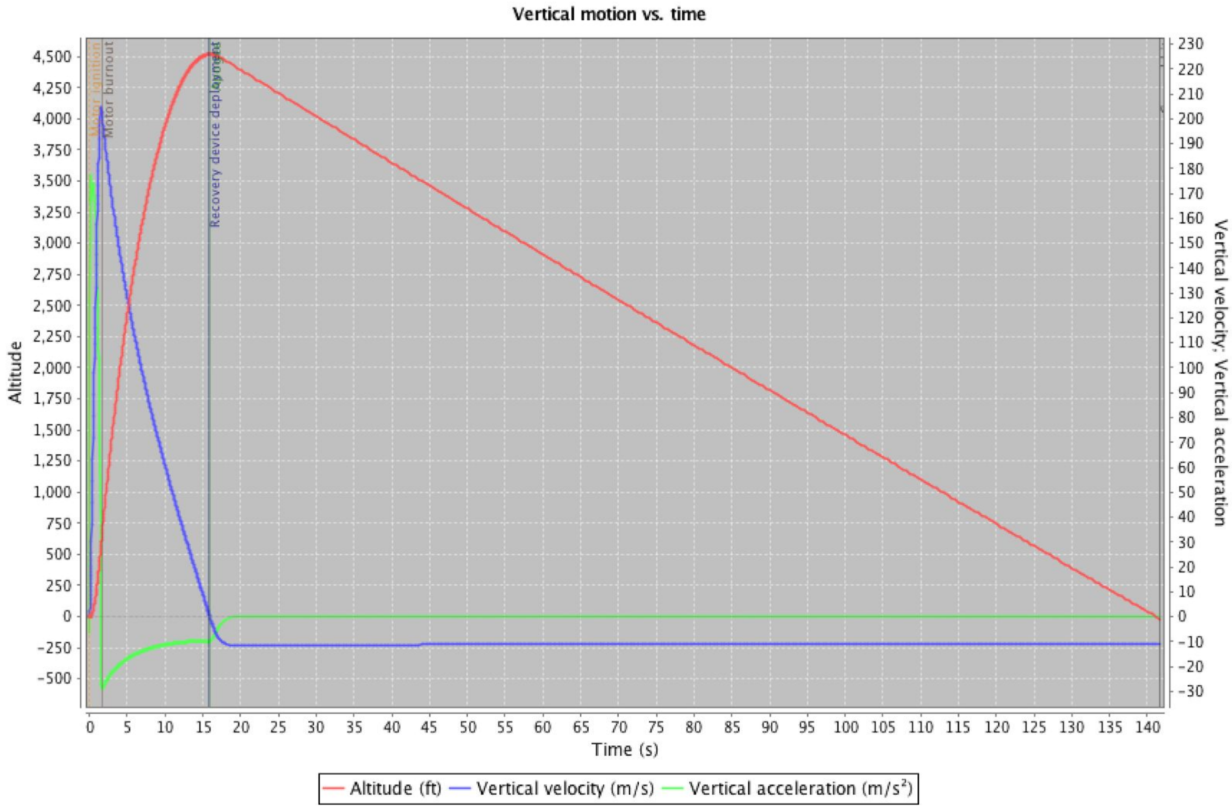
Estimated Peak Acceleration

With the J420R-14 motor, OpenRocket simulates an estimated maximum acceleration of 177 m/s^2 in an average wind speed of 2 m/s with a standard deviation of 0.2 m/s.

Estimated Descent Speed

With the J420R-14 motor, OpenRocket simulates a ground hit velocity of 10.7 m/s in an average wind speed of 2 m/s with a standard deviation of 0.2 m/s.

Figure 8. — A simulation of our rocket launching under average wind speeds of 2 ± 0.2 m/s.



Radio Bonus Challenge

We would like to attempt the bonus challenge that involves communicating with the rocket while it is both on the launchpad and in the air. To this end, we have included an XBee radio in our model for our avionics bay and have purchased a matching radio to use for the communication. We are currently looking into purchasing an antenna to attach to the radio within the rocket to allow us communication during as much of the flight as possible. The XBee radio will interface with the Raspberry Pi in order to compute calculations that we send it during the flight. We would also like to attempt to send alternate orientation instructions to the rocket while it is on the launch pad.

Figure 9 is an image of the XBee radio for reference.

Figure 9. — An image of the XBee radio from SparkFun Electronics (which is not the company we purchased our model from).
https://www.sparkfun.com/products/8665

Budget

Figure 10 shows our current budget for the build as of March 9, 2018. We have kept track of and categorized our purchases as best we could, but this being the first time we have had to purchase so many electronic components, we did not specifically assign a team member to keep track of purchases and organize receipts. As noted on the spreadsheet, our remaining balance is approximately $819.35. We anticipate a further $50 used for various last minute build supplies. Of the remaining $769.35, we anticipate purchasing 3 test motors from OffWeGoRocketry at ~$60 per motor leaving ~$589 for educational outreach rocket kits.

Figure 10. — The spreadsheet that describes our budget for the competition.

$819.35	Current Balance	NASA Space Grant	$1,900.00
		Registration Fee	-$400.00
		Electronics Order 1	-$87.86
		Electronics Order 2	-$72.29
		Electronics Order 3	-$60.24
		Extra Nose Cone 1	-$31.61
		Parts Order 1	-$89.85
		Residual Orders	-$338.80

Part	Total Cost	Listed Price	Shipping	Tax	Purchased From
Raspberry Pi Zero	$24.00	$24.00	$0.00	$0.00	Amazon
32 GB Micro SD	$14.97	$13.88	$0.00	$1.09	Amazon
Motor Driver Chip x5	$30.29	$14.65	$15.64	$0.00	Texas Instruments
Breakout Board	$4.61	$4.61	$0.00	$0.00	Walmart Online
Stepper Motor	$13.99	$13.99	$0.00	$0.00	Amazon
Gyroscope and Breakout	$38.16	$27.38	$7.99	$2.79	Digi-Key Electronics
Altimeter	$19.53	$9.95	$9.58	$0.00	Adafruit
Magnetometer	$14.60	$14.60	$0.00	$0.00	Amazon
LiPo SHIM and cable	$20.28	$10.70	$9.58	$0.00	Adafruit
LiPo holder x10	$8.49	$8.49	$0.00	$0.00	Amazon
LiPo Batteries	$16.48	$16.48	$0.00	$0.00	Amazon
LiPo Charger	$14.99	$14.99	$0.00	$0.00	Amazon
Extra Nose Cone 1	$31.61	$28.95	$2.66	$0.00	MadCow Rocketry
XBEE Radio	$91.45	$83.50	$7.95	$0.00	NextWarehouse
Eval Board/Motion Sensor	$38.16	$27.38	$7.99	$2.79	Digi-Key
Mobius Mini Kit/Cam/Coupler	$160.55	$153.25	$7.30	$0.00	LiquidFyre Rocketry
8 Bulkplates	$47.98	$39.04	$8.94	$0.00	Apogee Components
Capacitors	$0.66	$0.66	unknown	unknown	Digi-Key
8-inch Coupler Tube	$14.00	$14.00	?	?	MadCow Rocketry
Centering rings	$17.09	$17.09	?	?	Apogee Components
Terminal Block	$3.41	$3.41	?	?	Apogee Components
2 Screw Switches	$14.30	$14.30	?	?	Aerocon Systems
Motor Retainer System	$31.95	$31.95	?	?	Off We Go Rocketry
Rivets	$4.95	$4.95	?	?	Off We Go Rocketry
Ejection Charge Canisters	$3.15	$3.15	?	?	Apogee Components
Euro Style Terminal Block	$1.00	$1.00	?	?	Aerocon Systems