2014-2015 NASA Space Grant

Midwest High-Power Rocketry Competition

Flight Readiness Report

University of Minnesota Senior Design Team

Team: Space Cowboys

Peter Brackin Sean Conway

Scott Gleason John Kregness

Sean Moore Logan Rowell

Zack Thompson

Course: AEM 4333

Faculty Adviser: Professor James Flaten

May 4th, 2015

Table of Contents

1. Summary of Design

Figure 1. Launch-ready assembly of boosted-dart with the airbrakes section included.

In order to achieve drag separation between the lower booster section and the upper dart section, the rocket is designed with a long slender dart, and a short, wide booster. The transition phase between the two is built to hold the dart and constrain it to be only free to move in the upwards axial direction. The rocket is designed to function in two separate operational modes: with an airbrake section included in the booster, and without.

Avionics are included with the dart to provide altitude, acceleration, velocity, 3-axis rotational data, as well as an onboard camera to record the flight. In addition, a radio tracker is implemented for recoverability purposes. The avionics onboard the booster measure the altitude as well as actuate the airbrakes (when in use).

2. Budget

	Vendor	**Cost/Unit**	**Qt.**	**Total**
Kit Build	[Various Vendors]	$491.72	1	$491.72
Arduino Nano	Gravitech	$34.99	2	$69.98
10DOF Chip	AdaFruit	$29.95	1	$29.95
Micro SD Break Out	AdaFruit	$14.95	3	$44.85

BMP180	AdaFruit	$9.95	2	$19.90
FlyCam One Eco V2	SparkFun	$39.95	1	$39.95
FlyCam One Eco V2 - Battery	All-Battery	$30.00	1	$30.00
FlyCam One Eco V2	Ebay	$34.99	1	$34.99
FlyCam One Eco V2 - Battery (5-pack)	Amazon	$17.30	1	$17.30
Quick Connect Battery Connectors	Amazon	$10.59	1	$10.59
Ultra Light Carbon Fiber 3" Length = 45" thickness = .040"	Public Missles	$134.95	1	$134.95
FiberGlass 29mm x .0555" for 48" length	ApogeeComponents	$48.31	1	$48.31
24x24 G10 FR-4 Natural Fiberglass sheet thickness = .093	ePlastics	$49.01	1	$49.01
3/8" PTFE Virgin Rod	MSC Direct	$4.93	1	$4.93
3/8" PTFE Glass-Filled Rod	MSC Direct	$7.89	1	$7.89
3/8" PTFE Tubing	MSC Direct	$6.56	1	$6.56
1/16" 6061-T6 Aluminum Sheet 8"X8"	McMaster	$8.85	1	$8.85
1/8" 6061-T6 Aluminum Sheet 6"X6"	McMaster	$9.52	1	$9.52
HS-485HB Servo Motor	Robotshop	$16.99	2	$33.98
1/8" 2024 Aluminum Rod 3 ft	McMaster	$8.37	2	$16.74
Pr2032 Resin w/ Ph3660 Hardener Qt. Kit	PTM&W	$40.85	1	$40.85
Arduino Nano 3.0 - No Pin	Gravitech	$32.99	2	$65.98
High-G Accelerometer	Adafruit	$24.95	2	$49.90
Kevlar Cord 1500#	Apogee Components	$0.92	32	$29.44
Plastic 3" Ogive	MadcowRocketry	$17.95	1	$17.95
Carbon Fiber Rod .125"OD, 48" length	ACP Composites	$3.75	3	$11.25
Servo Gear .688" OD	Servo City	$4.20	2	$8.40
Rod Mounted Gear .375"OD	Servo City	$1.71	2	$3.42
PNC 29mm Boat Tail	Apogee Components	$8.63	1	$8.63
Pro54-1G Motor Casing	Offwegorocketry	$39.75	1	$39.75
Pro54-1G Motor Casing Closure	Offwegorocketry	$39.95	1	$39.95
475-I445-16A Vmax 54mm motor	Offwegorocketry	$52.99	3	$158.97
PTFE 1/4" ID Virgin Tube	MSC Direct	$3.16	2	$6.32
29mm x 6" G12 FW Fiberglass Coupler	Apogee Components	$11.33	2	$22.66
Phenolic Coupler 2.88" ID 5" length	PML Missles	$3.15	2	$6.30
Carbon Fiber Tube .196" OD	CST Composites	$2.95	1	$2.95
Washers #8	HomeDepot	$1.18	1	$1.18

JBWeld	HomeDepot	$5.67	1	$5.67
PTFE Spray	Amazon	$9.69	1	$9.69
E-matches	OffWeGoRocketry	$2.00	10	$20.00
MicroSD cards 8GB	Amazon	$4.97	3	$14.91
Loctite 770 Primer for Glues	Amazon	$23.30	1	$23.30
1/8" ID Washers	Amazon	$2.47	1	$2.47
Loctite 770 Primer for Glues	Amazon	$23.30	1	$23.30
Loctite Prism 480	Amazon	$25.17	1	$25.17
Molex 51021 2 Pin Connector	All-Battery.com	$1.50	6	$9.00
MOSFET N-CH 60V	Digi-key.com	$0.80	10	$7.95
Altimeter Two	Offwegorocketry	$69.95	1	$69.95
54mm Mother Tube (Motor Mount)	PML Missles	$13.99	1	$13.99
36" Nylon Conical Parachute	PML Missles	$27.29	1	$27.29
24" Nylon Conical Parachute	PML Missles	$21.95	2	$43.90
Rail Buttons 1"	Offwegorocketry	$5.85	5	$29.25
PCB Switches	Offwegorocketry	$4.96	2	$9.92
9" Nomex Flame Shield	The Rocketman	$14.00	2	$28.00
Raven 3 Altimeter	Featherweight	$155.00	1	$155.00
Kingston 8GB cards	Amazon	$9.74	1	$9.74
24" Thin Mill Parachute	TopFlightRecovery	$11.95	2	$23.90
Misc. Hardware	HomeDepot	$150.00	1	$150.00
Total Cost	---	---	---	$2,326.27

Table 1. Budget beginning from Fall 2014 semester through Spring 2015 semester.

3. Construction of Rocket

Using SolidWorks, drawings were used to lay-out the internals of both stages to confirm that the lengths would fit all avionics and recovery devices that were necessary for a successful launch. Once the lengths and modular format of the sections were confirmed, the overall lengths of the booster and dart were finalized and construction of both stages began. To assist in the machining of the body tubes, OrbitalATK in Plymouth, Minnesota was contacted and agreed to cut both the fiberglass and carbon fiber body tubes to the lengths required as well as cut the fin slits and airbrake slits in the fin sections and airbrake sections, respectively. They were able to do this by using the SolidWorks files provided from the initial sizing. The goal was to have OrbitalATK also machine the transition nosecone, by removing the top portion of the nosecone and cut four fin slits to fit the dart fins. However, because of the flexibility and likeliness of deformation of the thin walled plastic nose cone, the transition nose cone had to be machined by hand after some modifications were made, which are discussed below.

To modify the transition nosecone, which was a Madcow Rocketry, Plastic 4:1 Ogive, the shoulder ribs were sanded to make the shoulder as even as possible; this was to increase the bonding surface for the fiberglass and reduce sand time after fiberglassing occurred. The nosecone was then hand machined using a Dremel tool to remove the tip of the nosecone and add four fin slits. To accurately attain the proper diameter hole in the tip of the nosecone, a small portion was removed and then sanded until a section of the fiberglass 29mm body tube could easily slide in and out. Once this was complete the slits were cut to approximately the same depth of 1.25” to keep the dart from rotating about the central axis of the booster upon launching.

After these initial modifications, a fiberglass lay-up was done using fiberglass cloth and Aeropoxy resin. This not only increased the structural integrity of the flimsy plastic, but also increased the shoulder diameter to better match the outer diameter of the 3” carbon fiber body tube. A pattern was drawn to trace onto the fiberglass to ensure proper sizing with excess on both ends for folding over into the inside of the nosecone. Once the cloth was cut and the Aeropoxy added, it was placed on the nosecone and the ends were folded in and held in place by pressure using a balloon on the shoulder end and a cylinder on the transition end. The shoulder was then wrapped in a thin strip of fiberglass to build up the diameter and make a tighter fit between the nosecone shoulder and the body tube. There were 5 wraps added in total to this section. The final wrapping occurred by the fin slits. There was concern that these slits would reduce the durability of the nosecone, so a thin wrap of fiberglass was added from the leading edge of the nosecone to extend just beyond the bottom side of each slit. This was then wrapped in plastic and pressure sealed using tension and electrical tape.

Once dry, the nosecone had two bulkheads affixed inside to center the axial carbon fiber rod and allow the dart to rest on a bulkhead rather than the fin slits in the transition nosecone. These two bulkheads were laser cut to a diameter slightly larger than required, and then the edges were beveled to better fit into the nose cone. The upper-most bulkhead was 5.375” from the leading edge of the transition, which allowed the dart to be recessed into the transition this same distance. Once this was confirmed the 7”, 0.196” outer diameter, Standard Carbon Fiber rod and bulkheads were epoxied using DP 420. Figure 2 shows this rod and the upper bulkhead within the transition nosecone. To reduce the friction between the dart and booster, WD-40 Dry Lube PTFE Spray was/can be added to the carbon fiber rod.

Figure 2. An inside look at the transition nosecone showing the carbon fiber rod, which keeps the dart axially centered, and the upper bulkhead, where the dart boat tail rests prior to separation.

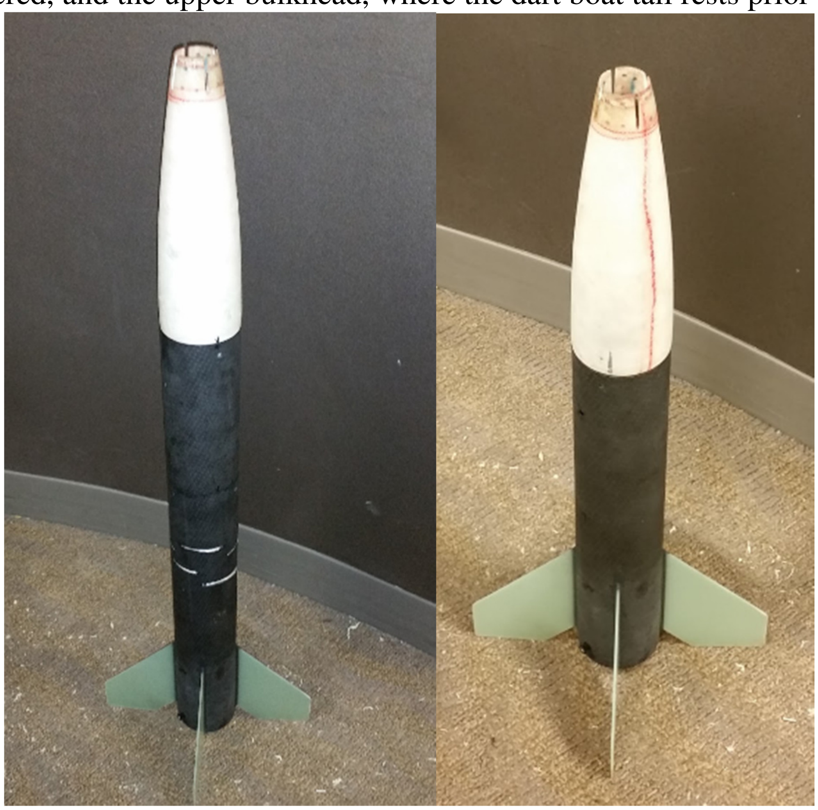

Figure 3. (From left to right) The booster in a longer configuration with airbrakes and a shorter configuration without airbrakes.

Three holes, ~120° apart, were drilled into the Payload/Avionics section of the body tube. Three matching holes were then drilled into the shoulder of the nosecone. This allowed for the Payload/Avionics Section of the body tube to be secured to the transition. Three nuts were aligned to these holes on the inside of the tube and epoxied into place. It was determined that using nuts and bolts were better than screws, especially because the carbon fiber body tube was thin.

The Payload/Avionics Section also required a coupler tube to be placed into the bottom. This coupler was phenolic and was modified with one lay-up of fiberglass to increase the outer diameter. A bulkhead of plywood was also fixed inside the coupler with the bulkhead flush to one end. This was an anchoring point for the parachute chord which attached to a loop of 1/16" steel cable. This coupler tube was then epoxied with half of it inside the Payload Section and the other half remaining outside to attach it to the lower section (depending on the configuration).

The Airbrake Section and coupler to the Payload/Avionics Section had three holes drilled into them and nuts mounted inside the coupler. This process was very similar to that previously discussed. A bulkhead was placed on top of coupler that was epoxied to the airbrake section. This coupler had two small aluminum pins which were opposite each other and stuck up into two holes on the bottom of the airbrake section to reduce rotational movements when the airbrakes actuated after burnout.

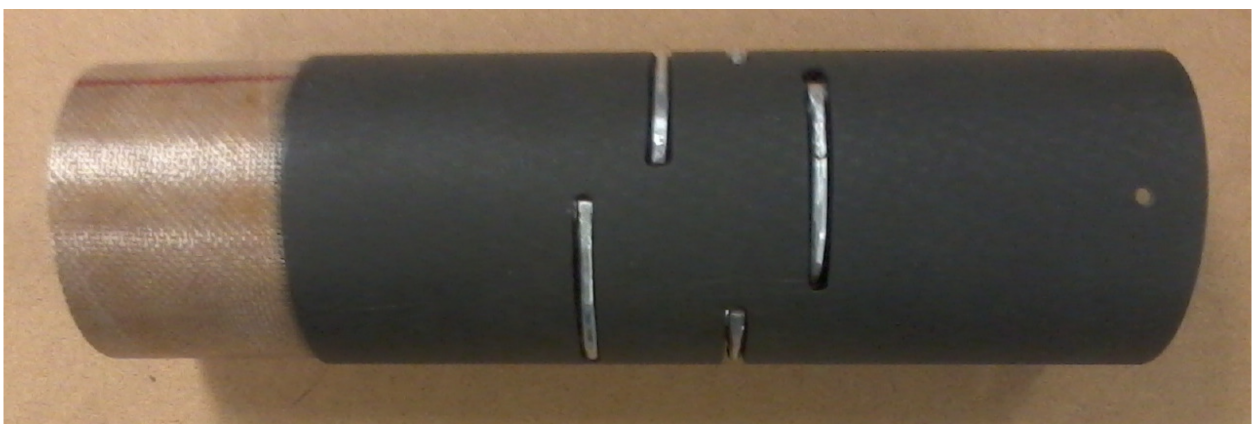

Figure 4. The Airbrake Section of the booster. The airbrakes can be seen through the slits in the body tube. The airbrakes are secured to a bottom bulkhead by two pins, which slid into holes in the airbrake construction.

The airbrake system was made out of aluminum sheets and rods. The airbrake bulkheads, discs and plates were machined using a CNC mill according to the SolidWorks drawing. The plates were 1/8" thickness while all other components were 1/16" thickness. The airbrake support rods and central shaft were made out of 1/8" aluminum rods cut to length by hand, according to the design drawing. All pieces were sanded and bonded together from the base of the airbrake system up using JB weld epoxy. Small washers were added above and below the plates on the vertical rods to hold them in position. Once competed, a servo gear was mounted to the central shaft using epoxy and all moving parts were lubricated using WD-40 Dry Lube PTFE spray. The plates were not perfectly constrained and as such, the slits in the carbon fiber body tube machined by Orbital ATK based on the SolidWorks model had to be widened using a Dremel to allow for consistent deployment of the airbrakes.

The final section of the booster was that of the fin section, for which OrbitalATK had machined the slits. The fins were cut from .0833” G10 Fiberglass using a band saw; any fine tuning beyond that was done with files and sandpaper. The fins were placed into each of the slits making sure that there was 90° from fin to fin. To make sure epoxy was applied only to the desired locations, each fin slit was taped with a small window to apply the epoxy; once applied, the epoxy was filleted to reduce any imperfections.

The motor mount was put into place by gluing the upper centering ring to the motor mount tube at a location above the fin slit. The next step was to glue the upper centering ring to the body tube. The lower centering ring was used to hold the motor tube in the correct location while the upper ring cured. The second ring was repositioned after the upper ring was dry and was then glued into place.

Thus the booster construction was completed and the overall length of the booster section is broken down as follows:

Booster Length Breakdown	
Component	**Length (Inches)**
Nose Cone (Transition)	9.75
Payload/Avionics Section	7.25
Airbrake Section	8.25
Overall Length	**25.5**

Table 2. Above is the component breakdown length of the booster. The overall length of the booster is 25.5” which is 0.75” greater than the values seen in the above table; this is because the fins are swept back and extend past the end of the body tube by 0.75”.

The dart had a similar construction to that of the booster. The nosecones/tailcones used for the dart were PNC 29mm styrene 3:1 ogive nosecones. However because the fiberglass body tube had a larger outside diameter than that of the nosecone fiberglass, lay-ups were done to increase the diameter and structural integrity. Four lay-ups were done on each nosecone, which made the diameter closer to that of the body tube. The dart nosecone was also filled with Aeropoxy resin to ensure that the center of mass was forward and that the dart had a static margin greater than 1. A small eye-bolt was also placed into the Aeropoxy to have an anchoring point for the shock chord for the parachute of the dart.

The main body tube of the dart measured 31.375” during the second generation build. This was longer than the first dart, but the reason the first dart was not recovered was due to sizing problems and being too tightly packed. Hence the second dart was built longer to ensure that this did not happen again. Once this section was cut to length, a notch wide enough for the camera lens to protrude out the side of the body tube was cut so that when the avionics bay slid in, there would be no interference with the body tube and camera. Directly above this notch, an aerodynamic 3D-printed shroud was attached with one small fiberglass lay-up. This was done using pressure and tension (same as the nosecones). The shroud was included to provide protection and reduce unfavorable aerodynamics generated by the protruding camera. Once the avionics bay was constructed (see Dart Avionics Section below for more information), a bulkhead was placed at the top of the avionics bay inside of the body tube to secure the avionics bay in place and provide the second securing location for the parachute shock chord. The location of this bulkhead was strictly dependent on the length and design of the avionics bay, hence why it was done after the construction and placement of the avionics bay within the dart.

The most critical portion of the dart construction was that of the transition area. The tailcone was built first by modifying one of the nosecones by removing the tip until the PTFE tube fit snuggly and the inner diameter 0.125” hole was fully accessible for the carbon fiber rod in the transition section. The PTFE tube was then cut to a length of 6” and primed externally with Loctite 770 so that adhesives would stick to it, because it acted as a contact point for all the fins inside the dart. After being primed, the PTFE tube was secured into place within the tailcone with Loctite 480 on both ends, with the upper end being centered by small plywood centering ring within the tailcone shoulder.

The fin section which started out as seen in Figure 5 was then built by inserting the tailcone/PFTE combination described above. The fins were cut from .0833” G10 Fiberglass with a band saw and modified to be identical with a belt sander.

These were placed into the fin slits and checked to make sure they were all snug against the central PTFE tube. After slight modifications to the fins, they were secured in place with Loctite 480 along the base of the fins. The coupler tube, which had fin slits cut into it from one end with a band saw, was marked by placing the coupler in the body tube to a position where the slots aligned. A camera slot was cut on the opposite end between two of the fin slits, just wide enough to fit the camera lens through when sliding the fin section/tailcone together with the body tube. The fin slots in the coupler were then slid in to the fin section to add another surface of security and inner fillets were applied to the fins and the coupler tube using DP 420. The leading edge of each of the fins was taped on the outside surface, and more epoxy was applied to seal any imperfections within the modifications of the fins and ensure that they were fixed into place. Once all this was complete, this section was slid into the body tube and three holes were drilled ~120° from each other. This was done to secure the two sections together with screws. This could not be epoxied or bolted at this location because this was the access point for the avionics bay. The completed tailcone/fin section can be seen in Figure 6 below.

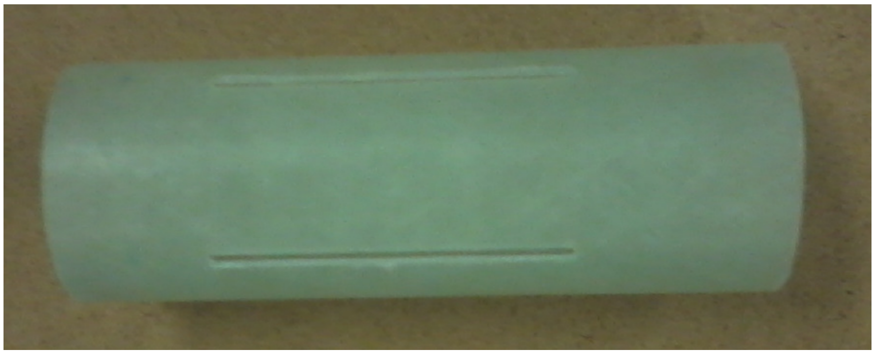

Figure 5. Above is the dart fin section, second generation, which was shorted by an inch to reduce wasted space and mass. This is also similar to what the booster fin slits looked like, only changing the diameter of the body tube and length of the slits.

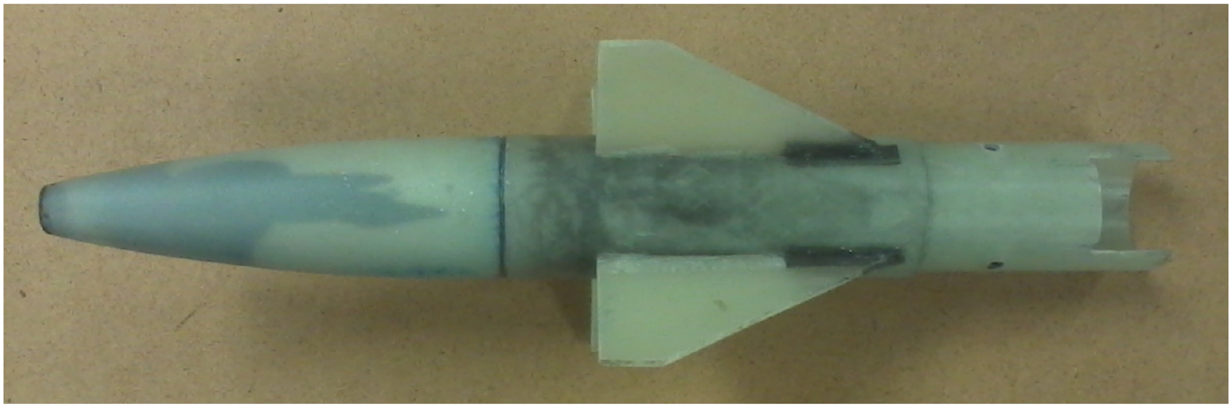

Figure 6. This is the fully constructed dart tailcone and fin section. The upper coupler tube slides into the dart body and the notch within the coupler tube holds the camera in place.

Figure 7. The tailcone/fin section placed into the body tube with the avionics bay onboard. Note the black object is the FlyCamOne Eco V2 located below the shroud.

Dart Length Breakdown	
Component	**Length (Inches)**
Nose Cone	4.25
Body Tube	31.375
Fin Section	3.5
Tail Cone	3.75
Overall Length	**42.875**

Table 3. The component breakdown length of the dart. The overall length of the dart is 42.875" which is nearly 9" greater than the length from the first dart which was not recovered. This allowed for extra space to ensure everything packed easily; this will likely be shortened as mentioned in the Planned Improvements Section below.


Figure 8. The completed dart construction.

The booster avionics bay was constructed by using a laser cutter to cut out medium density fiberboard based off of CAD files. The bay was assembled using DP 420 epoxy from 3M. A solderless breadboard was used to place the Arduino components that were being used for the data collection and the primary recovery. A 9-volt battery was used to power the Arduino system. The Arduino system is comprised of an Arduino Nano microprocessor, a BMP180 which takes altitude data, and an SD Breakout to record all of the altitude data as well as all of the servo actuations and when the recovery system is activated.

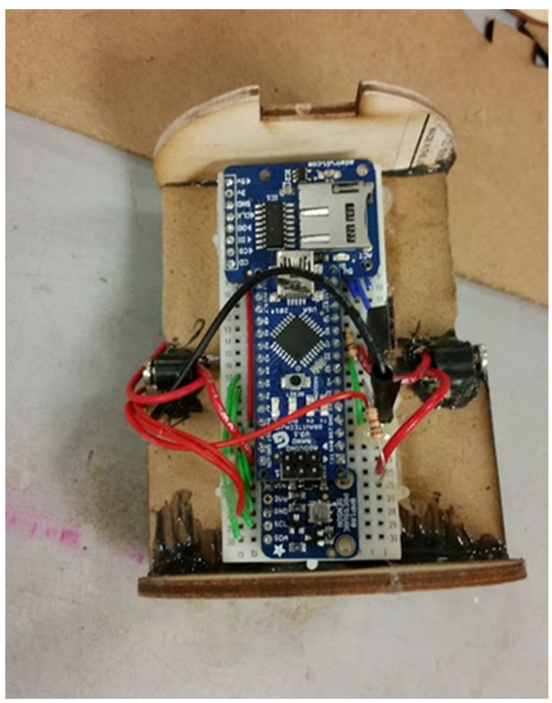
Figure 9. Assembly of booster avionics, which is used to initiate a primary ejection charge and airbrake servo.

The dart avionics bay was constructed in a similar way to the booster avionics. A laser cutter was used to cut out medium density fiberboard based off of CAD files with particular attention paid to the locations of the screw holes and any protrusions on the chips. This allowed some of the larger chips, such as the camera, to be set into the board which in turn allowed for a better fit of the avionics bay in the dart body tube. The Arduino system is composed of an Arduino Nano, a 10 DOF board to take rotation and altitude data and an SD breakout board to store the data. A 9-volt battery was used to power the Arduino system. The Arduino system is used as the secondary ejection method with a Raven3 Altimeter being the primary. The Raven3 was powered off a separate 9-volt battery. The camera used was a FlyCam One Eco V2, which had its own Li-Po battery. The final component of the dart avionics system is a radio tracker beacon which was an independent system powered off a small button battery.

Figure 10. Dart avionics bay sled made of laser cut fiberboard.

4. Test Flight Report

A test flight of the entire boosted dart system was completed on April 26th, 2015. The booster was flown in the configuration which included the airbrakes section. Down looking video was collected from this flight, as well as apogee altitudes for both the dart and booster. The altitude for the dart was collected by a Raven3 altimeter as well as an Altimeter Two. The booster altitude was collected by an Altimeter Two as well as an Arduino based avionics system that used a BMP180 altitude sensor. Onboard rotational data was not collected on this flight due to complications experienced the day before launch, but data can be collected from the video footage. The down looking camera shows the booster rotating at 15 rpm for 2 seconds, and the dart rotating at 60 rpm after separation. The test launch was overall very successful. The dart separated smoothly, soon after motor burnout. This was observed visually, as well as in the video that was collected. The video also confirmed the actuation of the airbrakes soon after dart separation. Upon recovery of the booster, it was observed that the airbrakes remained open throughout the flight, when they should have been retracted after apogee. This issue will be resolved prior to the competition to reduce the risk of damage to the airbrake system upon impact with the ground. Despite the airbrakes remaining open, both the dart and booster sections were recovered successfully, in relaunchable condition.

4.1 Boost Performance

The avionics on the booster section included the Arduino system and the Altimeter Two. These systems performed as expected. During the test launch the Arduino actuated the air breaks open, and recorded all of the data from the altimeter. This data can be seen in Figure 12 in section 4.2 coast performance. The Arduino also successfully ignited an e-match to set off the ejection charge. The Altimeter Two performed well on the test flight and the information from the Arduino system agreed with its results.

In figure 11, the boost performance of the booster is calculated from the Raven3 altimeter on-board the dart while the two sections are still in contact.

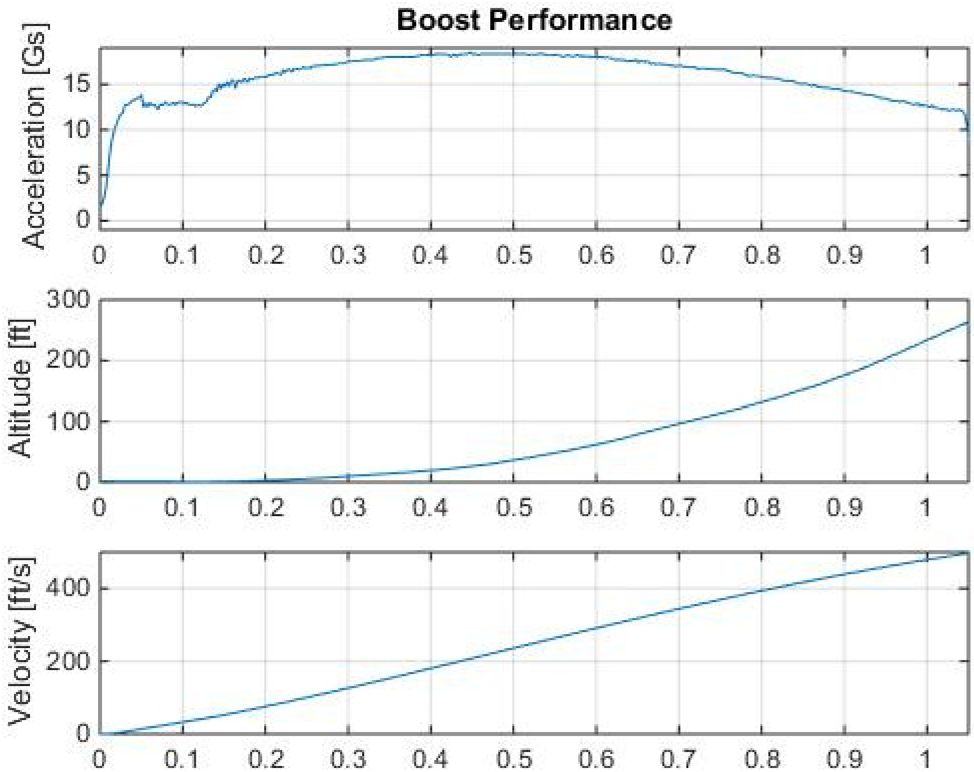

Figure 11. The boosting performance of the booster and dart as a combined configuration as recorded from the Raven3.

The Altimeter Two performed as expected and its results were confirmed with the Arduino system on board the booster.

4.2 Coast Performance

The coast performance of the booster can be seen in Figure 12 below. Apogee was reached at 647 meters.

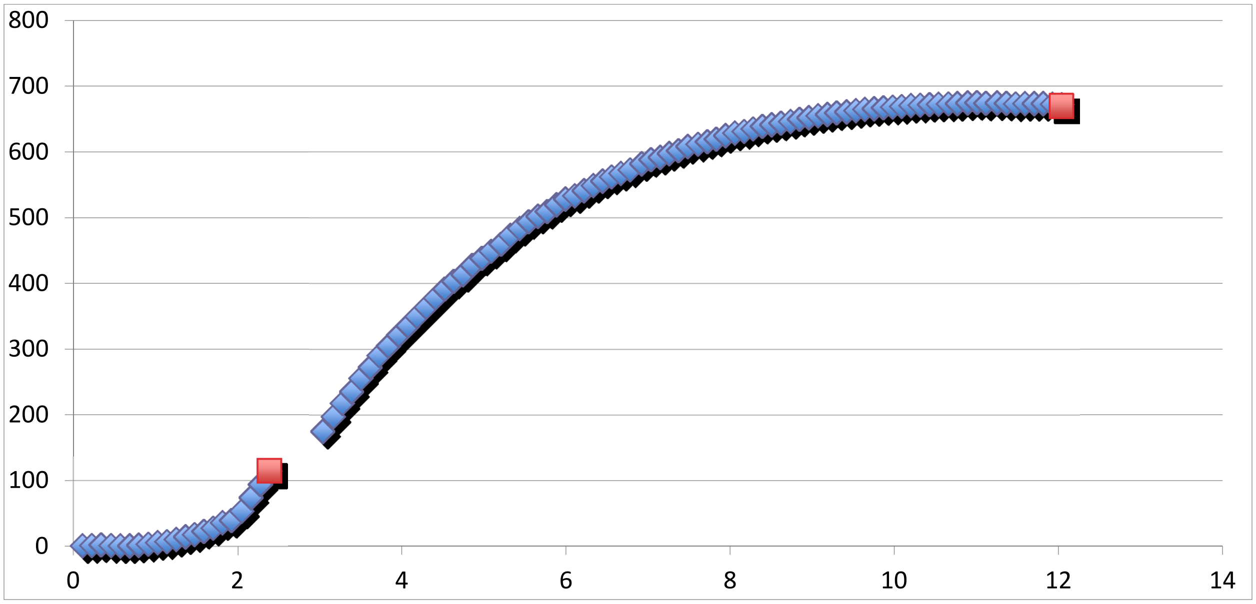

Figure 12. Coast performance of the booster as recorded by the Arduino system. The red squared denote the time and altitude at which the airbrakes were deployed, and retracted (according to the code). The ejection charge was set off by the Arduino at the same time as the airbrake retraction was attempted. The gap in the data after the airbrake deployment is due to the fact that the Arduino had to wait for the servo to complete its rotation before returning to the data collection loop.

The coasting performance of the dart was recorded from the Raven3 altimeter, as seen in figure 13.

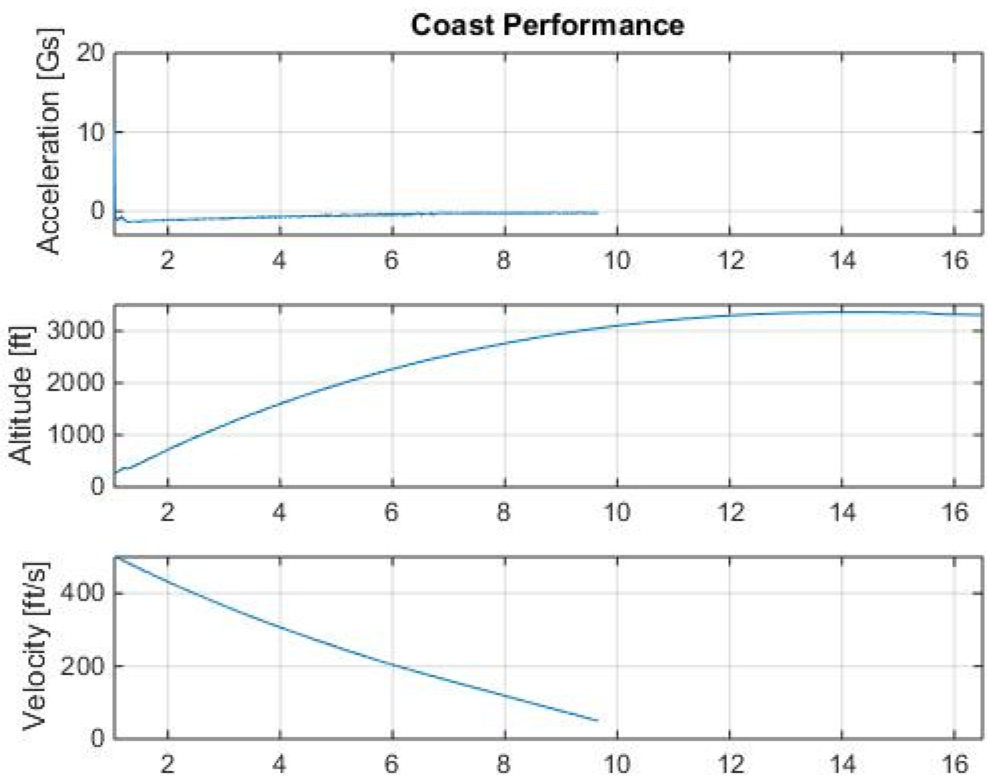

Figure 13. Coast performance of dart as recorded by Raven3 altimeter.

The Altimeter Two recorded the booster-coasting phase to be 9.1 seconds. The Altimeter Two recorded the dart having a coasting phase of 13 seconds long.

4.3 Separation Performance

Based off the systems located on the dart and booster, the Arduino system on the booster recorded apogee at 2210 feet, while the Raven3 altimeter on the dart recorded an apogee of 3362 feet. This gives an apogee separation of 1152 feet.

During the second test launch, the Altimeters Twos were used to collect data and to ensure that they worked properly before competition. The Altimeter Two from the dart recorded apogee at 3365 feet. The Altimeter Two from the booster recorded an apogee of 2206 feet. The overall performance of the separation was 1159 feet.

4.4 Recovery System Deployment Performance

The recovery system in the booster is triggered by the Arduino system as the primary and the motor eject as the secondary. The Arduino is set to trigger the ejection charge 3 meters lower than the recorded apogee. During both test launches the Arduino set off the charge.

Figure 14. The second successful recovery of the booster section with modular airbrake section.

The dart recovery system was triggered by a Raven3 altimeter as the primary eject. The Dart's Arduino Nano was not used for this test launch as a backup eject. Figure 15 shows the altitude curve of the dart for the duration of the flight. The conditions for triggering ejection were based on being under a threshold velocity 300 feet per second and increasing in barometric pressure. The data from the Raven3 shows that ejection occurred after apogee, as required.

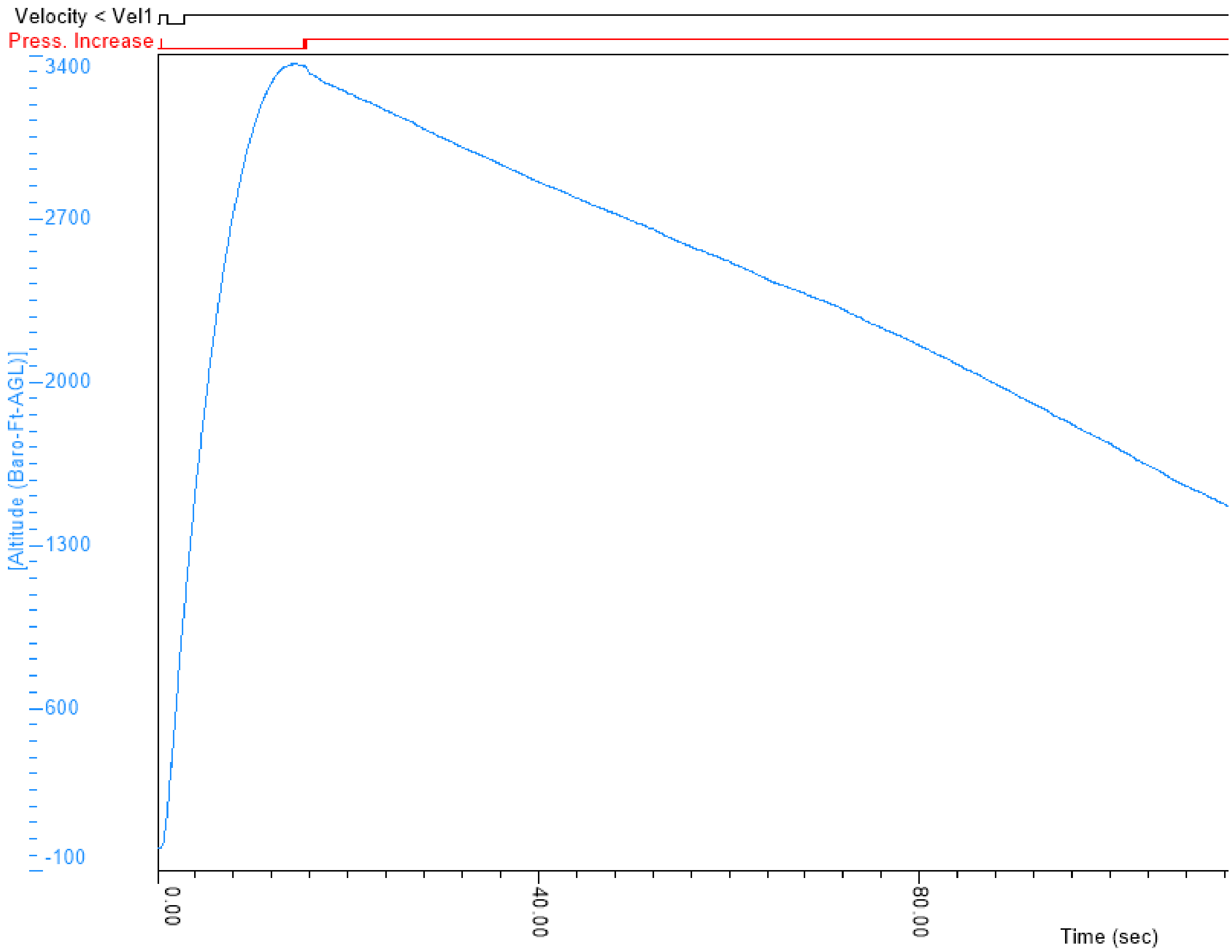

Figure 15. Data curve of altitude versus time of the dart. The conditions for triggering ejection are shown above the graph. High conditions indicate that the conditions for triggering ejection are met. Ejection is only triggered when both conditions are met.

4.5 Table of Flight Characteristics

Data Collection System	**Altimeter 2 - Booster**	**Arduino - Booster**	**Altimeter 2 - Dart**	**Raven - Dart**
Altitude	2206 ft	2211 ft	3365 ft	3362 ft
Top Speed	601.3 ft/s	592.5 ft/s	583.7 ft/s	498.5ft/s
Thrust Time	1.8 s		1.7 s	
Peak Accel	20.4 g's		19.9 g's	18.51 g's
Average Accel	17.6 g's		17 g's	
Duration	83 s		192 s	191 s
Coast to Ap	9.1 s		13 s	13 s

Table 4. Shows data collected from the test launch from four different data collection systems, two on the dart and two on the booster. It can be seen that the data collected by each independent system agrees quite well in all categories apart from the top speed. The Raven reported a top

speed which was about 100ft/s slower than the speed reported by the other three systems. This difference could be due to a calibration error on the Raven or an issue with the static ports on the dart.

5. Discussion of Results

5.1 Predicted vs. Actual Apogee Difference

Dart altitude data was recorded by a Raven3 altimeter and Altimeter Two. Booster altitude data was recorded by an Arduino Nano and Altimeter Two. Figure 16 shows predicted and actual altitude data for both the booster and dart and indicates their respective apogees. The actual peak altitude of the dart outperformed the predicted peak altitude by 286 feet at an apogee of 3362 feet. However, the predicted apogee difference compared to the actual apogee difference shows a decrease in apogee difference from 1543 feet to 1148 feet. Possible reasons for performing better than predicted in maximum altitude could be due to weather conditions and weather cocking. The predicted results account for approximately 15 mph wind conditions and error due to weather cocking. The actual launch conditions had 4 mph winds and the boosted-dart experience minimal weather cocking. In regards to the discrepancies in apogee difference, the friction at the transition section between the booster and dart was more than desired. The difficulty for the dart to overcome the friction at the transition would account for the change in apogee difference from predicted to actual.

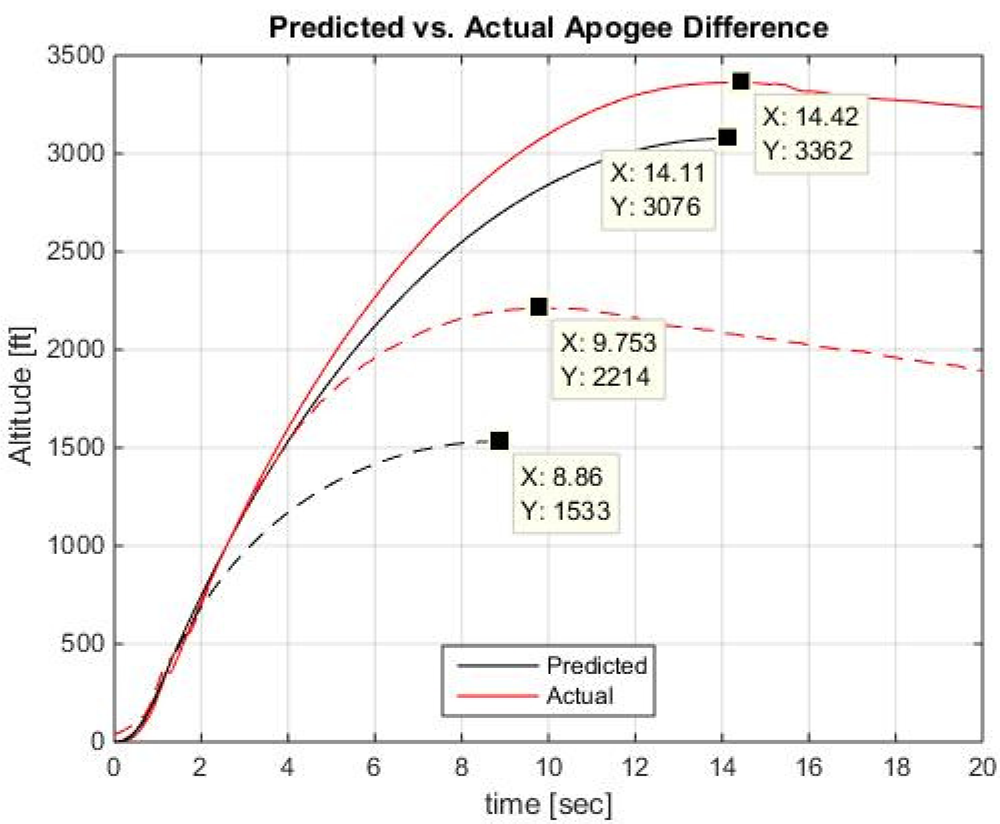

Figure 16. Predicted versus actual altitude curves for the booster and dart. The solid line variant shows the dart altitude curve and the dashed line variant shows the booster altitude curve.

5.2 Predicted vs. Actual Peak Velocities and Accelerations

The predicted versus actual velocity and acceleration curves are shown in figure 17 and figure 18, respectively. The actual peak velocity and peak acceleration was lower compared to predicted results, but were very similar. While the predicted velocity and acceleration curves indicate that the dart was predicted to reach a higher maximum altitude, the actual results show that dart experienced less drag than predicted, which contributes to a higher altitude.

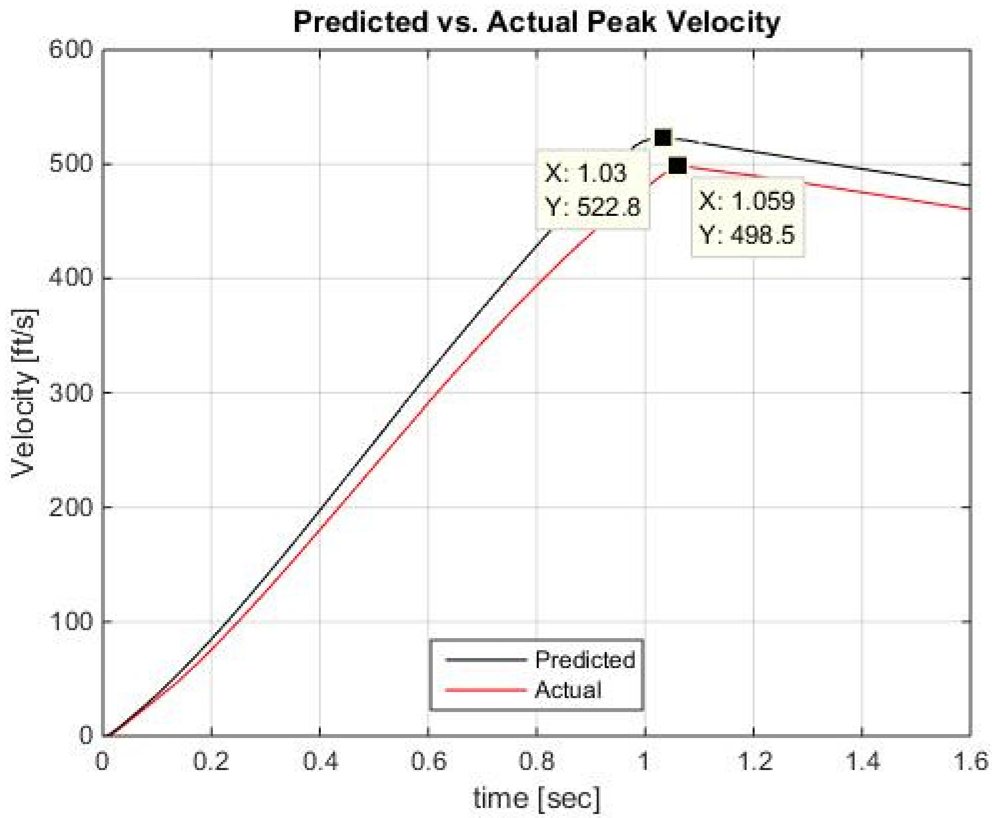

Figure 17. Predicted versus actual velocity curves during the boosting phase. The peak velocity was predicted to be 522.8 ft/s, but the actual peak velocity fell short at 498.5 ft/s.

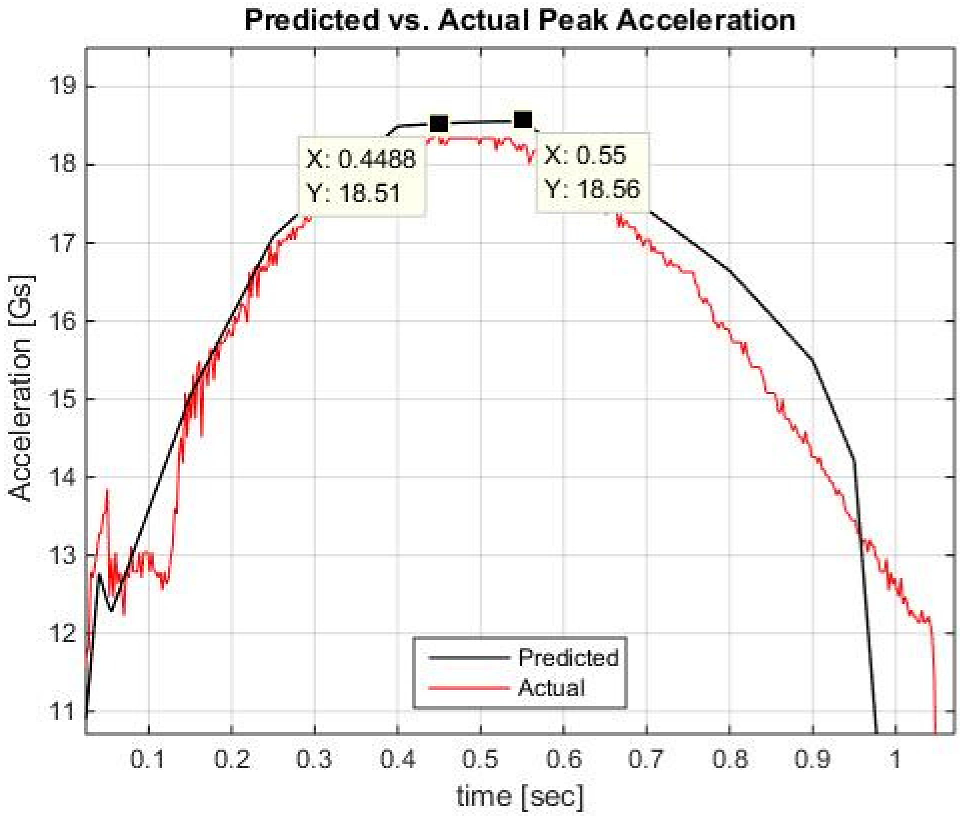

Figure 18. Predicted versus actual acceleration curves during the boosting phase. The peak accelerations were nearly identical, although the curves differ near burnout.

5.3 Performance of On-board and Down-looking Video and 3-axis Rotation

During both test launches the Ardunio chip that collects rotation data was not on board due to complications in the avionics bays. As a result, no rotational data has been collected. The on board video for the second test launch was a success and we captured the air breaks deploying on the booster. This actuation of the airbrakes can be seen in Figures 19 and 20. As seen from these photos, the video has a good picture with the center ninth being the dart/launch pad.

Figure 19. Screen shot of the video with the booster without the air breaks deployed.

Figure 20. Subsequent frame from the video showing the air breaks open. Note the ring midway along the body tube of the booster as a result of the airbrakes actuating.

6. Planned Improvements Prior to Competition

Rather than using a solderless breadboard for the booster avionics, the components will be mounted directly to the avionics bay and connected using stranded wire, as in the dart avionics. This change will reduce the weight of the booster and the possibility of a connection coming loose from the solderless breadboard.

To improve tracking security, the dart avionics bay will include changes to the radio tracker section. The battery will be held in place with a secured plate which will bolt down to the avionics bay sled, ensuring the tracker is constantly emitting a signal throughout the flight. The avionics bay in both the dart and booster will also be fully accessible from the outside of the dart body tube on the launch pad, so that all systems can be armed with the rocket in the vertical condition.

The rod and tube used in the transition section will be sprayed with WD-40 Dry Lube PTFE to reduce the friction thus improving separation.

The gears, components, and coding for actuation altitude and retraction of the airbrakes will be modified to improve actuation efficiency and ensure safe recovery.

The dart fins will be smoothed with sandpaper to reduce drag with the leading edges being tapered to be more aerodynamic, and the overall length of the dart will be shortened by 3 or 4 inches to reduce excess weight and drag. This shortening will be determined by packing the parachute and shock chord repeatedly and recording the lengths of the materials inside the body tube, so that the consistency of this can be noted and thus provide the maximum reduction length.

The dart body tube's leading edge will be sanded to better match the maximum diameter of the nosecone, thus reducing drag. Similarly a small curved piece of body tube will be added below the camera notch on the coupler tube to make the fit of two pieces more exact and reduce surface drag.

Both the dart and booster sections will be painted increasing the visibility of the system and reducing surface roughness and therefore drag. Once painted, all the center of masses and center of pressures will be marked on the booster (both configurations) and dart and on the system together.

The Raven3 altimeter will be recalibrated and ground tested and static port sizing will be reviewed for the dart to reduce inconsistency in top speed data recorded by the Raven and Altimeter 2 in the dart.

7. Pre-Flight Checklist

The following checklist, Table 5, is performed prior to launch, as required by the competition guidelines.

Prior To Arrival At Launch Site	**Booster**		**Dart**
	Grind Down Motor Eject		
At Launch Site			
	Prepare E-Charges		Prepare E-Charges
	Check Ejection Charge Safety		Check Ejection Charge Safety
	Wire Charge to Recovery System		Wire Charge to Recovery System
	Seal Bulkhead at Ejection Charge with putty		Seal Bulkhead at Ejection Charge with putty
	Wire Batteries		Wire Batteries
	Insert Motor		Slide in Avionics Bay
	(Wait for Dart)		Test Radio Beacon
	(Wait for Dart)		Screw in Boat Tail Section
	Turn on Altimeter Two		Turn on Altimeter Two
	Pack Parachute		Pack Parachute
	Assemble on Launch Pad		Assemble on Launch Pad
	Check Ejection Charge Safety		Check Ejection Charge Safety
	Switch on Avionics		Switch on Avionics
	Switch E-Charge Protection		Switch E-Charge Protection
	Wire Charge to Motor		

Table 5. Pre-flight procedures, as required by competition guidelines.