Flight Readiness Report

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Executive Summary

This report contains information about the flight readiness of the University of Iowa's high-power rocket. Included are descriptions of the rocket design and construction, along with a stability analysis, analysis of construction for safe flight and recovery, and proposed changes that will be made to the rocket. Reasoning behind design modification and construction decisions are discussed. Diagrams of the rocket's flight and overall design are given. The original budget and actual expenses are tabulated and discussed.

Summary of Design

The majority of construction followed standard rocketry construction procedures, including sizing of airframe tubes, attachment of fins, coupling section sizing, bulkhead placement, and general component construction. All machining operations were completed using university-supplied hand and power tools, as well as CNC tools such as an end-mill, lathe, and water-jet. However, the custom-designed parts required additional and innovative manufacturing techniques.

Fins were designed by optimizing a trapezoidal shape to achieve the desired center of pressure and drag. While three fins would have been more aerodynamically efficient, four fins were used to simplify manufacturing. The material used for the fins was a 1/16 inch (0.1588 cm) thick woven carbon fiber reinforced polymer plate. As the fins were made from a woven carbon fiber composite sheet, typical cutting operations were not sufficient to produce quality cuts. Therefore, with the help of trained operators, a water-jet was used to cut the composite sheet into the desired shapes.

The section that required the most non-traditional rocket construction solutions was the dart/booster interface. As no standard drag-separation hardware was deemed acceptable, a custom dart tailcone was turned from solid aluminum stock using a lathe and mill. To decrease weight, the aluminum coupler was bored out to remove excess material. As the shaft on the end of the tailcone needed to connect to the booster, the booster nosecone was heavily modified. This involved trimming off the tip, attaching a centering ring to the back, and then inserting and securing a section of Blue Tube.

To hold all of the electronics, a custom rail was designed and 3D printed using a fused deposition modeling technique and ABS plastic. In order to connect the electronics rail, tabs were designed into the 3D printed part. These tabs locked the rail into slots cut in the back portion of the dart. While this increased the construction complexity, it allowed for faster and easier access to the electronics. The electronics rail was also designed to attach to the aluminum coupling section via protrusions and screws at the back of the rail.

The airframe of both the booster and dart were made from Blue Tube, a commercially available vulcanized paper tube. The dart had a total length of 113.39 cm, which includes the nosecone/coupling section (44.45 cm), dual-deployment system bay (2.90 cm external length), electronics bay, aluminum tailcone/coupling section (5.08 cm), and parachute bays (60.96 cm). The mass of the dart, including all electronics, was 2.061 kg. The booster had a total length of 93.66 cm, which includes the nosecone (18.10 cm), motor mount/parachute bay section (55.88 cm) and coupling sections (19.69 cm). The mass of the booster was 1.548 kg not including the mass of the motor. The combined booster/dart system had a length of 206.85 cm and can be seen in Figure 1.

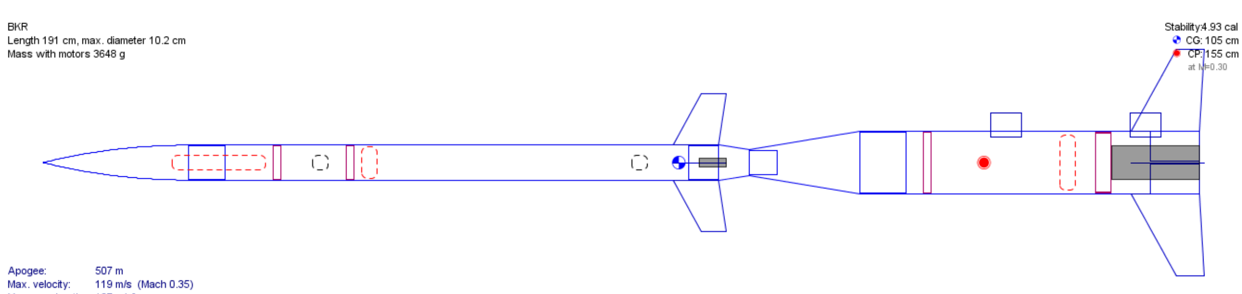

Figure 1: Diagram and locations for CG (blue) and CP (red) of combined booster/dart

The nosecone of the dart and booster were both bought through Apogee Rocket Components and are constructed of polypropylene plastic. Both nosecones had a standard ogive profile and were 24.13 cm in length. They each include a small tab on the inside for the connection of a parachute and shock cord. Due to packing constraints and construction techniques, these tabs were removed. For the dart, a bolt has been run through the nosecone for the attachment of the streamers and shock cord. The tip of the booster nosecone has been removed so as to provide a flat surface for the interface between the booster and dart.

The motor used for the test flight was a Cesaroni I445 motor, the same as to be used in the competition. This would allow for consistency between the test and competition launches. The motor was placed in a Cesaroni 54mm 1-Grain Case with a rear closure. A Pro-54 delay adjustement tool was used to remove six seconds from the ejection charge delay, resulting in a 10 second delay between motor burnout and ejection charge deployment. This time was selected to ensure sufficient time for drag separation between burnout and ejection.

To ensure safe recovery, the parachutes selected were designed to safely recover a mass of 5 pounds (2.268 kg) at 15 ft/s (4.772 m/s) for each section. For the dart, a dual-deployment system was to be used, and so streamers were selected for the first deployment stage. The streamers would minimize horizontal travel of the dart, and were rated for a decent of 50 ft/s (15.24 m/s). To achieve this, two 6 inch by 60 inch (15.24 cm by 152.4 cm) nylon streamers were packed into the upper deployment bay of the dart. The base guideline for main deployment parachute calculations was that 3.5 square feet (3250 square cm) of parachute would be required for every pound of recovered weight. Using this value, it was determined that a 50 inch (127 cm) parachute would be acceptable for both the booster and the dart. However, 50 inches is not a standard size for parachutes, so the decision was made to increase the size to the next-largest standard parachute sized, which was 52 inch (132.1 cm). Since the dart and booster were estimated to have the same recovered weight, 52 inch (132.1 cm) Angel parachutes were purchased for both components.

In order to meet competition avionics requirements, a custom avionics system was developed that attempted to minimize the weight and size of the components. Separate devices were chosen to accomplish the tasks of collecting video and flight data. The video collection device consisted of one Mini DVR 808 #16 V3 –Lens D Car Key Chan Micro Camera HD 720P Pocket Camcorder which was modified with a 24 position 0.5mm pitch 6in Flat Flex Cable in order to extend the camera from the rest of the avionics system. The data collection system consisted of an Arduino Micro, an ITG3200/ADXL345 Accelerometer/Gyroscope combo, and an Adafruit MicroSD card breakout board. A 3D printed ABS enclosure was used to seat the avionics system within the dart.

The center of pressure (CP), which is the balance point of all aerodynamic forces on an object, was calculated both by hand and by computer simulation. The simulation program used to calculate the center of pressure was Open Rocket. Both of these calculations used the Barrowman method, which assumes incompressible flow and no viscous forces. From the simulation results, the CP was found to be 155 cm from the tip. Combined with the CG point, located at 105 cm from the tip, the overall predicted stability coefficient was calculated to be 4.93 cal.

Budget

The estimated costs associated with this competition can be found in Tables 1, 2 and 3. The Iowa Space Grant Consortium was kind enough to offer sponsorship of the team. They will be covering the cost of competition registration as well as the cost of hiring a judge. $950 was granted towards construction costs. The team has also reached out to departments within the College of Engineering at the University of Iowa and to date has received a total of $4,500 in sponsorship outside of the Iowa Space Grant Consortium. To date, the team has spent $2,199.54 on various supplies ranging from construction materials and motors to paper towels and screwdrivers. It was anticipated that mistakes would be made during construction, which is why costs were overestimated when funding was applied for. Much of the unanticipated cost came in the form of shipping fees for materials ordered online, which to date have cost the team $221.16. The remaining $3,250 will be used to cover the cost of hotel rooms and transportation along with any last minute items that might need to be bought for touch-ups to the rocket.

Table 1: Proposed budget estimated for rocket project (construction)

Project	**Material**	**Projected Cost**
High-Powered Rocket		
	2 x PNC Nosecone	$41.48
	Aero Pack 54P TC Retainer	$43.87
	2 x 52" Angel Parachute	$168.00
	2 x Nylon 6" x 60" Streamers	$15.98
	4 sq ft economy Dragon plate	$123.00
	Motor Mount	$11.99
	Aero Pack Retainer P	$28.89
	Thrust Plate	$30.14
	G5000 RocketPoxy	$38.25
	Blue Ebay	$39.95
	LOC Stiffy Body Coupler	$5.78
	PNC-56A Transition Piece	$13.96
	Large Airfoiled Rail Buttons	$10.00
	Ball bearing swivel	$5.00
	U-Bolt assembly	$5.49
	4 x Quick Links	$13.00
	Madcow Parachute Protector	$8.51
	Dual Deployment System	$33.95
	Materials Testing	$500.00
		$1,137.24

Table 2: Proposed budget estimated for rocket competition (travel)

Project	***Expense***	***Cost***
Rocketry Competition Traveling Expenses		
	4 rooms, 3nights in hotel	$1,680
	3 cars, 2 trips	$262.08
		$1,942.08

Table 3: Specified cost of materials testing

	Material	Cost
High-Powered Rocket		
	1 x (11021) 3.9in (98mm) LOC Body Tube	$11.50
	1 x (10505) 98mm Blue Tube	$38.95
	Aervoe 20 Oz. Mold Releas & Protector (Case of 12) 3470	$64.90
	TotalBoat 5:1 Epoxy Kit (Gallon, Slow Hardener)	$109.99
	1 x 26.45 4.0 inch carbon fiber Light sleeves (cost for 5ft)	
	1 x 21.45 4.0 inch Kevlar sleeves (cost for 5ft)	
	1 x 16.95 4.0 inch lght Fiberglass sleeves (cost for 5ft)	
	1 x 71.82 5.0 inch diameter Treated Shrink Tubing (cost for 18ft)	$ 136.67
	4 x 2X4-8' Stud	$11.52
	2"X5' Solid PVC pipe	$4.64
	3"X5' Cell core PVC pipe	$6.40
	2 x 1"X18" black nipple (solid weight)	$9.72
	Venom latex 100CT S-M gloves	$9.97
	3M Latex respirator w/ valve	$6.37
	3M paint/sand valved respirator	$6.97
	1 PK Jubilee paper towel	$1.18
	Heavy duty shears	$4.99
	2 x LOC instant mix 5min 14M	$7.54
	1 QT mix and measure cup	$1.18
	7X2 Construction Screw	$3.79
	3M Sandpaper fine	$2.17
	3 x 3" Galvanized strap-bulk	$3.33
	1X8-3' #2 Quality board	$2.45
	Shipping and tax	$71.89
		$516.12

Construction of Rocket

The construction of the rocket followed standard high-powered model rocket procedures, including work on the motor mount, fin attachment, coupling sections, and bulkheads. Images from the construction process can be seen in Figures 2 – 9.

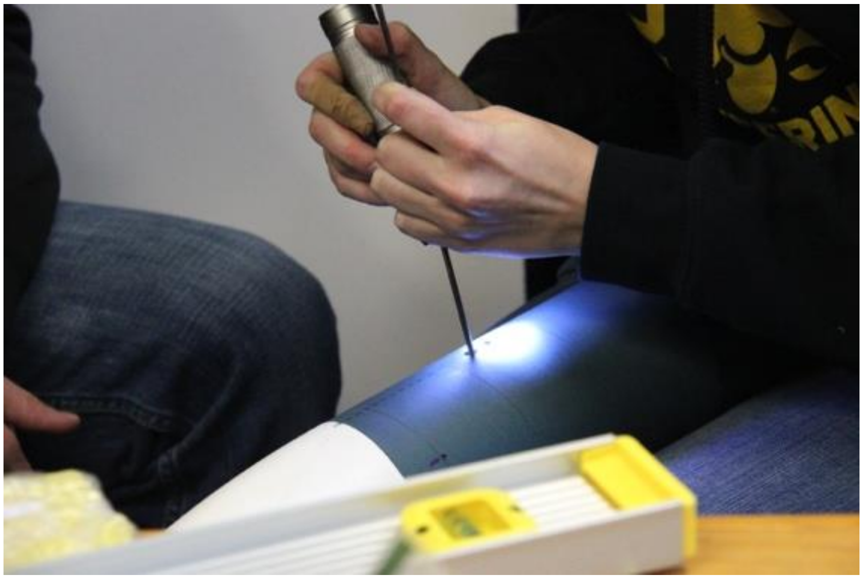

Figure 2: Placement and testing of booster altimeter

Figure 3: Attachment of rail buttons to booster

Figure 4: Filing of epoxy used to attach fins on booster

Figure 5: Attachment of fins to dart

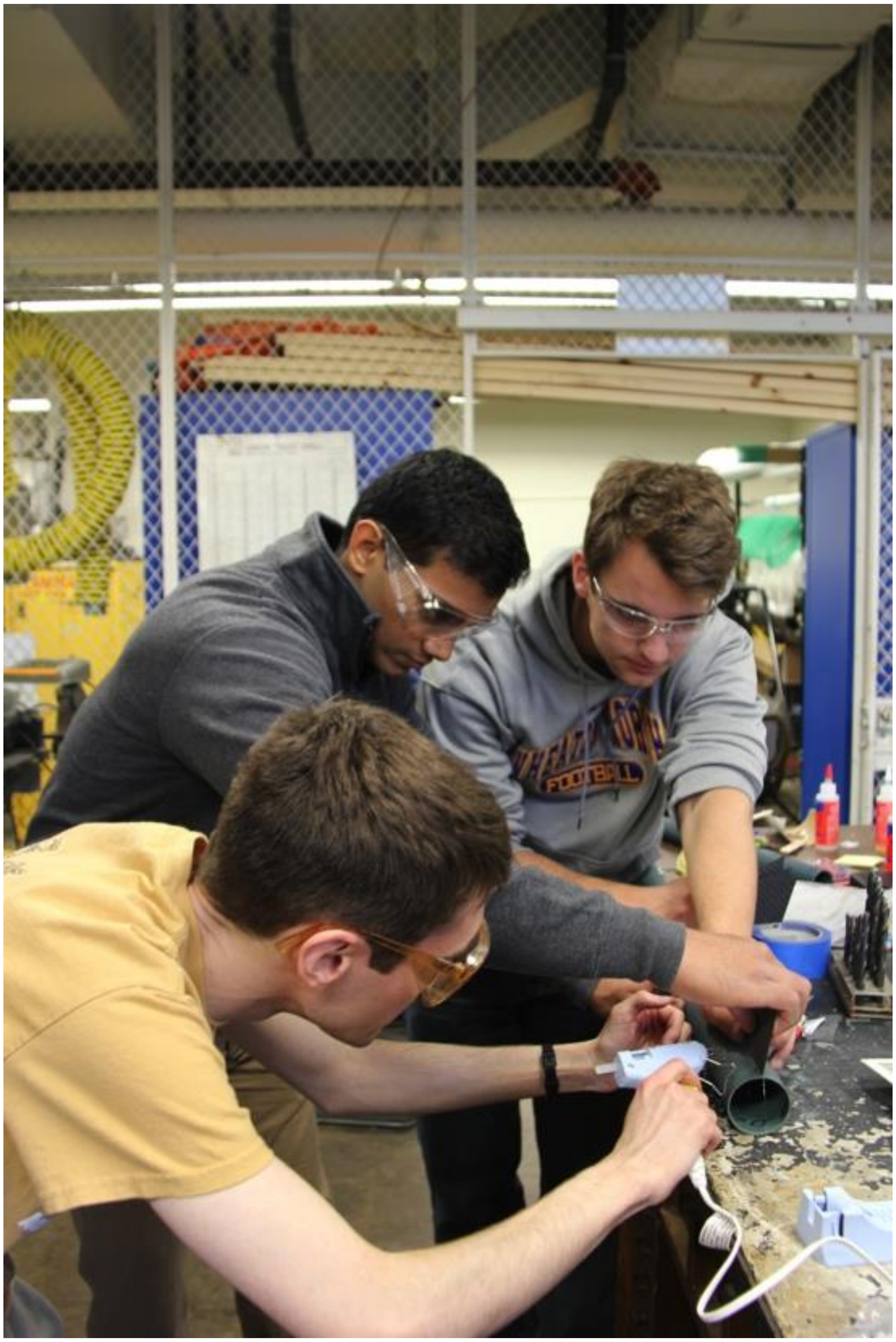

Figure 6: Attachment of fins to dart body

Figure 7: Drilling holes for connection screws

Figure 8: Completed booster tail-end (pre-paint)

Figure 9: Attaching safety ring to motor casing

Test Flight Report

The data that was collected from the test launch seen in Table 4 correlates with the simulation data. However, there were technical difficulties with the competition provided altimeter, which was placed in the booster. Because of this there is no flight data recorded for the booster.

Table 4: Summary of flight statistics

		Peak Accel. (m/s^2)	Apogee (m)	Horizontal Distance (m)	Peak Velocity (m/s)	Chute Deployment Height (m)
Dart	Simulated	136.6	505	276	119	No data
	Actual	No data	503	No data	103	274
Booster	Simulated	780	480	230	119	No data
	Actual	No data	No data	No data	No data	No data

Even though booster data was not collected, the altimeter in the dual deployment system recorded the flight before separation. The maximum height for the simulation was 1656 ft (505 m) seen in Figure 10 and the maximum height recorded by the dual deployment altimeter was 1650 ft (503 m) seen in Figure 11. This is extremely close to the predicted apogee with a difference of only a few feet. There is a larger difference between the test and simulation for the peak velocity. The simulation yielded a maximum value of 342 ft/s (119 m/s) during the combined flight at burnout. The maximum velocity recorded by the altimeter in the dart was 338 ft/s (103 m/s) as seen in Figure 12.

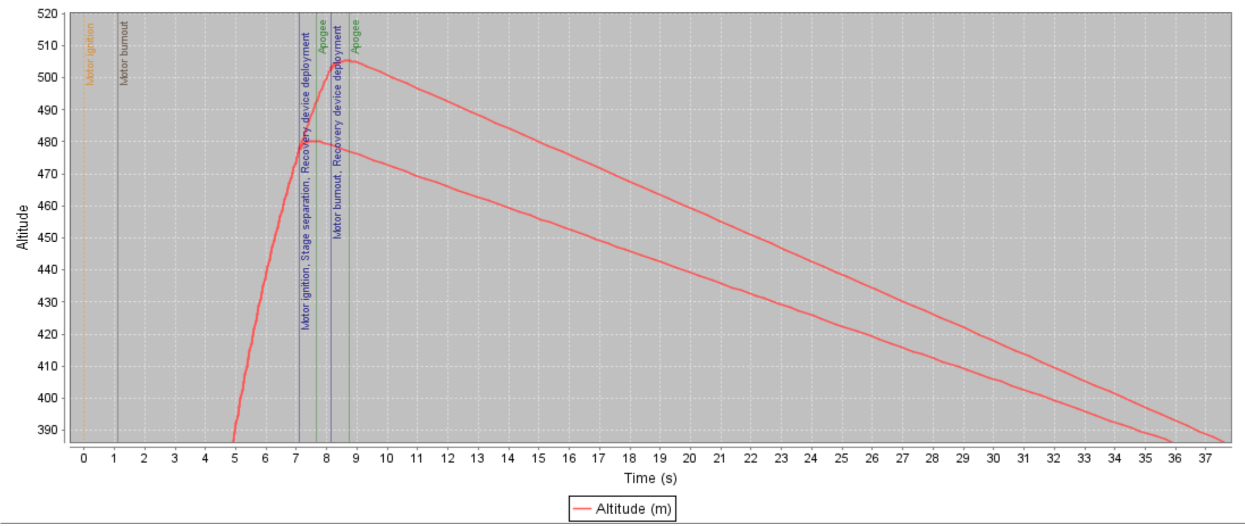

Figure 10: Separation between booster and dart

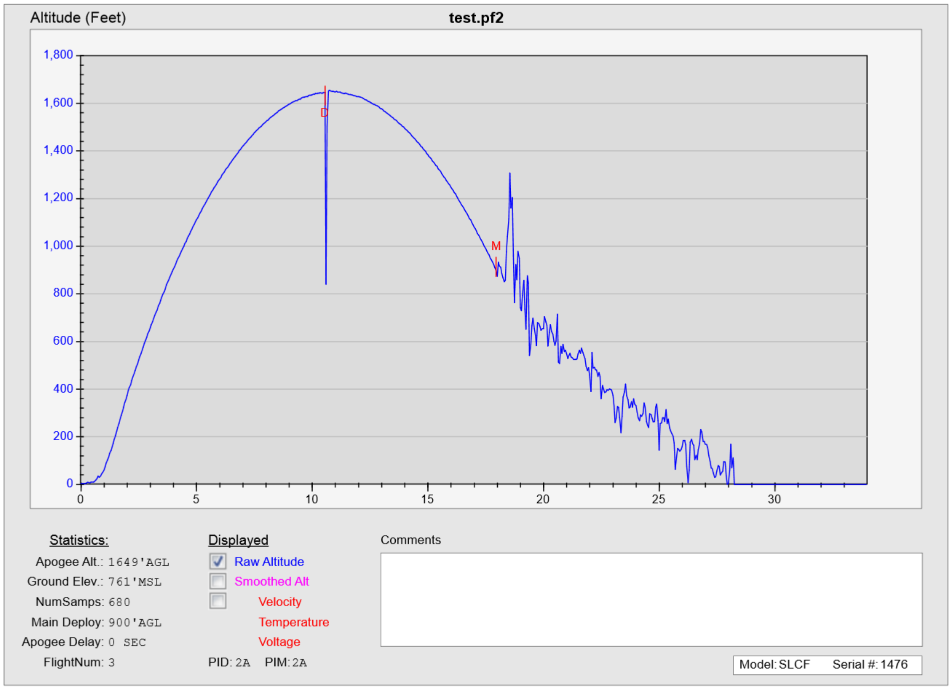

Figure 11: Dart test flight altitude data

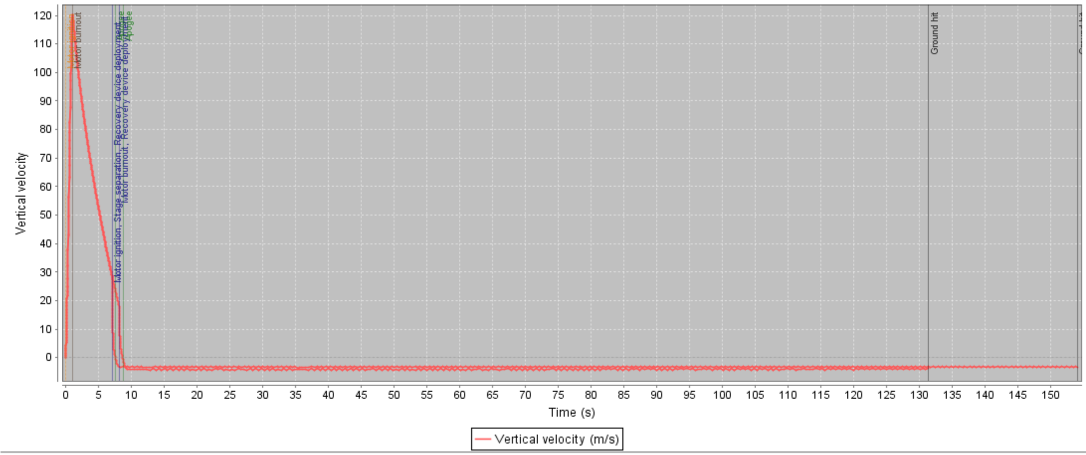

Figure 12: Open Rocket velocity data

The peak acceleration was not recorded by the altimeter in the dual deployment system and the booster altimeter did not record data. The peak accelerations from the simulations were 448 ft/s^2 (137 m/s^2) and 2559 ft/s^2 (780 m/s^2) for the dart and booster respectively seen in Figure 13. The value for the booster is most likely a simulation error but without test data we have no evidence to reject this value.

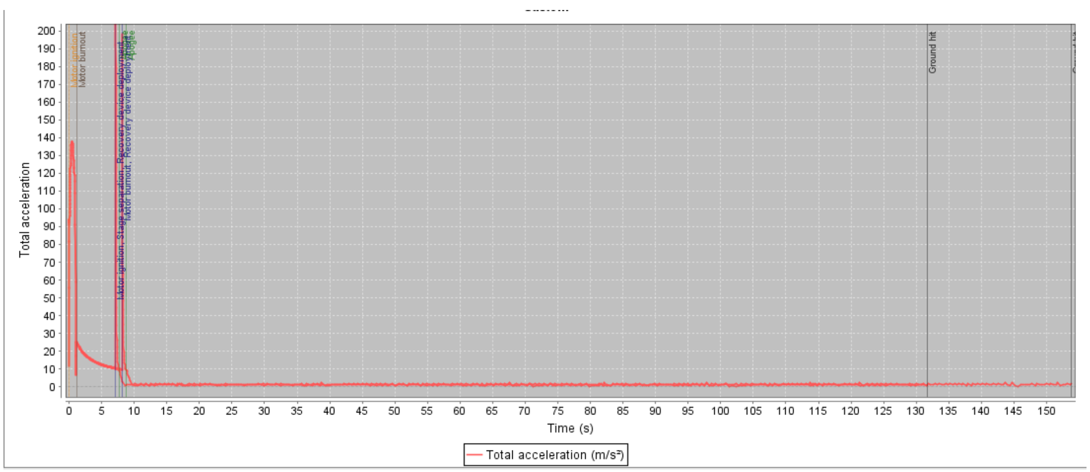

Figure 13: Open Rocket acceleration data

Open Rocket predicted a separation distance of about 90 feet (27 m). This separation is measured from the point of separation to the apogee of the dart. According to the simulation, the booster separated about 7 seconds after launch, but no altitude data was collected from the test launch to confirm this prediction. The separation was confirmed visually from a video recording of the launch from the ground but distances are unable to be measured.

The recovery system of the booster was successful but and the flight time was similar to that of the simulation but again no flight data was recovered. The dual deployment system in the dart had two black powder ejection charges. There were also three shear pins between each end of the system. Both charges successfully ignited as seen in Figure 11 at 900 ft

(274 m) above ground level as set by the computer in the dual deployment system. The first charge, while breaking the shear pins, did not separate the dart sections meaning the streamers in the nosecone could not deploy. The secondary charge was able to shear the pins and separate the sections, but the parachute was overpacked and did not deploy. The only thing that slowing the descent of the dart was the Kevlar shield that was used to protect the shock cords from the explosion. The dart impacted the ground about 28 seconds after launch; the simulation with parachute and streamer deployment calculated impact at about 130 seconds.

Figure 14 shows the complete flight from the simulation. The separation occurs around 7 seconds, as seen by the distance between the two lines. The dart then continues to a maximum altitude of 1658 ft (505 m) and a separation distance of 90 ft (27 m), corresponding to a maximum altitude of 1576 ft (480 m) for the booster). The estimated flight time is 130 seconds for the dart and 158 seconds for the booster, with a horizontal distance of 225 m for the booster and 230 m for the dart with wind speeds of 2 m/s. The calculated velocity at impact for the dart and booster are 4.0 m/s and 3.2 m/s, respectively.

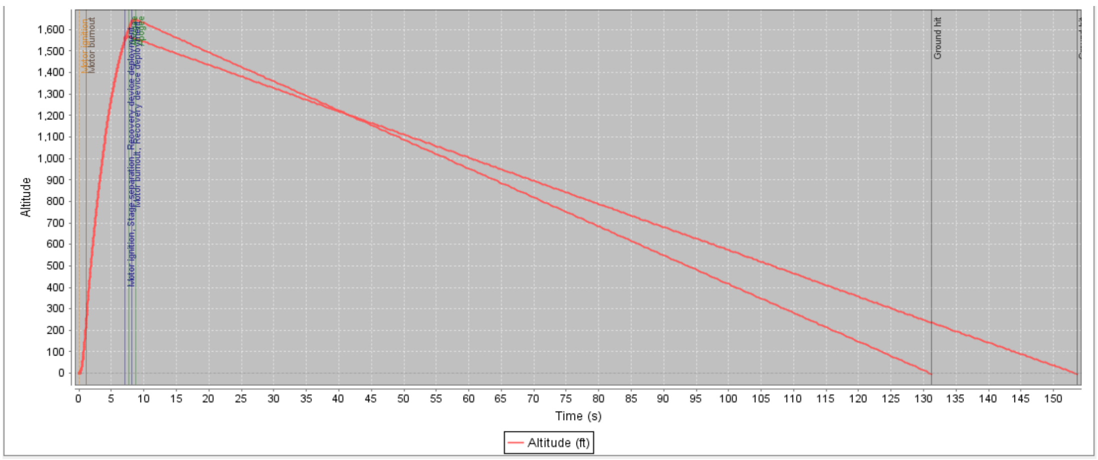

Figure 14: Open Rrocket altitude data

Figure 15 shows the Center of Gravity and Center of Pressure distances from the tip of the nosecone for the duration of the flight. As the motor burned fuel, the distance for the Center of Gravity decreased because mass was being lost from the back end of the rocket, while the front end kept a consistent mass. This also explains why the Center of Gravity becomes consistent after burnout, because then there was no mass being lost at either side of the rocket.

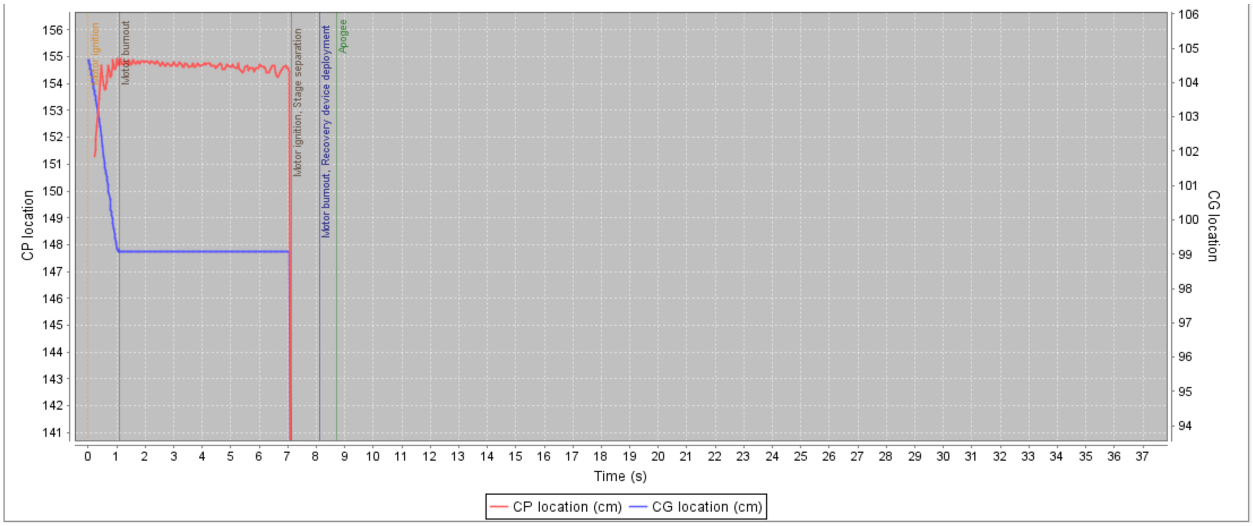

Figure 15: Simulation CP & CG locations during flight until separation

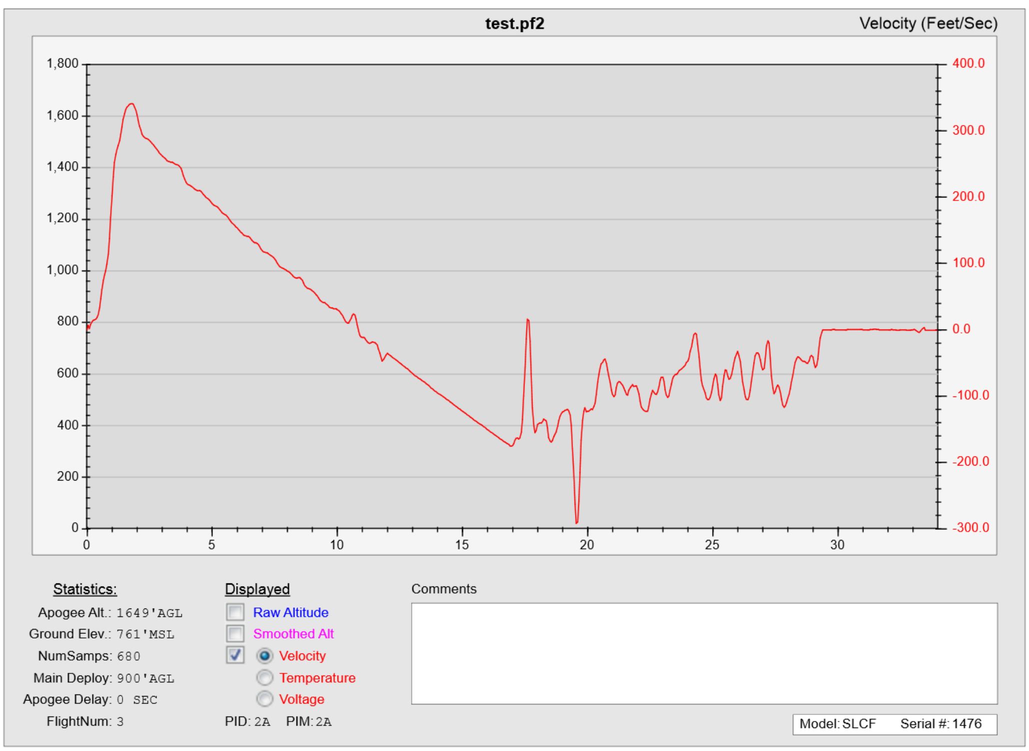

Figure 16: Dart test flight velocity data

Discussion of Results

The on-board video system worked for the duration of the flight, but the video was unable to be retrieved. Since the dart recovery system failed to deploy, the dart fell to the ground faster than anticipated and impacted first at the tailcone/electronics rail. Upon impact, the camera cable severed, and the video was not saved to the SD card before severance.

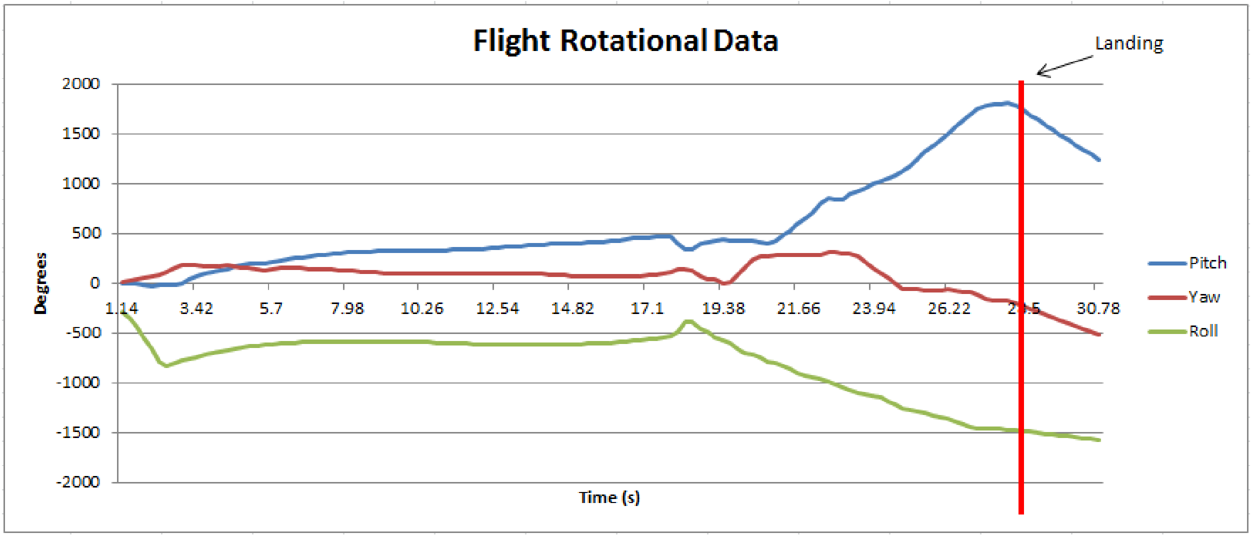

Figure 17: Yaw, pitch, roll of rocket

The data-logging system worked as expected and successfully recorded launch data. The current design of the system involves installing the battery during rocket assembly, meaning that all components are on from the time of assembly to the time that the recovered dart is disassembled. This system will be changed through the use of a switch. This is explained in more detail in the *Planned Improvements* section. The gyroscope recorded data in degrees per second at consistent (but undetermined) time increments. Post-processing was required due to the Arduino's capabilities. The post-processing began by converting the text file output into a comma-separated values file to be imported in to Excel. The majority of data, collected from before launch and after landing, was removed from the file. Data obtained from the dual-deployment system was also used to determine the time of flight from launch to impact. The total time was determined to be approximately 28.5 seconds. This time was then applied to the Excel file incrementally. The rotational data was originally in terms of velocity, so the values were integrated to obtain the desired position data. This integration was performed to obtain the yaw, pitch, and roll of the rocket. Figure 17 shows the plots of the yaw, pitch, and roll.

According to the data, the rocket initially rolled approximately -800 degrees (2.2 counter-clockwise rotations), then rolled back roughly 200 degrees before stabilizing. The yaw showed an early spike to 200 degrees, then returned to nearly 0 degrees. Because it is impossible for the rocket to have rotated 200 degrees after 3 seconds in a successful launch, it is likely that the gyroscope took some time to correct its drift. The pitch slowly increased as the rocket arced through flight, but showed values much higher than expected. Around 18 seconds into the flight, the deployment system fired, but did not deploy the parachute. This caused the rocket to rotate uncharacteristically through the air, providing a lot of noise in the data.

The simulated performance of the rocket was very close to the actual performance. The minor difference in altitude can be equated to the fact that the actual rocket had an imperfect surface. The grooves in the dart along with the protruding screws and shear pins added drag to the rocket. Improvements will be made to mitigate these surface imperfections. The planned improvements are further discussed in the *Planned Improvements* section.

As seen in the flight statistics summary Table 4, the altitude from the test flight and simulations were nearly the same but the peak velocity for the test flight is 16m/s slower than the simulation. This difference is most likely due to the surface finish on the actual rocket. In the simulation it assumes a near perfect surface finish for each component of the rocket. The rocket flown during the test had imperfections from the shear pin head and fixed screw heads, holes for altimeter data acquisition, and relatively large fin fillets. This combined with a not ideal surface finish means that there was more drag on the actual rocket. The Planned improvements section discusses the strategy for reducing this drag and bringing the peak velocity closer to the predicted value.

The separation distance during the test flight could not be determined but even the simulation predicted it to be a relatively low value. Assuming that the separtation distance followed the simulation data as closely as the altitude and velocity for the booster it would be between 70-90 ft (21-27 m). This separation is small because of the weight of the dart. To achieve a better separation distance the weight and surface roughness of the dart will be reduced, also discussed later in the improvements section.

Planned Improvements

The dart is the main component to be improved, with a focus on reducing weight and improving the aerodynamics of the dart. Spackle will be used to fill in the seams on the Blue Tube airframe. This will then be sanded to give the dart a smooth, uniform surface before painting. The fins will be reattached to the dart using more epoxy clay and a procedure similar to the initial attachment. Once cured, the clay fillets will be sanded down to make them more aerodynamic and to aid in weight reduction.

The aluminum coupling piece will also be modified to reduce weight. Weight will be removed from the top section of the coupler nearest to the electronics. Figure 18 shows the cutouts that will be made to reduce the weight. The weight reductions will be done on the section of the coupler that goes within the booster to prevent any changes to the overall aerodynamics of the coupler. A hole will also be drilled for a new camera that better meets the competition requirements. The original camera faced normal to the angled section of the coupler. The new hole will be drilled at a steeper angle so that the recorded video will be at a more downward-facing angle as required by the competition.

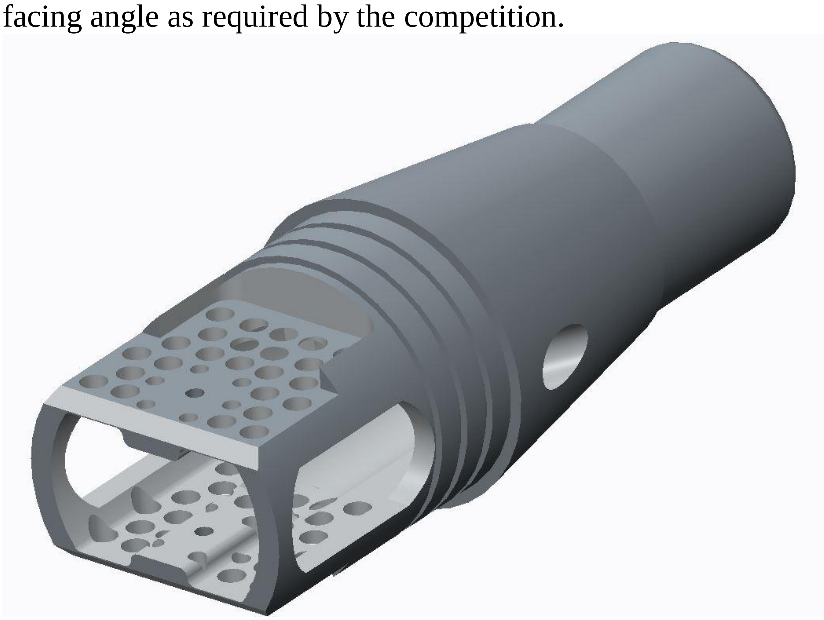

Figure 18: Modified aluminum coupler

A new parachute will be used in the dart as well. The original 52” parachute was oversized for the weight of the dart, and had too much friction in the dart to deploy properly. By using a 30” parachute instead, the parachute will be able to deploy as needed. The new parachute weighs 3.1 oz, compared to the old parachute’s weight of 12.2 oz, helping with the goal of weight reduction. The combined changes to the dart will reduce the dart’s weight by nearly a pound, allowing for a higher maximum altitude.

For the booster there will be an adjusted delay on the ejection charge to prevent airframe damage from the shock-cord. The currently used delay resulted in a little damage to the coupling section due to the speed of the booster when the chute ejected.

The electronics will also be changed to account for the issues that occurred during the test flight. The new camera will be placed at the downward angle as mentioned before, and the cable connection will be improved to prevent severance during flight. The data acquisition system will also be improved for timelier post-processing that is easier and more efficient. This improvement includes an Excel spreadsheet that can be used to quickly import data and process it as needed. A switch will also be installed so that data will not be recorded during assembly of the rocket. The switch will be used to initialize the electronics package once the rocket is on the launch stand to ensure that only pertinent data will be recorded.