Flight Readiness Report

Wichita State University

Team RISE

Rocket Inspiring Shocker Engineering

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1.1 Design Specifications

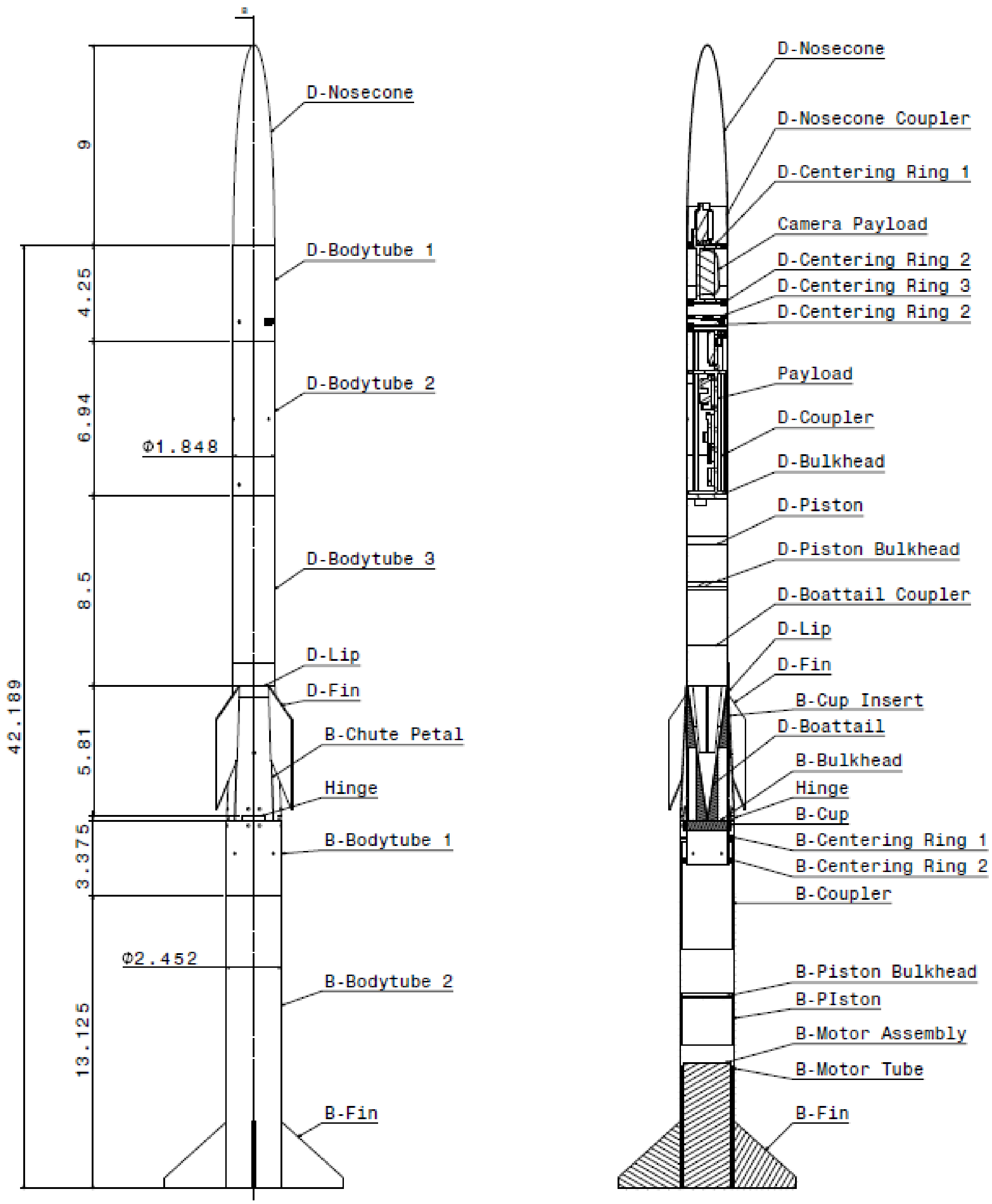


Figure 1. Detailed rocket assembly with dimensions.

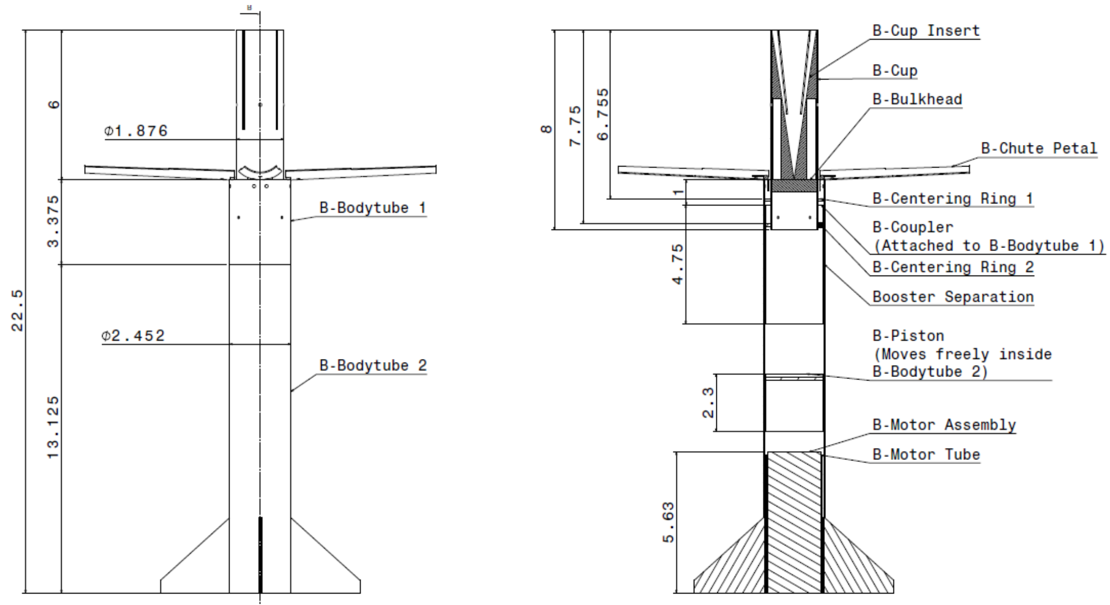


Figure 2. Detailed booster drawing with dimensions.

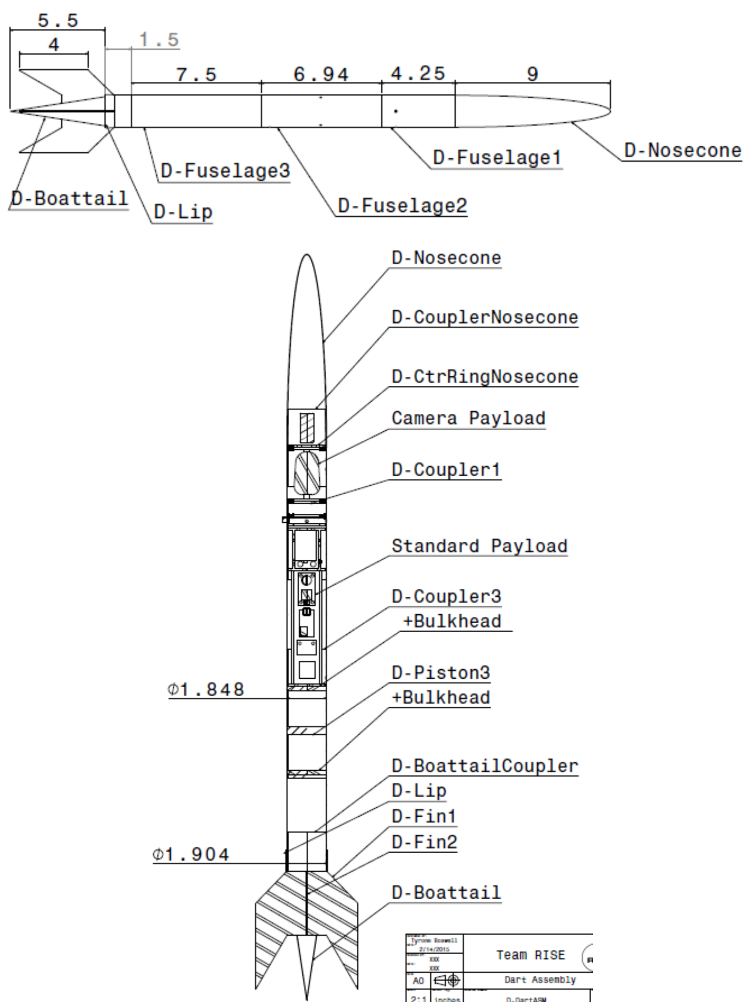


Figure 3. Detailed dart drawing with dimensions.

Rocket Design Specification				
Parameter		**Constant**	**Flight 3**	**Flight 5**
Booster Fins	Root	3 in		
	Tip	4 in		
	Span	1.4 in		
	Sweep	1.5 in		
Dart Fins	Root	3 in		
	Tip	0.5 in		
	Span	2.8 in		
	Sweep	2.5 in		
Booster Length		22.50 in		
Dart Length		34.75 in		
Rocket Length			51.5 in	50.5 in
Booster	CP		19.46 in	17.5 in
	CG		13.59 in	13.59 in
	Stability Caliber		1.90	1.30
	C_D		1.63 in	10.78
Dart	CP		22.03 in	22.03 in
	CG		19.25 in	19.38 in
	Stability Caliber		1.54	1.47
	C_D		0.57	0.424
Rocket	CP		40.1 in	40.1 in
	CG		36.46 in	36.0 in
	Stability Caliber		1.49	1.67
	C_D		0.8	0.69
Weight	Booster		2.59 lb-f	2.59 lb-f
	Dart		1.38 lb-f	1.37 lb-f
	Rocket		3.97 lb-f	3.92 lb-f
	Electronics	79 g		

1.2 Stability Analysis

Actual center of gravity and center of pressure locations matched our predicted values as a whole for each rocket configuration. Evidence of proper stability could be seen in all of our launches. In all flights (even in Flights 1 and 2 prior to premature separation) the rocket could be seen properly correcting itself as well as having appropriate reaction to any wind gusts. However, specifically in Flight 4, we saw that the rocket as a whole was very susceptible to wind. It was found that due to the lack of surface contact between the dart and booster sections the dart was allowed to move more freely than expected causing the nose of the rocket to change overall angle of attack resulting in a large S-curved flight path during propelled flight as seen in Figure 4. After burn out, both the booster and the dart continued in straight-line flight further showing that the cause of this disturbed flight path was not a lack of section stability, but a poor connection between sections. We were able to improve our flight path performance by improving this contact point prior to Flight 5; though there was a motor failure, this flight showed that no s-curve motion occurred during ascent.

Figure 5. S-curve as seen in Flight 4.

2. Budget

There is a $427 difference between the planned PDR budget and the current budget. This increase is due to supplies that were not taken into consideration during the design and planning stages. Among these items are aluminum foil sheets for composite layup, Dremel reinforced cutting discs to trim carbon fiber body tubes and fins, hardwood for centering rings, CA glue, and spray paint. There were a few material substitutions: the insulation foam cup was substituted with plywood centering rings, and the bungee chord with elastic. PDR budget accounted only for one motor while the updated budget considers a total of seven motors for five test launches and two launches at competition. Additional changes include adding the altimeter cases for easier installation and an update on transportation from Wichita, KS to North Branch, MN and back.

The following is the current budget, and all changes from PDR are identified with an asterisk.

Type	Component	Quantity	Unit Cost	Cost
Construction	1/8 Plywood	1	$4.59	$4.59
Construction	*1 in Step Hard Wood	1	$9.54	$9.54
Construction	Carbon fiber (5320-1/8HS)			Donated
Construction	Film adhesive (FM-300)			Donated
Layup	2.5 in & 2 in aluminum rod	49 in		$160
Layup	Vacuum bags			Donated
Layup	*Aluminum foil sheet	2	$4.00	$8.00
Electronic Payload	Dart Radio Tracking System			Donated
Electronic Payload	Battery (Lithium)	1	$6.95	$6.95
Electronic Payload	Lipo Battery Charger	1	$14.95	$14.95
Electronic Payload	Switch	1	$2.19	$2.19
Electronic Payload	Wires	2	$2.50	$2.50
Electronic Payload	Arduino	1	$19.95	$19.95
Electronic Payload	Micro USB Cable	1	$4.95	$4.95
Electronic Payload	Gyro/sensor	1	$49.95	$49.95
Electronic Payload	SD Card & Holder	1	$9.95	$15.47
Electronic Payload	Camera	1	$45.99	$45.99
Electronic Payload	Altimeter (Easy Mini)	1	$85.60	$85.60
Electronic Payload	Altimeter 2 (Competition)	2	$69.95	$139.90
Electronic Payload	*Altimeter Case	2	$9.95	$19.90
Propulsion	Motor	7	$52.99	$370.93
Propulsion	Motor casing & closure	1	$42.75	$42.75
Recovery	Black Powder & container			$20.38
Recovery	E-Matches	8	$1.50	$12.00
Recovery	Shock cord (Dart & Booster)	5	$1.99	$9.95
Recovery	Parachutes	2	$23.62	$47.24
Drag Chute	*Elastic	12 yards	$1.35	$16.20
Construction	Sandpaper			Donated
Construction	Phenolic Motor Tube	1	$7.00	$7.00
Construction	Epoxy	5	$5.29	$26.45
Construction	*CA glue	1	$6.00	$6.00
Construction	*Reinforced cutting discs	1	$16.00	$16.00
Construction	*Spray Paint	3	$3.44	$10.32
Propulsion	Airfoiled Launch Buttons	1	$7.00	$7.00
Hardware	Screws, hinges, etc.			$38.00
Competition	Registration	1	$400.00	$400.00
Competition	Hotel (2 rooms, 3 nights)	6	$89.00	$534.00
Competition	Transportation (flights)	4	$524.00	$2,096.00
Competition	*Transportation (driving)	1	$90.00	$90.00
			Total	**$ 4,340.65**

3. Construction of Rocket

Earlier in the design stage, weight reduction was identified as a key requirement in order to be able to fulfill the competition mission and have a competitive advantage. Therefore, all fuselage pieces were manufactured from carbon fiber and internal support components for the payload from plywood. Team members performed all manufacturing efforts.

3.1 Body Parts

The mandrels for these parts were manufactured from solid T6061 Aluminum bars. Cylindrical mandrels for pieces like body tubes, pistons, couplers, etc. were machined on a manual lathe. Appropriate spindle speed was found to acquire a suitable surface speed of the material as well as a good feed rate for the cutting tool. Mandrels for complex shapes such as the nosecone, boattail, lip, drag chute petals, etc., were machined on a CNC lathe. The code was written using the correct vernacular in Notepad where the tool was programmed to do an initial stair-step pattern followed by a straight tapered line for cones or a series of tapered lines for curves. Lathing efforts can be seen in Figures 5 and 6.

Figure 5. Solid T6061 Aluminum bars before (left) and after being lathed with a manual lathe (center) and CNC machine (right)

Patterns for all the parts were cut from prepreg 53201-1 carbon fiber plies and FM-300 film adhesive. After covering mandrels with release agent and a release film layer, the two carbon fiber plies were laid-up on the mandrels and covered with the film adhesive. Each piece was covered with aluminum foil, breather material, vacuum-bagged and placed in the oven at 250 ±10°F for approximately five hours. Finally, all pieces were sanded down to have a smooth finish and to ensure a perfect fit. Figure 7 shows the lay-up process.

Figure 6. CNC machine (top) for transition and manual lathe (bottom) for body tubes.

Figure 7. Body tube wrapped in carbon fiber (left), film adhesive (top) and vacuum-bagged (bottom).

3.2 Fins

Fins were laid-up on a flat metal plate covered with release film. On top of the release film, five plies and ten plies of carbon fiber were laid-up for the dart and booster fins, respectively, and covered with another release film (Figure 8). Afterwards, the mandrels were vacuum-bagged and placed in the over at 250 ±10°F for five hours. Dart and booster fins were cut using a water-jet cutter and additional back up fins were cut using a Dremel and sandpaper.

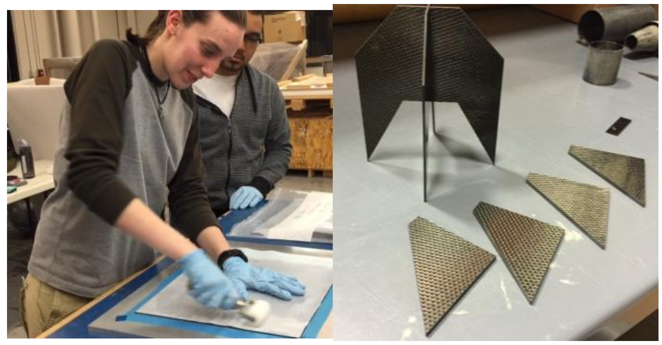


Figure 8. Carbon fiber plies being laid-up (left) and fins after being cut (right).

3.3 Payload bed, bulkheads and centering rings

After using CATIA V5 to make all the necessary patterns for the payload bed structure, piston bulkheads, centering rings and tooling to install fins, the pieces were cut using a laser cutter. All parts were installed in the appropriate places using CA glue and epoxy.

3.4 Payload Assembly

The electronics were installed on the plywood payload bed as seen in Figure 9 using screws and zip ties. The camera rests below the nosecone on a carbon fiber stick that was cut from the same carbon fiber composite sheet as the dart fins.

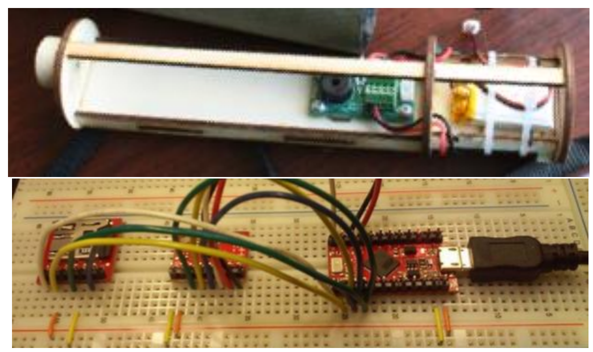


Figure 9. Payload bed and gyro system.

3.5 Overall Assembly

The fuselage pieces, couplers, pistons, motor tube, and bulkheads were assembled using epoxy. To construct the drag chute system, the cup structure was installed within the booster using centering rings and the hinges were attached with screws extruding from the outside of the fuselage into the cup structure. Earplugs were placed in between the hinges and body tubes to secure them in place since limited space prevented the use of nuts. Finally, elastic strips were installed first within the cup and then onto each petal securing it with washers, screws, and nuts as seen in Figure 10.

Figure 10. Drag chute assembly.

Pressure holes were drilled in the booster piston area and on the dart around for the altimeters. Holes for the camera and safety pin were also drilled in the appropriate spots. After full structural construction of the dart and the

Figure 11. Dart-booster alignment.

booster, the payload bed and parachutes can be inserted. For complete rocket assembly, the dart is aligned and placed within the booster as seen in Figure 11.

4. Photographs of Completed Rocket

Figures 12 to 15 show the completed rocket assembly at several instances.

Figure 12. First launch with a transition.

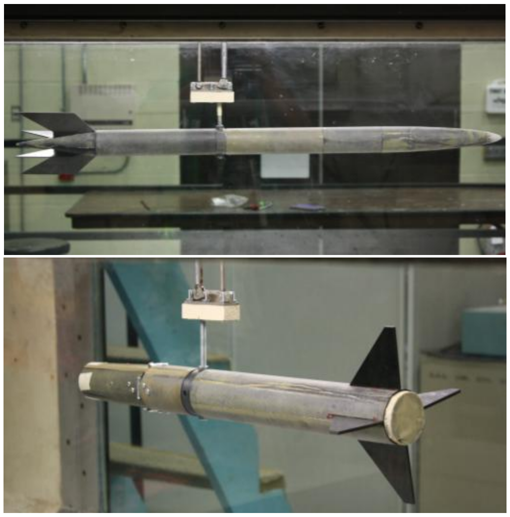


Figure 13. Dart and booster during wind tunnel testing.

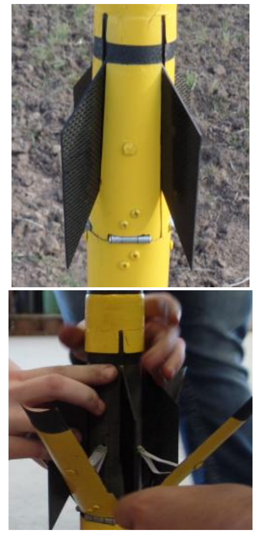


Figure 14. Drag chute closed and deployed for fifth launch.

Figure 15. Fifth launch with drag chute system.

5. Test Flight Report

5.1 Overview

In order to reduce risk and variables during the first test launches, a transition piece was used to replace the drag chute petal system. A summary of all test launches and results is found below. These results will be discussed in more detail in the following sections.

Flight	Transition or Drag Chute	Winds	Complications	Improvements
1&2	Transition	5-10 mph	Early booster recovery deployment	Additional pressure holes and tighter friction fit
3	Transition	0-10 mph	Great Success!	Drag predictions
4	Drag Chute	15-35 mph	Severely Arched Trajectory	More surface contact in transition region
5	Drag Chute	0-10 mph	Motor Failure	Repairs

5.2 Boost Performance

During the third launch, the boost performance of the dart matched the predicted performance in many aspects. The maximum acceleration during boost was 827 ft/s^2.

The maximum velocity during boost was 621 mph or Mach 0.8. Separation occurred at an altitude of 911 ft. The boost performance is shown on the graphs below in Figure 12.

5.2 Coast Performance

For Flight 3 during coast, the dart performed as predicted. The maximum altitude of the dart was 3726 feet and the maximum altitude of the booster was approximately 1900 feet. The total time of dart flight was 127.7 seconds. Coast performance is shown in Figure 13.

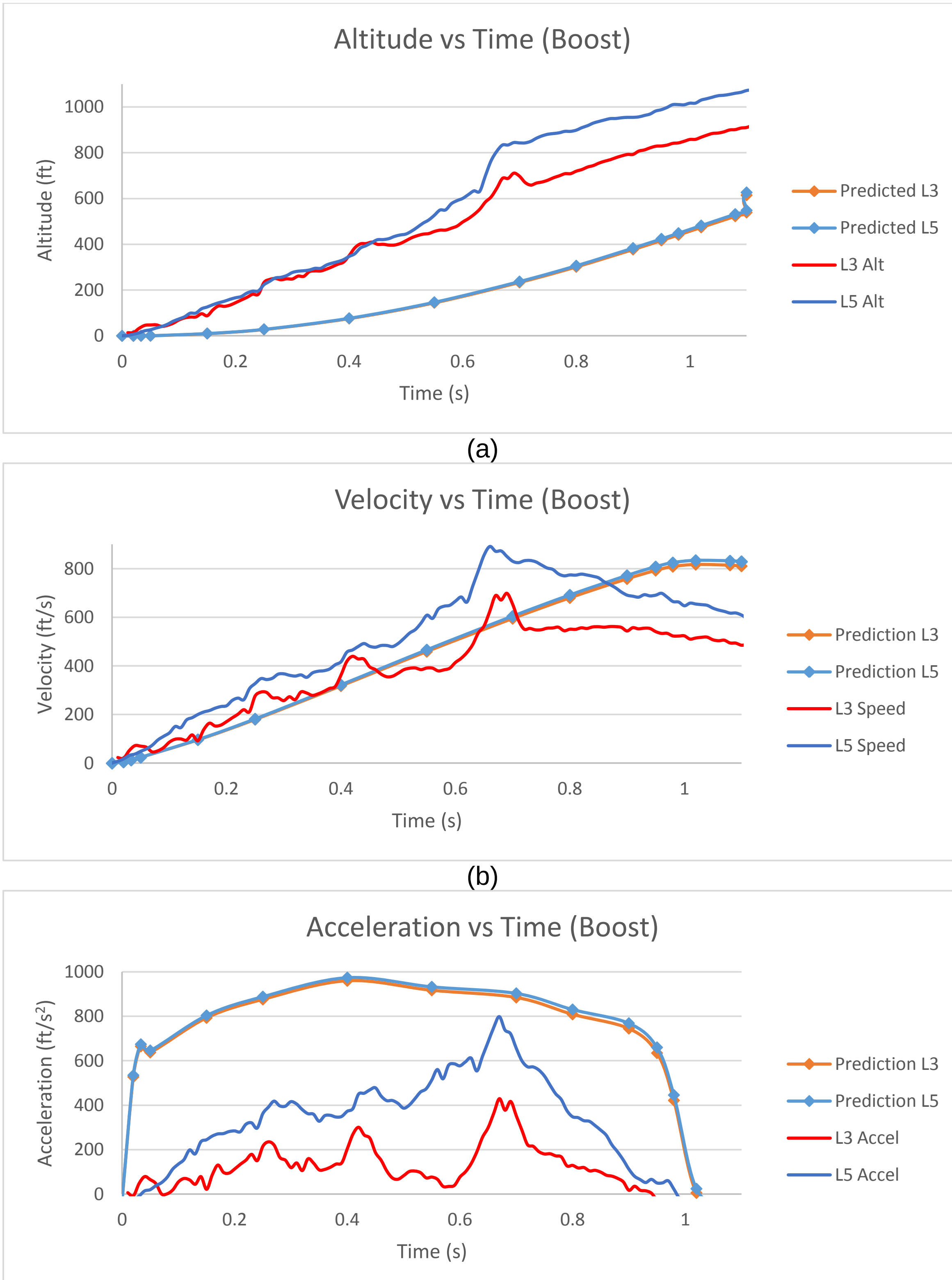
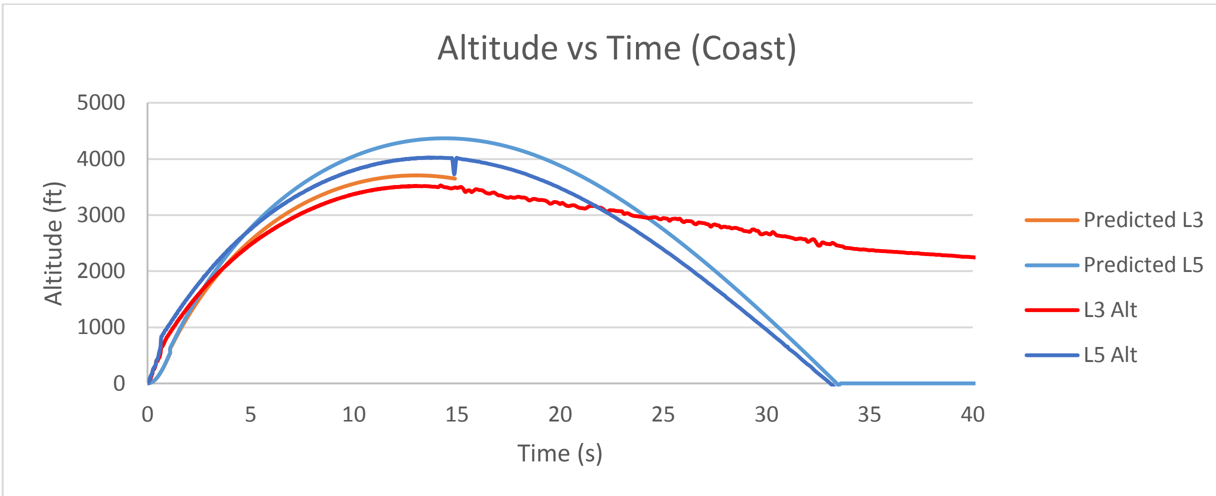


Figure 12. Boosted performance: (a) Altitude, (b) Velocity, (c) Acceleration.



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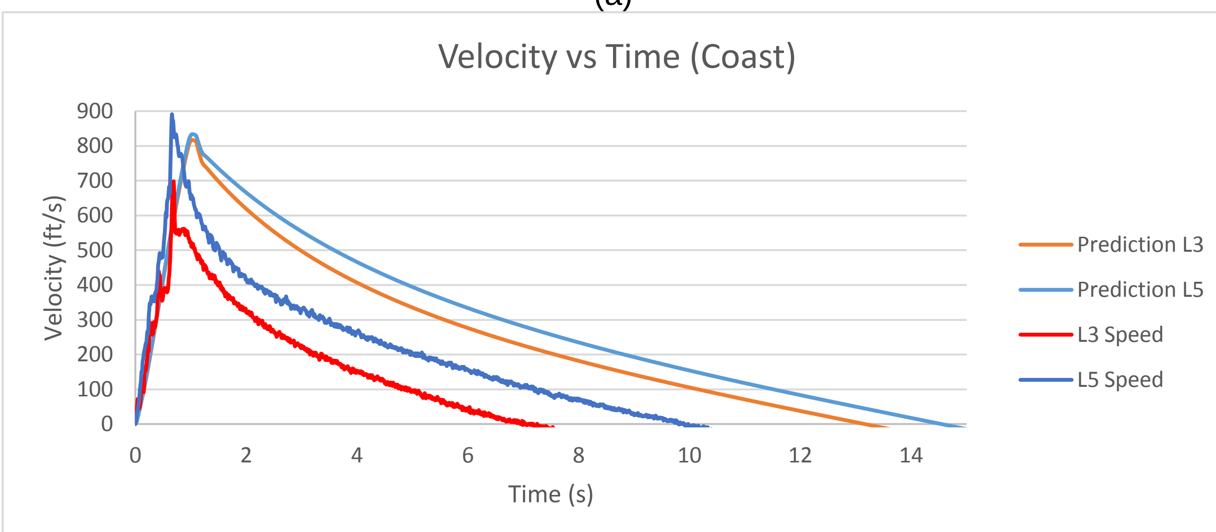

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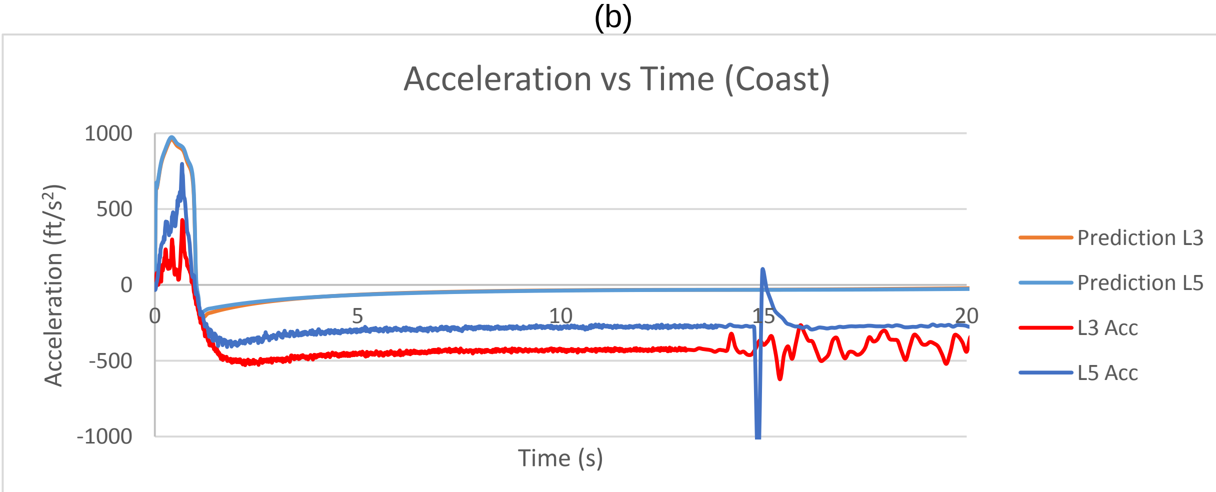


(c)

Figure 13. Dart performance: (a) Altitude, (b) Velocity, (c) Acceleration.

5.3 Separation Performance

Using on board video as confirmation, the dart separated from the booster via drag separation in both flights. This occurred at 1.2 seconds. Separation occurred as expected, with the booster releasing its parachute in time for a safe recovery for Flight 3. For Flight 3, the drag petals were not deployed, but the drag petals were used during Flight 5.

5.4 Recovery System Deployment Performance

The dart recovery system was designed to use an altimeter programmed to deploy its parachute one second after apogee. However, the booster uses the delay charge in the motor to deploy its parachute. The Cesaroni motors come with a 16 second delay charge and a 2 gram ejection charge. This was modified to have a delay charge of 11 seconds for transition flights and 5 seconds for drag chute flights with an ejection charge of 0.4 grams.

For Flight 1 and 2, the dart recovery system preformed exactly as designed. However, the booster recovery system deployed prematurely. After reviewing flight video, it was found that the booster parachute deployed at dart-booster separation. Later, it's seen that the ejection charge deploys at its expected time. The conclusion was the rocket was drag separating at the booster coupler in addition to the dart-booster connection. To fix this problem the booster was friction fit tighter and more pressure holes were drilled below the booster piston.

During Flight 3 the dart recovery system deployed when expected, but the parachute struggled to fully eject from the body tube. The recovery system is packed very tight in the dart body tube. To ensure this did not happen again, the ejection charge was slightly increased to 0.2 grams and additional ejection charge testing was done. The booster recovery system performed as designed for Flight 3.

Flight 5 had a motor failure which clogged the nozzle. This caused an over pressurized motor and extremely high loads, causing the booster shock cord to be disconnected prior to ejection charge. It also caused the boattail to be severely jammed into the bottom dart body tube, the location where the recovery system deploys. The ejection charges for both systems worked as expected, but damages to the rocket caused the parachutes to not deploy correctly.

Flight	Dart	Booster	Solutions/Fixes
1&2	Success	Early Deployment	Friction fit & pressure holes
3	Difficultly deploying	Success	Increased dart ejection charge
4	Success	Incorrect Delay	Delay charge corrected
5	Motor Failure	Motor Failure	Repair damages

5.5 Flight Characteristics Table

Dart Characteristics				
	Predicted (L3)	L3	Predicted (L5)	L5
Max Altitude (ft)	3704 ft	3726 ft	4368 ft	4188 ft
Max Speed (mph)	557 mph	621 mph	568 mph	701 mph
Mach Number	0.74	0.8	0.75	0.9
Max Acceleration (ft/s^2)	960 ft/s^2	827 ft/s^2	974 ft/s^2	1042 ft/s^2
Max Acceleration (G)	30 G	26 G	30 G	32 G
Booster Characteristics				
	Predicted (L3)	L3	Predicted (L5)	L5
Max Altitude (ft)	2023 ft	~1900 ft	714 ft	729 ft
Max Speed (mph)	557 mph	--	568 mph	496 mph
Mach Number	0.74	0.8	0.75	0.9
Max Acceleration (ft/s2)	960 ft/s^2	--	974 ft/s^2	867 ft/s^2
Max Acceleration (G)	30 G	30 G	30 G	27 G

6. Discussion of Results

6.1 Predicted vs Actual Apogees

The analysis for altitude performance was adjusted after Flight 3 when performance did not match the predicted values. The dart's apogee was almost 2,000 feet lower than expected, but earlier wind tunnel testing gave similar drag coefficients and OpenRocket simulations calculated similar altitudes. After seeking advice from professors and mentors, it was determined that separated flow could cause such a significant difference. Any differences between the OpenRocket model, wind tunnel model, and actual rocket was accessed. Pieces not initially included in calculations but that are on the rocket include: launch buttons, the dart camera lens, the lip structure, and a temporary booster camera for Flight 3. The drag coefficient for launch buttons was found in the OpenRocket documentation[2] and the cameras were simply modeled as flat plates using coefficients found in Hoerner[1]. However, the major contributor to loss of altitude was found to be the lip structure. Since the lip protrudes away from the dart fuselage while extending over the boattail, the small gap is essentially enlarged, causing separated flow, negating the drag benefits of the boattail. This was confirmed by calculating the altitude when including base drag for the area projected by the base of the lip. This resulted in error of less than one percent for dart apogee for Flight 3. Unfortunately, Flight 3's altimeter data was lost for the booster. Based off of remembered values for altitude though, predictions were still within 10% of performance. Since there were no other complications for Flight 3, it is the best for performance comparison. As repeatability was not able to be proven, there is the chance other factors such as wind, axial rotation, or launch rail interaction could be small sources of error that could cause minor changes in future launches.

6.2 Predicted vs Actual Peak Velocities and Accelerations

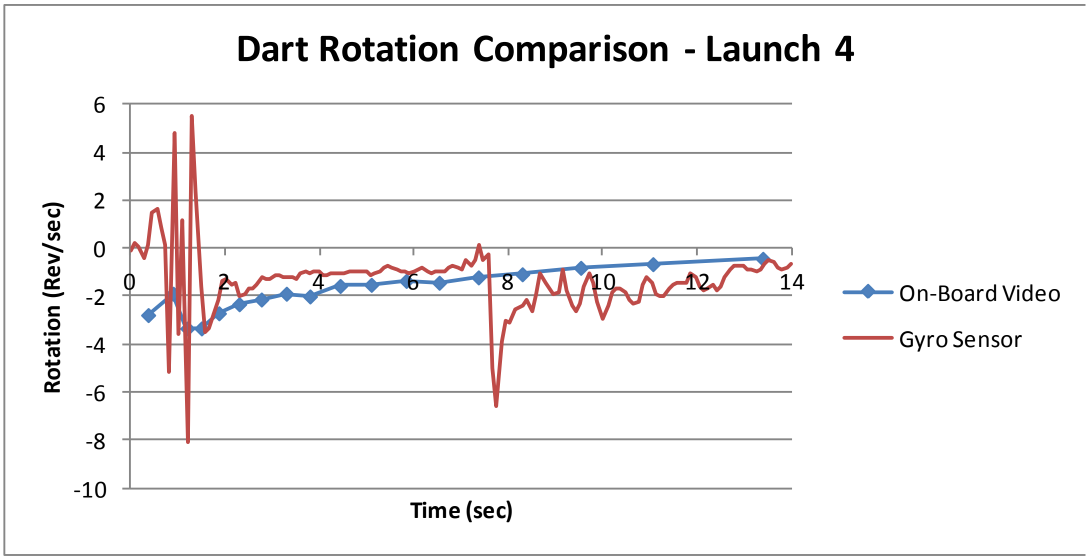
Acceleration and velocity predictions did not compare as well to performance as altitude. For Flight 3, there is a 11.5% difference in maximum velocity and 13.9% difference maximum acceleration for the dart (again, the booster data was lost). The graphs also show that the velocity has a trend with the predicted values while the acceleration data does not follow. This can be due to a combination of how the analysis is calculated along with how the actual flight data is gathered. While the thrust curve can be found, the time stamps are varied and wide in comparison to the total burn time. Motor propellant was also assumed to be lost at a linear rate which was another factor when calculating acceleration. This allows acceleration and then velocity to be more generalized during this very concentrated moment of forces. Meanwhile, the altimeters gather this data by initially gathering pressure, then calculating height, velocity, and finally acceleration by taking the derivatives. Any disturbance from a gust of wind to spinning could cause a disturbance, producing an error, which would then get compounded through the calculations.

6.3 Performance of On-board Video and Gyro Data

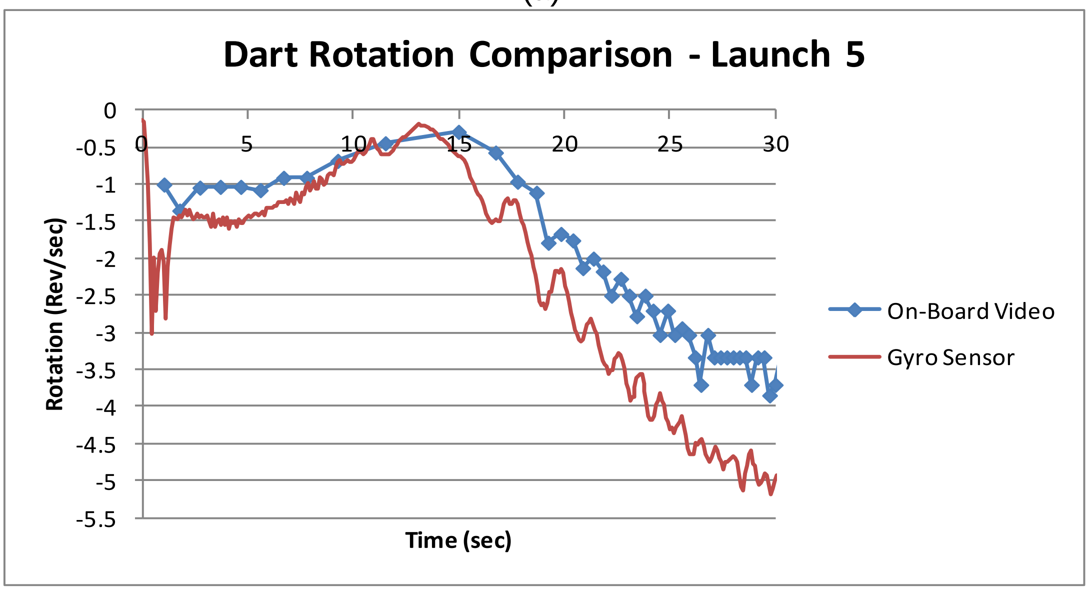
On-board video was recorded with a direct downward view using the 808 Keychain Camera with a lens mounted externally to the dart using an extender ribbon cable. This camera records HD footage at 30 frames per second. The launch pad is visible during the entire accent. Separation and dart parachute ejection could also be easily viewed in the footage. During a majority of the flights, the booster parachute ejection or other key events can also be seen as shown in Figure 14.

Figure 14. View from onboard camera.

The rotation logger was programmed to record data every 0.1 seconds at 2000 degrees per second setting. Data was only collected during Flights 4 and 5. To compare the collected data to the on-board video, the video was observed and time stamps were hand recorded using a reference point on the ground. The two rotation rates during flight can be compared in the following two graphs for both flights. There was some error in rotation found for the rotation logger, but there could also be large error in recording rotation by eye from the on-board footage. To reduce the error in the rotation logger system, a lower setting of 250 or 500 degrees per second will be selected for future launches.



(a)



(b)

Figure 15. Dart rotation data for Flight 4 (a) and Flight 5 (b).

7. Planned Changes and Improvements

After each test flight, improvements were made. Flights 1 and 2 revealed the friction fit problem between the booster pieces. Flight 3 made us confident to move on to the drag chute system to increase the separation distance and revealed the inaccuracies in the drag predictions which were then corrected. Flight 4 exposed the vulnerability to wind and made us focus on the joint between the dart and booster. The surface contact points between the dart-booster was increased by moving the lip forward on the dart body tube allowing the drag petals could secure themselves against the dart. This created 4 contact points with one being on the dart body tube and the remaining on the boattail whereas before there was only 3 on the boattail. Improvement could be seen when fitting the two together on the ground, and both on-board and ground footage from Flight 5 show that no S curve happened during flight.

As stability considerations have been taken into account, performance improvements will be important as we rebuild. The weight of the rocket was under what was predicted, so improving drag would be most the critical improvement. Moving the lip farther up the dart would continue to eliminate base drag on the dart by allowing the flow to reconnect before the boattail. Other small steps like making a leading edge for the dart camera and airfoiling the dart fins will also be considered.

References

[1]Hoerner S. F., Fluid-Dynamic Drag, Great Britain, 1992

[2]Sampo Niskanen and others, OpenRocket, Model Rocket Simulator Software, Ver. 13.11, 2007.