The Ohio State University High Power Rocketry Team

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I. Recap of Rocket Design

a Design and Dimensions

The rocket was designed using open rocket, with a target apogee of 1380 meters, using a Cesaroni J410 motor for propulsion. In total the rocket is 144 cm tall with a diameter of 7.62 cm. The nose cone selected for use is ogive, and has a length of 28.6 cm. The rocket body tube measures 115.4 cm long, and has a diameter of 7.62 cm. The four fins used were designed in open rocket, and then exported to Solidworks to be laser cut with a thickness of 0.3 cm. The dimensions for the fins can be seen in figure 1.

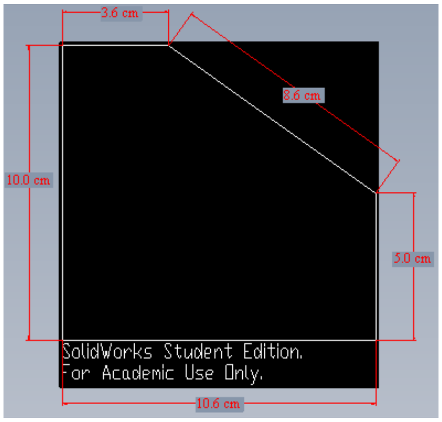

Figure 1: Dimensions of a Fin

The active drag system was designed using Solidworks and uses a motor and a threaded rod to adjust the height a platform which controls the angle of the deployed flaps. Pictured in Figure 2 is the active drag system in a fully deployed state. The diameter of both platforms for the active drag system is 7.62 cm. The flaps for the drag system measure 10 cm in length by 3.6 cm in width.

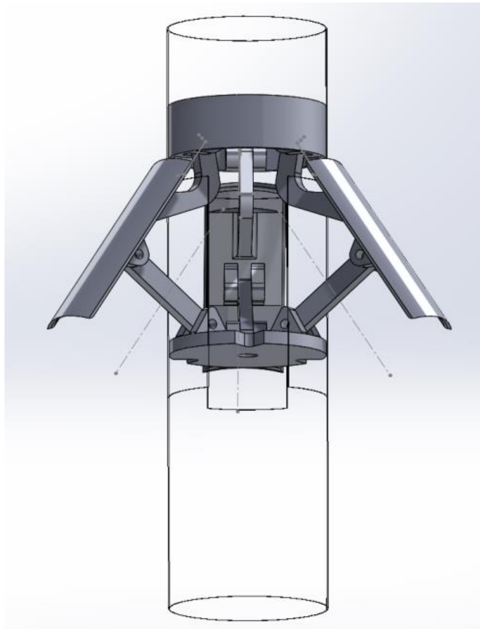

Figure 2: Active Drag System

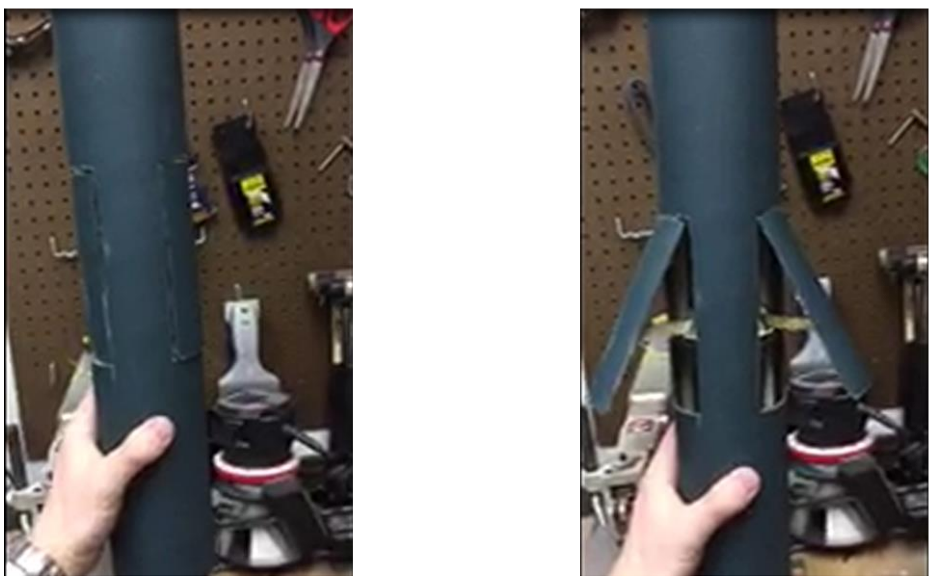

Figure 3: Inactive & Active Drag System

Figure 4 is the final open rocket design for the rocket. The rocket weighs 3.378 kg with the motor, and 2.944 kg after motor burnout. The center of gravity is located 98.1 cm from the front of the rocket, and the center of pressure is located 112 cm from the front.

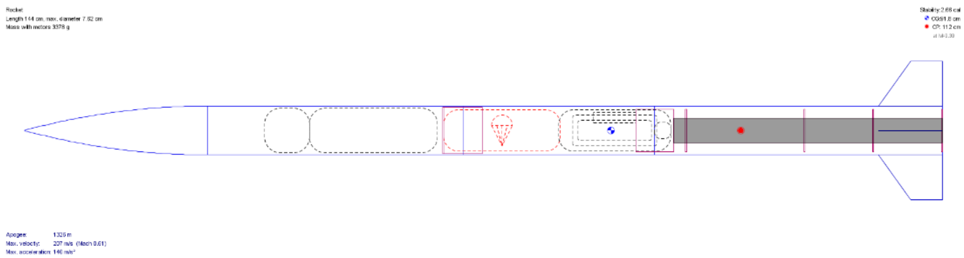

Figure 4: Open Rocket Design

b Construction Techniques

The rocket construction consists of integrating four main components; the body tube, drag system, fins, and motor tube. Each component was thoroughly assessed before advancing to the next steps of assembly and integration. The body tube was created out of 3 inch diameter cardboard tubes. These were wrapped with three layers of fiberglass using epoxy for the adhesive. The tubes were all sanded in order to remove sharp edges, bumps and rough patches. A coupler was 3-D printed to connect the body tube containing the motor and the section containing the parachute. The coupler contains a wooden bulkhead intended to aid in ejection. The electronics are all mounted within a bay above the drag system. The drag system was modeled using SolidWorks, and was then 3-D printed. While the plastic used is not as strong as metal, its weight is far less. Furthermore, the airbrakes are not expected to incur forces greater than sixty pounds and thus will have enough strength to withstand the aerodynamic stress. The printed pieces are held together using small nuts and bolts. The stabilizing fins at the bottom of the rocket were laser cut from wood and coated in fiberglass for added strength. Narrow slits were cut on the body tube into which the fins were inserted. Once the fins were slid into place, epoxy filets were applied to edges of contact between them and the body tube to fill gaps and add sturdiness. This method was proven in a test launch to be effective in creating connections capable of withstanding large impacts.

The motor tube was constructed around a PVC pipe. Trash bags were wrapped around the pipe, followed by a layer of Mylar. Mylar is a thin plastic sheet, added so that the trash bags did not stick to the fiberglass. Centering rings were laser cut and equally spaced along the length of the motor tube.

Figure 5: Fin Construction

Figure 6: Motor Tube Assembly

Figure 7: Final Product

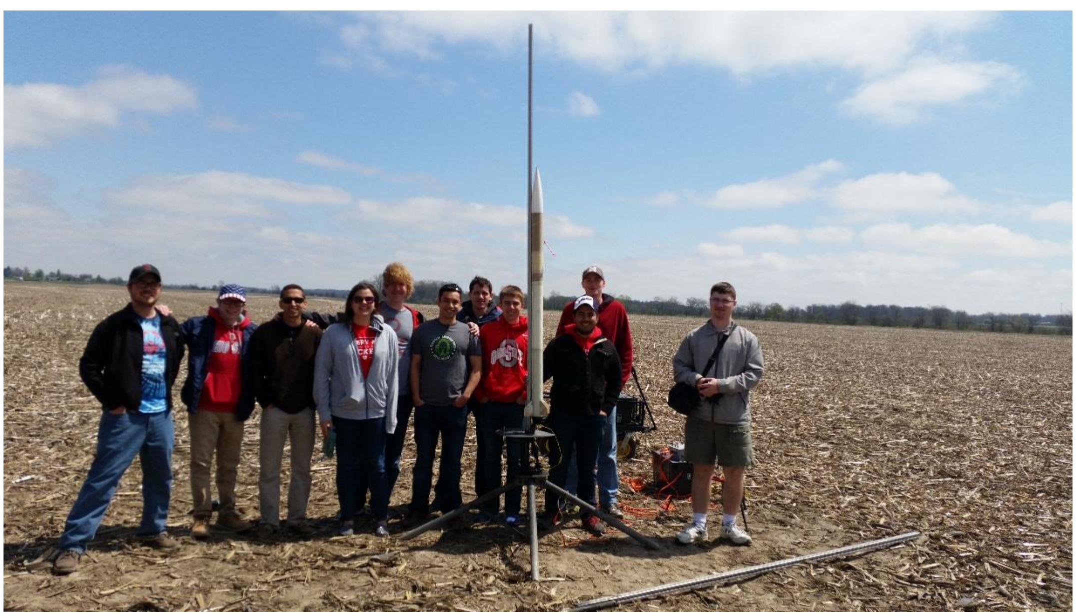

Figure 8: Test Launch

c Stability Analysis

The stability of a rocket determines how its motion will be affected in flight. Instability occurs when a rocket cannot produce enough restoring force in response to perturbation to return it to its flight path. This can be caused by wind or other forces making an unbalanced total normal force acting through the center of pressure. The center of pressure is the point on a rocket through which aerodynamic forces act. The center of gravity is the location of the average weight of a rocket and is the point about which rotations will occur. The center of gravity is calculated using the dimensions of the rocket along with its mass distribution. The center of pressure is calculated using the Barrowman method.

The distance between the center of pressure and the center of gravity defines the stability and is called the static margin. This is measured in calibers. The positions of the center of gravity and pressure were determined by the program, OpenRocket. This program found the static margin to be 2.66 calibers. The center of gravity was located 91.8 cm from the top of the rocket and the center of pressure was located 112 cm from the top of the rocket. This stability margin allowed the rocket not to spin unpredictably and to reach an apogee of 1581 m during flight with the inactivated drag system. The stability margin in flight with an active drag system was not flight tested but would actually be lower. Both the centers of gravity and pressure would shift towards the top of the rocket, with the center of pressure shifted slightly more than the center of gravity.

d Constructed for Safe Flight & Recovery

The demanding stresses that the rocket design was subjected to during flight required strong structural materials to prevent deformations and fractures. Fiberglass composites were used to reinforce the exterior of the body tube and could have been dangerous to work with. Before coating in the hardening epoxy solutions, safety gloves and glasses were worn during the coating processes and respirators were used post-hardening sanding to prevent inhaling the airborne glass fiber particles. The J410 Rocket Motor was a highly flammable solid rocket fuel that ignites with high temperature sparks. The motor was stored in a fire-safe cabinet when not in use and was handled with care during transportation to the field and during launch procedures.

e Discussion of Changes since Preliminary Design Report

The largest changes made to the design of the rocket since the preliminary design report includes movement of internal components. The parachute and recovery system have been moved to directly above the motor tube to make use of the motors ejection charge. The electronics including the Arduino board, sensors and battery were moved to the top section of the rocket. The drag system was positioned below the electronics and above a bulkhead separating it from the recovery system. A strap was used to connect the two sections of the rocket that separate during parachute ejection. After moving the internal components the stability of the rocket was reanalyzed to assure proper flight. It was also determined that the drag system would be assembled and created more accurately if it were 3D printed. The parts for the system were printed and connected using small bolts.

II. Budget

Midwest Budget	1300
Travel/hotel Budget	2200

	Quantitiy	Cost Ea. ($)
Registration	1	400
Rocket Body		
74 mm Body Tube (4 pack)	1	20.57
38 mm Casing	1	59.15
38 mm Retainer	1	43.87
74 mm Coupler	1	4.13
Flight Tags (5 pack)	1	10.95
J410 motor	2	12.95
34 mm long Nosecone	1	17.95

In house materials	1	0
Electronics		
Raspberry Pi Kit	1	69.99
Perfectflite Alt.	1	54.95
BerryIMU	1	34.00
Camera	1	39.95
Force Sensor	1	30.76
Protoboard (3 pack)	1	8.50
LiPo Battery	1	89.23
Remaining Budget		2590.1

The budget has remained unchanged thus far. All of the major components were purchased before the Preliminary Design Report was due. Every component that was needed after March was provided free by The Ohio State University. There may be some additional last minute purchases that will be rush ordered, but we will remain fully in budget.

III. Rocket Operation Assessment

a Launch and Boost Analysis

The launch phase lasted 1.65 seconds with a maximum velocity of 236.5 m/s occurring at burnout. At .0317 seconds the rocket lifted off the ground. At 0.20168 seconds the raspberry pi lost power at an altitude of 12.19 m. The boost phase subjected the rocket to a total of 17.4 G's. The actual flight complimented our initial calculations with little error. The next launch will record a far larger set of flight data will allow for more accurate data collection.

b Coast Phase Assessment

At 1.65 seconds the rocket went into coast phase with an initial velocity of 236.5 m/s. There was a moderate wind on the day of the launch which gradually tilted the rocket by a few degrees as it reached its maximum altitude. The rocket reached a maximum altitude of 1581 m after a coast time of 15.2 s. The actual rocket outperformed its simulated launch, reaching a greater maximum altitude.

c Drag System Assessment

The drag system remains untested thus far. Due to manufacturing defects, the 3D printed components were fabricated incorrectly and would not have been safe to test in flight. However, the error has been corrected and the system is expected to perform in accordance with simulations and without disturbing stability.

d Recovery System Analysis

The recovery system ejection occurred at 1406.7 m after apogee. The time after apogee was 6.4 seconds. The parachute was packed too tightly failed to deploy resulting in a freefall. The rocket consequently hit the ground at 23.2 m/s. There have been two conclusions drawn to remedy this failure. The parachute will be changed from 1.5 m to 1.2 m and there will also be less cellulose packed in the ejection chamber.

e Pre & Post Launch Procedure Assessment

The pre- and post-launch procedures adhere strictly to the Tripoli guidelines. Our team launches with Tripoli members every time and thus has adopted their system**.** Preparing the rocket for launch included the packing of the parachutes into the body tube sections with protective wadding. Once assembled, the rocket motor was slid into the aluminum motor housing and secured into the motor tube. After the rocket was secured to the launch rails, the electronics devices were armed with a pull-pin switch to prepare for data collection. After the rocket was secured to the launch rails, the rocket ignitor was placed inside the motor and discharge leads connected to the launch station. The custom electronics were set to record data following the thrust of the motor start up and recorded until they sensed that the rocket returned to the ground. Upon completion of the launch, the rocket was recovered and the saved data log file was recorded to a computer for analysis and compared to estimated results.

Table ##: Key Flight Data

	Drag System Inactive		Drag System Active	
Data Type	Simulation	Altimeter 2	Simulation	Altimeter 2
Apogee (m)	1372.4	1581	1209.9	
Time to Apogee (s)	16.092	16.06	14.902	
Cd	0.5174	N/A	0.6851	N/A
Max Velocity (m/s)	202.05	236.5	197.43	
Time of Max Velocity (s)	1.774	N/A	1.777	N/A

IV. Test Launch Actual Vs. Predicted Performance

a Peak Altitude Comparison

With the drag system inactive, the simulated apogee was 1372.4 meters at 16.092 seconds, while the Altimeter 2 gave an apogee of 1581 meters at 16.06 seconds during the test flight. With the drag system activated, the simulated apogee was 1209.9 meters at 14.902 seconds. Due to a manufacturing error with the 3D printing of the drag system, no data was able to be collected with the drag system active. The two values for the apogee with the drag system inactive are very different. This difference could have been caused by many different circumstances, one of which being the nature of the OpenRocket simulation. Due to wiring, the internal design of the rocket had to be changed from the simulation, which could have caused slight differences in the center of gravity. The simulation also assumes the rocket body to be perfect, which, due to the creation of the body tubes, fins, and other parts of the rocket, is not the case for the actual rocket. Ambient conditions likely played a factor in the difference as well, as the simulated conditions in OpenRocket were likely quite different from the actual conditions of the launch. Due to electronic systems failing, full flight data for altitude vs time is unavailable.

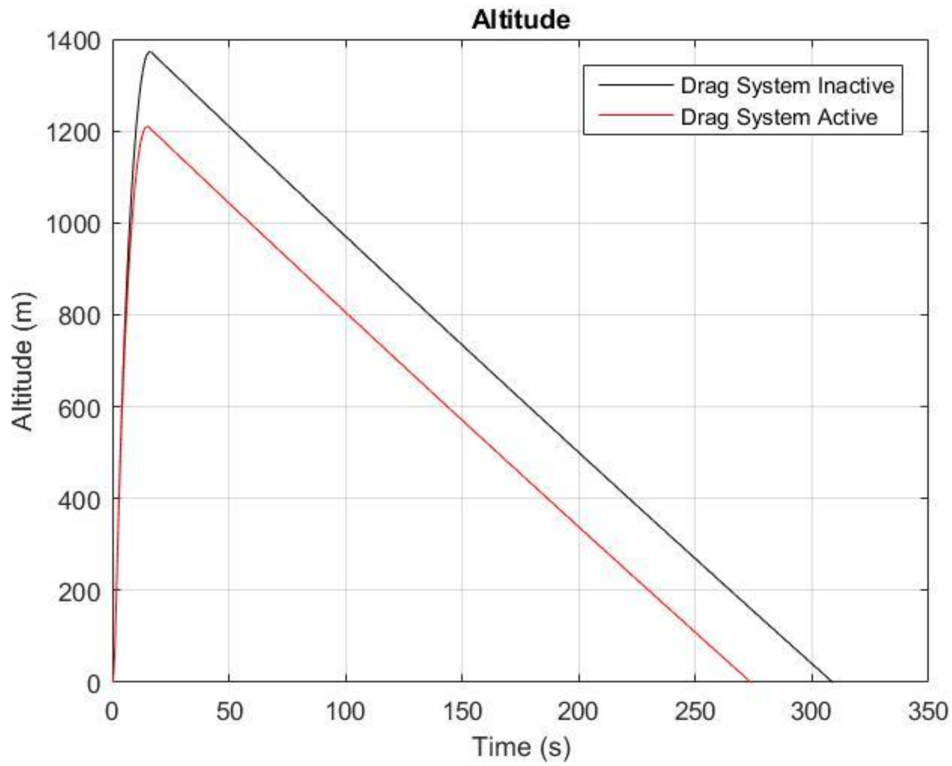

Figure ##: Altitude vs Time for Simulation

b   Coefficient of Drag Comparison

Calculated from the data from the simulation, the simulated drag coefficient with the drag system inactive was found to be 0.5174, while with the drag system active, the coefficient of drag was 0.6851. Due to the electronics failure, the data for the coefficient of drag for the inactive drag system case was not obtained. Although the drag coefficients cannot be compared to any experimental results, the simulated data of the drag coefficient being higher with the system active agree with our expectations. Though the drag coefficient should be constant, there are trends throughout the graph. The velocity changes of the rocket likely influenced the simulation’s drag coefficient, and the noise at the end of the graph is caused by the activation of the recovery system.

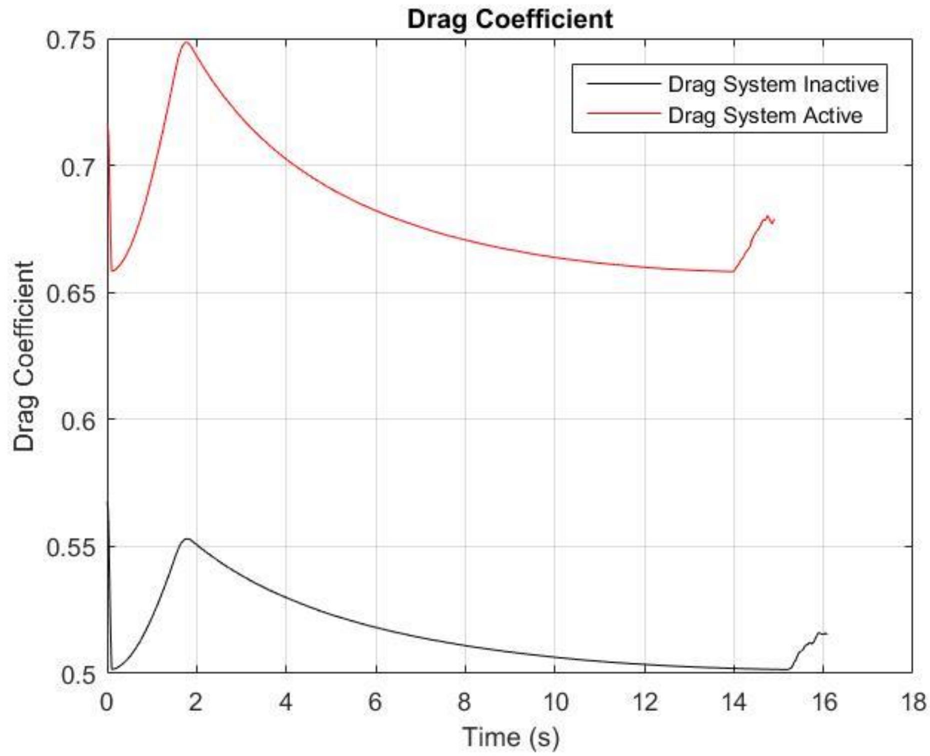

Figure ##: Drag Coefficient vs Time for Simulation

c Peak Velocity Comparison

The simulated peak velocity with the drag system inactive was 202.05 m/s at 1.774 seconds, while the Altimeter 2 shows a maximum velocity of 236.5 m/s. With the drag system inactive, the peak velocity was simulated to be 197.43 m/s at 1.777 seconds. The lower velocity for the drag system being active is in agreement with expectations. The significant difference in the peak velocities could be explained by the same simulation errors present in the analysis of the apogee of the rocket. The small hiccup in the data just before the flat section of the graph is likely caused by the deployment of the recovery system at these points. Due to the same electronics failure, velocity data for the full flight is unavailable.

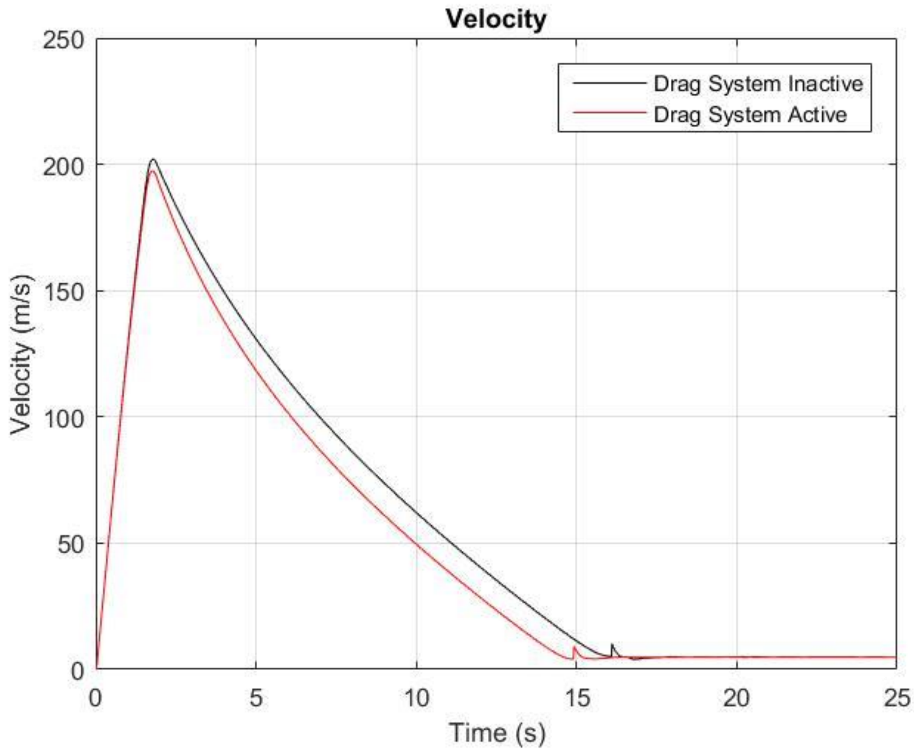

Figure ##: Velocity vs Time for Simulation

d   Video and Data Logging

Due to the focus on more important priorities, the video logging was not focused on during the test launch, however, a custom mount for the recording device has been made and is ready to be put on the rocket. The electronics have been tested and inputted into the source code. Although no video data is available now, video will be recorded upon launch.

V.   Findings and Future Work

a   Key Findings

There were several milestones that have been achieved throughout preparing for this competition. As time has progressed, knowledgeable data has been received. The rocket has been proven to fly true and outperform simulations. With this data, our team will be able to accurately implement adjustments to make our simulations more accurate. The electronics continue to improve daily. The data gained from the launch, and the failures that came with it have allowed us to hit the ground running. A hat for the pi is being made, the source code is being improved and reanalyzed, and the chute ejection has been fixed.

b Potential Design Improvements

Unfortunately, the 3D printed drag system broke during installation on the rocket because the plastic was not strong enough. To ensure the drag system can withhold the forces applied on it during flight, it will be printed again with a higher density of plastic or it will be laser cut. The second improvement on the rocket concerns the parachute. During the test launch the parachute did not deploy. In order to have the rocket land closer to the launch site, part of the parachute was tied off before the test launch. This may have altered the fit of the parachute in the rocket, which could have caused the parachute to become stuck in the body tube. In the future, part of the parachute will not be tied off and more care will be taken when packing the parachute into the body tube. Another issue that arose during the test flight was that the Raspberry Pi stopped recording data about 5 seconds into the flight. There was a loose wire in the electronics package, so to fix this issue the wires will be soldered into place.