Flight Readiness Report

Kent State University High-Power Rocket Club

Kent State University

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AE: Aerospace Engineering
AET: Aeronautical Systems Engineering Technology
CS: Computer Sciences
FT: Flight Tech
MECH: Mechatronics Engineering Technology
PH: Public Health

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Table 1: Table of Terms

GLOSSARY	
TERM	**DEFINITION**
Arduino Nano	A small, lightweight, and programmable, microcontroller
C++	An object-oriented, compiled, and low-level programming language
Communications Device *(Also, Logging Device)*	Arduino Nano which receives data from the Control device, logs the data on an SD card, and transmits the data through an XBee Pro to a ground station.
Control Device	Arduino Nano which interacts with sensors, moves control surfaces, and sends data to the Communications Device
I2C *(Also I^2C)*	Inter-Integrated Circuit: 2 wire communication protocol
I/O	Input/Output
LED	Light Emitting Diode
Quaternion	A method of representing a rotation by describing a vector about which the rotation occurs and the angle of the rotation
RAM	Random Access Memory
SPI	Serial Peripheral Interface: 4 wire communication protocol

Table 2: Table of Symbols

Symbol	Meaning
θ	The rockets current roll
θ_g	The target roll
$\dot{\theta}$	The rockets roll rate
$\ddot{\theta}$	The rockets roll acceleration
φ	The physical output (e.g. fin angle)
I	The rockets moment of inertia about its roll axis
k	The "spring constant"
c	The "damping term"
τ	The torque on the rocket about the roll axis
τ_i	The torque on the rocket about the roll axis due to the rocket's passive aerodynamics
τ_g	The torque on the rocket about the roll axis that the system is trying to achieve
$\Delta\tau$	The difference between the torque due to passive effects and the torque the system is trying to achieve

Recap of Rocket Design

Design

A pre-glassed phenolic tubing was chosen for the rocket body in order to increase durability. This type of tubing added a significant amount of weight which later caused a few changes in materials used aboard the rocket in order to remain under the maximum weight limit. The body tube has a 4-inch diameter which allows for easier access when utilizing our avionics bay and roll control system. The rocket is designed with two avionics bays for a total of 6 major sections. Nose cone, main chute body tube, upper coupler, drogue chute body tube, roll control coupler, and motor mount/fin assembly. The upper coupler will house our non-commercial data package. The lower coupler will house our variable pitch canard roll control system. Assembling the rocket requires 6 nylon sheer pins, 4 rivets, and 6 machine bolts. When the main chute ejects during descent, the rocket will be separated into a total of 3 sections.

Dimensions

The motor mount/fin assembly section is 18 inches in length. These 18 inches allow clearance for an Aerotech 54/1280 casing and 1.5 inches of a coupler while providing 5.6 inches of clearance between the lower coupler bulk plate and top of the motor casing. The 1.5 inches of the lower coupler are secured to the motor mount/fin assembly section using 6 machine bolts, which connect to 6 nut-plates. The nut-plates are secured inside the roll control coupler using impact resistant adhesive. The lower coupler is fitted with two exhaust pipes with an inner diameter of 0.5 inches in order to direct the force of the motor ejection charge to the drogue chute tube.

The motor mount consists of 4 centering rings; One positioned above the fins and three positioned bellow the fins. Two of these centering rings are wooden while the other two are G-10 fiberglass. The G-10 fiberglass centering rings provide a greater structural strength and are used to ensure structural stability in the event of a hard impact. The wooden centering rings are used primarily for centering the motor casing tube (mother tube) and were selected to help reduce overall weight as well. Located 3.5 inches from the top of the mother tube are the six holes where the roll control coupler will be held into place using machine bolts.

The drogue chute body tube is 18 inches in length. It connects to the top of the lower roll control coupler using shear pins and the bottom of the upper avionics coupler using rivets. The upper main chute body tube is 29 inches long. This tube will be fixed to the top of the upper coupler using 2 rivets and to the nosecone using 3 sheer pins. Both upper and lower parachute housing tubes are designed to stay attached to the upper avionics coupler when both chutes are deployed.

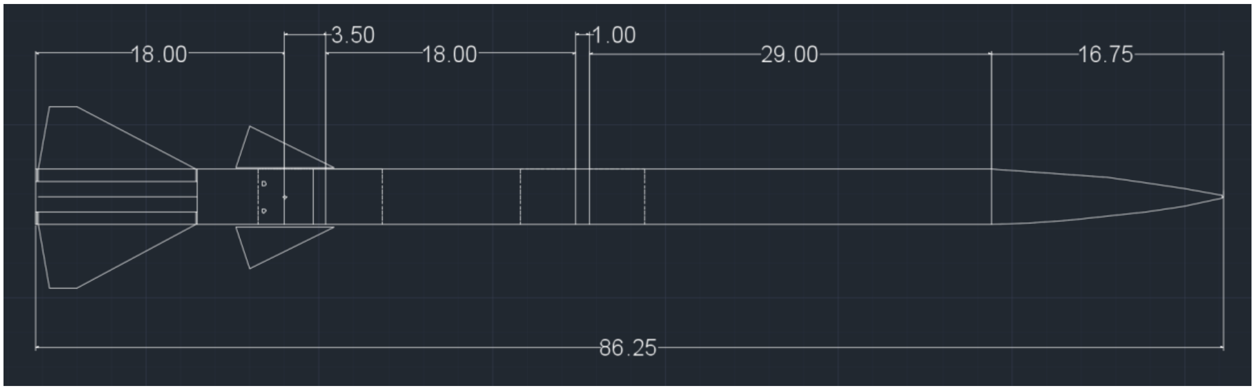

Figure 1: Rocket Dimensions

Figure 2: Unpainted Rocket

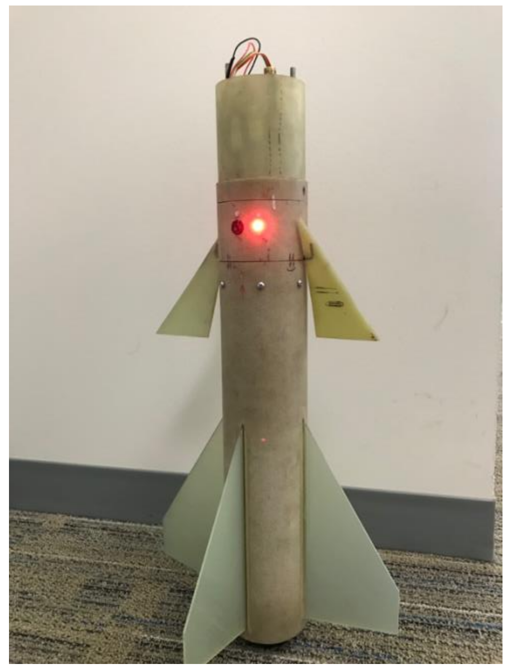

Figure 3: Roll System Activated

Construction Techniques

The motor mount section of the rocket was constructed by first installing the mother tube. First, we used structural adhesive to mount one of the interior (wooden) centering rings to the mother tube. We installed this ring first so that it will help keep the mother tube in line with the body of the rocket throughout the process of installation. After the centering ring was attached to the mother tube, we applied more structural adhesive to the interior of the body tube just above the fin slots and carefully placed the mother tube. To help further align the mother tube, we temporarily placed another centering ring just blow the fin slots while we waited for the structural adhesive to cure. Next, we installed 4 fins one at a time using structural adhesive to bond the fins to the mother tube and to the interior of the body tube. To ensure proper fin alignment, first we made sure that the fins were perpendicular to the body of the rocket. We then we applied duct tape to ensure the fins would not move through the curing process. After we were satisfied with how the fins were installed to the interior of the rocket, we applied a final layer of structural adhesive to the fin slots on the exterior of the body tube to improve structural strength.

Variable pitch canards were constructed using fiberglass, structural adhesive, and piano wire. Two pieces of G-10 fiberglass were cut to identical sizes. A small section from the identical pieces was then cut from each face of the canards. Thick piano wire was then bent and placed into each cute. Using structural adhesive, the identical pieces were pressed together and cured to form one of our canards. This process was replicated six times for size corrections and spare parts.

The roll control coupler was made using a 9-inch long fiberglass tube. The coupler has two copper tubes attached that act as exhaust pipes for directing for force of the motor ejection charge to the drogue chute tube. Both bulk plates were cut to allow the exhaust tubes to pass freely through the coupler. The roll control coupler needed to be bolted into the top of the motor mount/fin assembly section of the rocket. We came up with a way to modify the bottom bulkhead of the lower coupler so that it would contain nut-plates to bolt into. We cut a separate piece of fiberglass to create a fiberglass ring with a smaller outer diameter that could slide into our coupler. We then attached the fiberglass ring to the bulkhead using impact resistant adhesive in addition to the structural adhesive. This fiberglass ring contains nut-plates that the motor mount will use to attach to the lower coupler. Since the canard mount and canards were designed to slide directly into the coupler tube, we used a bandsaw to cut two slots all the way up to the switch band on the bottom of the coupler. These slots allow for the canards to fit neatly into the coupler, which allows for easier access to the system. The canard mount itself was 3D printed and mounted onto two 0.25-inch all-thread bars using nuts and washers to keep it at the proper orientation. The 3D printed mount has spots designated for the servo and canards to fit into neatly.

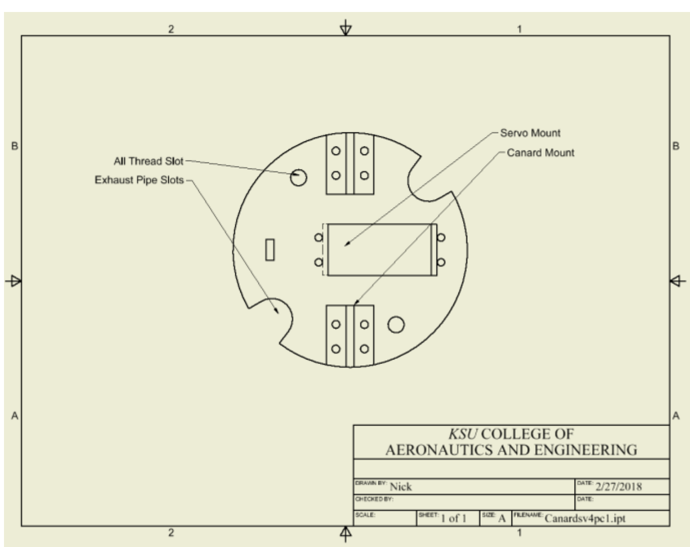

Figure 4: Roll Control Servo/Canard Mount

The upper avionics coupler is a phenolic tubing with a pre-glasses phenolic switch-band. Both upper and lower bulk-plates on this upper coupler have small PVC wells installed, which hold black-powder charges. The electronics inside the avionics coupler are housed on a 3D printed sled. Both upper and lower couplers will contain 3D printed sleds. These 3D printed sleds improve ergonomics within each coupler while keeping weight down relative to a wooden sled.

Stability Analysis

We created an excel spreadsheet to help adjust our calculated center of pressure (CP) values any time we made changes to the structure of the rocket. This method gives us a calculated CP location of 71.79-inches from the tip of the nose cone (reference point). An *OpenRocket* model of our rocket places the CP location 69.40-inches from the reference point. The differences between the two locations can be attributed to the differing calculation methods used to calculate CP. Using a balance test, our measured CG value is located 59.6-inches from the reference point. The CG value calculated by *OpenRocket* is located at 58.5-inches from the reference point. The difference in these locations may be the result of differing materials used in *OpenRocket* but is still within a comfortable margin of error.

Table 3: OpenRocket Center of Pressure and Gravity Values

	Center of Pressure (in)	Center of Gravity (in)	Static Margin
HPRC Calculations	71.79	59.6	3.05
Open Rocket Calculations	69.42	58.5	2.73

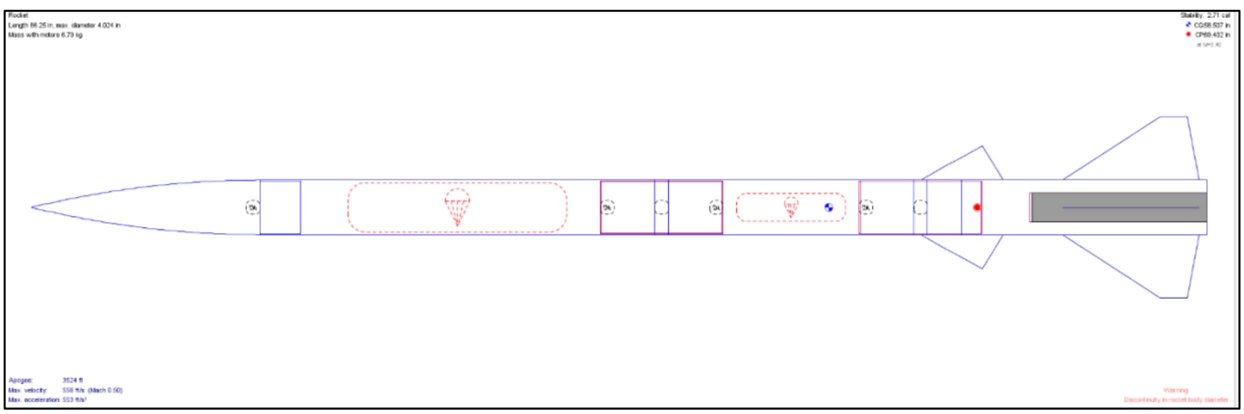

Figure 5: CP/CG Graphic Model

Areas			
Area of Triangle	diameter (in)	height (in)	
	4	16.75	33.5
Area of upper body	diameter	length	
	4	29	116
Area of mid body	diamter	length	
	4	18	72
Area of lower body	diameter	length	
	4	18	72
Area of fins			27.752
Triangle 1 (large)	base	height	
	4.625	7.125	16.4765625
Rectangle	length	width	
	4.626	2	9.252
Triangle 2 (small)	base	height	
	0.875	4.625	2.0234375
Area Avionics	diameter	length	
	4	1	4
Area other coupler	diamter	length	
	4	3.5	14
Carards	height	width	
	5.9	2.95	8.7025
Total Height	86.25		
weight	14.22 lbs		

Center of Pressure (Tip of the Nose is Reference Line)			
Component	Area	Center of Pressure (individual)	Moment
nose cone	33.5	11.16666667	374.0833333
upper body	116	31.25	3625
avionics coupler	4	46.25	185
mid body	72	55.75	4014
other coupler	14	66.5	931
lower body	72	77.25	5562
fins	27.752	81.86541541	9087.716033
Canards	8.7025	69.01333333	1201.177067
	Area (total)	Center of Pressure	Moment (total)
	347.9545	71.79092793	24979.97643

Moment of fins				
Geometry	Area	Location	Moment	
triangle large	16.4765625	4.75	78.26367188	
rectangle	9.252	8.125	75.1725	
triangle small	2.0234375	9.416666667	19.05403646	
	Area TOTAL		Moment TOTAL	cp
	27.752		172.4902083	6.215415405

Figure 6: Measured CP/CG Values

Avionics Bay Design

Early in the design process, we decided to use two separate couplers to house the instrumentation for data logging and roll control. Utilizing two separate couplers gives additional space to add additional mechanical and electrical components. Two couplers also allow for better organization. The avionics bay consists of an Altus TeleMetrum, Altimeter 2, and a StratoLoggerCF. The components are mounted on a 3D printed sled that was designed to be organized and easy to access. The exterior of the avionics bay is a phenolic tubing that was selected to reduce the overall weight of the avionics bay. The switch-band is 1-inch in length and made of pre-glassed phenolic to maintain exterior strength.

The roll control system was designed to be simple, safe, and easy to modify. The system itself consists of two canards placed behind the center of gravity. The canards are mounted to piano-wire that is fixed to a plate on the interior of the lower coupler in a way that only allows it to roll in place. The piano wire is bent upwards at a 90-degree angle and fed through holes in a servo mounted disk. When the servo actuates, either clockwise or counter clockwise, the disk will cause the wire to roll in place, thus turning the canards on the outside of the rocket. This design doubles as a mechanical failsafe. If the servo actuated canard system were to fail, the worst possible outcome would be a greater induced roll. By turning the servo disk one direction, the system can only induce a roll because of the one servo one disk setup. The design is also user friendly. It allows the user to easily install and activate the system. The board simply slides into the coupler and requires the user to plug in LED lights, the servo, and the systems on/off switch. The simple sliding mechanic makes the board easy to access and repair if needed. The design meets our goal of being simple, safe, and easy to modify.

In the Preliminary Design Report, the initial layout of the roll control bay included 4-inches of space above and below the 1-inch switch band. Those dimensions have changed to allow a more user-friendly design. One of the goals of our roll control system was to make it easy to access and easy to repair. For those reasons, we designed the system in a way that would allow it to slide in and out of the bay. To make it easier to access and repair, we found it intuitive to place our system further down the coupler and extend the switch band. Using a larger switch band with the same length coupler raises a safety concern with the bottom half of the roll control bay as it could create issues with a traditional rivet setup. As a result, we decided to use six bolts to hold the bottom portion of the roll control bay in place utilizing the strength of the fiberglass couplers and the fiberglass exterior of the body tube.

Changes Since Preliminary Design Report

Length of the upper and lower body tubes has changed since the preliminary report due to a long main chute. The main parachute did not easily fit in the 18-inch section, so we switched the location of the two tubes. The upper main chute body tube is now 29 inches long. Both body tubes simply switched locations.

One of the biggest learning lessons from our checklist was on our second test launch. On our second launch of the day our main parachute deployed at the proper time but was not attached to the shock cord. In the variation of the checklist used that day, only four parachute quick links were listed in the setup and check of the pre-launch procedures. The rocket descended using only its drogue chute. Luckily the result of not having a main parachute were not terrible. There have been additional items added to the checklists to ensure this problem does not happen again.

New cameras are being utilized and have proven effective. We purchased Foxeer Legend 1 cameras and will no longer be using the Mobius Mini ActionCam.

A new 80-inch main chute was added in place of the old 72-inch chute due to an increase in weight. Due to this increase in weight, our 38-inch drogue chute landed with a snapped shroud line. We swapped the old drogue chute with a new 42-inch chute.

Rocket Operation Assessment

Pre- & Post-Launch Procedure Assessment

A detailed manual of procedures and checklists was created for pre- and post-launch procedures for the 2016 - 2017 NASA Space Grant Midwest High-Power Rocketry Competition. These procedures and checklists were used as a starting point for this year's competition and were better developed to reflect the challenges of this year's competition. The checklists and procedures are followed at every test launch with new procedures annotated and latter updated. This year's edits consisted of changes from last year's competition and overall improves to smooth out launch procedures.

Checklists are broken down into safety, pre-launch, launch and recovery sections. The safety items checklist consists of everything that must happen in order to set up a safe launch. These items consist of contacting the land owner, securing a NOTAM, recording the day's METAR, ensuring a risk assessment is filled out, clearing the launch site in accordance with Tripoli (or

NAR), bringing all required safety equipment (i.e. fire extinguisher, safety glasses, first aid kit, etc.), and completing a safety briefing.

The pre-launch checklist contains everything that must take place in order to properly set up the competition rocket. The key points in this checklist are proper setup the avionics bay (including setting ejection charges and checking continuity of electronic matches), ensuring both parachutes are properly set, all rivets and shear pins are in places, and motor assembly procedures are followed.

The launch pad checklist is to ensure the rocket is prepared for launch. In this checklist the rocket is placed on the launch rod, the camera is turned on, the TeleMetrum V2, StratoLoggerCF, and roll system are turned on, and the motor ignition wire is set.

The recovery checklist is to ensure safe recovery of the rocket and data. The safety recovery checklist ensures that both charges have gone off, both parachutes are handled properly, and all data is properly recorded. The checklist manual also contains motor specifications, Tripoli and NAR minimum safe distance charts, and a launch SOP.

Test Launch: Actual vs. Predicted Performance

Table 4: Peak Altitude, Velocity, & Acceleration Comparison

Test Flight #	Motor Type	Mass(kg)	Apogee(ft)	Velocity(ft/s)	Acceleration(ft/s/s)
1	J-460	0.789	1639	350	208
1	J-460		2037	266	261
2	J-389	0.5468	1408	312	175
2	J-389		1452	207	199
3	J-800	1.134	3124	576	347
3	J-800		3508	406	376
4	J-460	0.789	1592	341	203
4	J-460		1995	263	264
5	J-480	0.789	1592	341	203
5	J-480		2505	286	193

Predicted
Actual

Matlab was utilized to make the predicted flight performances of each motor tested on our rocket. The force, motor mass, propellant mass, and burn time were adapted in the code for each of the different motors. We speculate the cause for the slight variations in expected values and actual values is that we use a constant drag value instead of a varying drag value in the Matlab formulas. Initially we used J-235 and J-460 motors to ensure our rocket was stable before moving to higher-powered motors. On our second day of launching the first motor we used was a J-389 blue thunder. This motor was selected to allow us to determine if our rocket was a risk of going past our altitude limit of 4,800 feet at our launch site. When we were positive that our rocket was stable and not at risk of surpassing the 4,800 feet altitude limit we began testing with

J-800 motor. We selected the J-800 motor for its rapid take off and altitude potential with our designed rocket. We found the motor to be ideal for the competition conditions. By selecting a motor with a quick burn out time of 1.6 seconds, we are able to achieve a quick take off; thus, creating a more stable launch as there is far less time for the rocket to rotate. The competition specifies that the rocket must reach a minimum of 3,000 feet and through our calculations that is achievable with the J-800 motor.

Peak Altitude Comparison

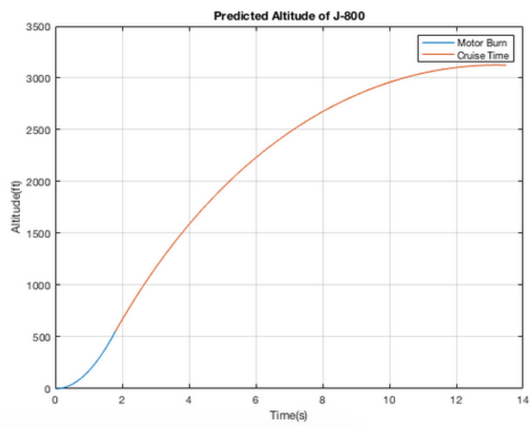

Figure 7: J800T-L Predicted Altitude v Time

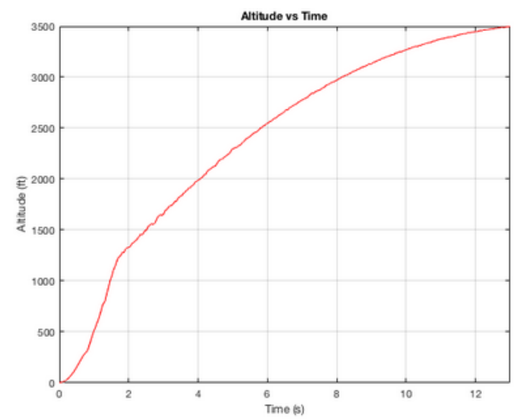

Figure 8: J800T-L Actual Altitude v Time

Peak Velocity & Acceleration Comparison

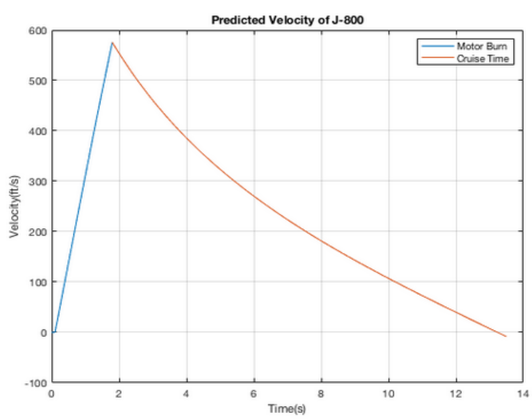

Figure 9: J800T-L Predicted Velocity v Time

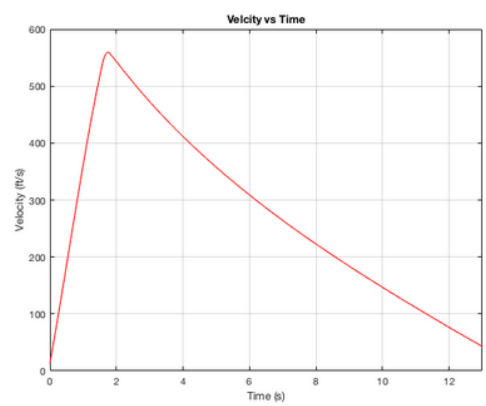

Figure 10: J800T-L Actual Velocity v Time

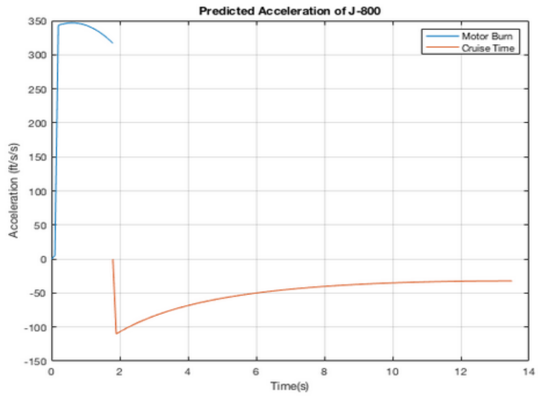

Figure 11: J800T-L Predicted Acceleration v Time

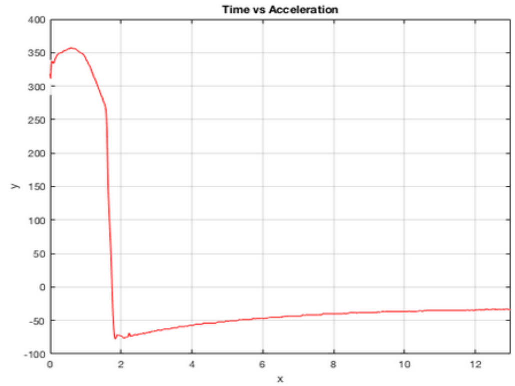

Figure 12: J800T-L Actual Acceleration v Time

Recovery System Performance

Main parachute is set to deploy at apogee using a StratoLoggerCF with a TeleMetrum V2 as a backup charge. Drogue chute is set to deploy at 500ft AGL using both altimeters.

Descent Velocity Comparison

To meet the design goal of a descent rate less than or equal to 24 ft./s, we selected a parachute size based on the weight to descent velocity ratio equation as follows:

$$d = \sqrt{\frac{8mg}{\pi \rho C_D V^2}} \qquad \textbf{[Eqn. 1]}$$

Where;

d $= chute\ diameter\ [m]$
m $= rocket\ mass\ [6.62\ kg]$
g $= gravitational\ acceleration\ \left[9.81\ \frac{m}{s^2}\right]$
ρ $= density\ of\ air\ \left[estimated\ at\ 1.7\ \frac{kg}{m^3}\right]$
$C_D = drag\ coefficient\ [.61\ for\ round\ canopy]$
V $= descent\ velocity\ \left[\leq 7.315\ \frac{m}{s}\right]$

Equation 1 then becomes: *(for a descent rate of* $\leq 7.315\ \frac{m}{s}$ *only);*

$$d \geq \sqrt{\frac{1}{6.7} \frac{W}{\pi \rho C_D}}\ , Where;\ W = weight\ [N] \qquad \textbf{[Eqn. 2]}$$

Therefore, our selection consisted of parachutes having a minimum diameter of 80-inches. Verifying with *RockSim*, we found our chute to be the correct diameter for a descent rate of less than 24m/s.

Predicted descent rate with an 80-inch main parachute was 20ft/s while the actual descent rate was determined to be 18ft/s on average.

Video Results vs. Data Logging of Roll Angle

Recovery System

The drogue parachute is set to deploy at apogee out of the second body tube of the rocket. The drogue chute is attached to the rocket by a braided nylon shock cord. Shock cord is attached to an O-ring mounted on top of the roll control bulk plate with the drogue parachute attached to it. The drogue parachute and shock cord are protected by NOMAX material to prevent the black powder charges from burning them. The same setup was used for the main parachute, there is a nylon shock cord attached to the top of the avionics bay and the bottom of nose cone.

Roll control/orientation system performance

After ten test flights, we have made the decision to increase the size of the canards and to find a way to increase the deflection amount. The system has activated successfully in flight and started to control roll; however, after more analysis we decided that there was not enough force to effectively control roll. Specifically, test flight 10 was set to deflect the canards 30 degrees to counter the roll. When the system actuated, the natural roll was not affected as much as we would have liked. This was in part due to the systems orientation confusion and the effectiveness of the canards. More investigation will be done over the next test flights before the day of the competition.

Active Roll Angle Monitoring System Discussion

Main Control Board Software

Technologies Used

Programing language:

All flight software is written in C++. The C++ language was selected not only because it is the primary language supported by the Arduino, but also because it is a compiled language that supports low level functionality, works well in embedded applications, and supports object-oriented programing.

Arduino Libraries

The Arduino compiler provides several functions not present in regular C++ for directly controlling the hardware. The SoftwareSerial library is responsible for communicating with the XBee. The Wire and SPI libraries handle interactions between the control device, communications device, and other devices. Furthermore, other standard Arduino libraries are used in the program.

Sensor Libraries

Both the BMP280 and BNO55 have manufacturer provided libraries which allow easy access to the data provided by the sensors. They are used because they are written by the manufacturer and minimize the amount of work needed to get usable information from the sensors.

Matrix math library:

Since calculations based on rotation matrices must be performed, and these calculations are not directly supported in C++, a 3rd party library optimized for the Arduino is used.

Software Architecture

Configuration file

Some properties vary from flight to flight and from rocket to rocket, and since editing source code for each flight is not optimal these properties are stored as text in a configuration file, separated by a newline character, on an SD card, allowing for easier manipulation of data. The logging device reads in properties and passes them to the control device one at a time until a specified number of properties is reached.

Flight Plan

Flight plan parsing will be performed on the communications device. The flight plan for the rocket will be provided as a string and represents the rotations and timing that the rocket must complete while ascending. For example, the string "#3;+0901000;-0001000;~1802000;" might be provided. The first part of the flight plan is the number of commands to execute, represented by the sequence "#<number_of_commands>;" which, in this case is 3. After that, the list of rotation angles and timings, separated by semicolons, follows. Each element in the list has three parts, the direction of rotation specified by a symbol, the angle, specified by the first three digits, and the time the rocket should take to make the turn.

The direction symbol could be one of three symbols, '+', '-', or '~'. '+' represents clockwise rotation and '-', counterclockwise rotation. '~' tells the software to take the shortest possible rotation to get to the desired angle. The following three numbers represent the angle of the rocket in terms of degrees. The final four digits specify the roll time in milliseconds, which are the most accurate timing data available to our sensors. After completing the flight plan, the rocket holds the final orientation until it reaches the apogee.

Given the previous example, the rocket rolls clockwise to 90° in one second. It then turns counterclockwise in another second. Finally, it turns 180° in two seconds, most likely going counterclockwise to use its momentum. Also, using this format, one could specify that the rocket hold a position by using two commands, "+1801000;~1803500;". This would tell the rocket to roll to 180° in 1 second and then to roll to its current position for another 3.5 seconds, essentially keeping it in the same place.

Providing a flight plan to the rocket happens one of two ways. By default, a flight plan will be pre-programmed and placed into the configuration file for the rocket. The plan can be verified manually before being loaded and verified by the rocket before flight. The second method sends a flight plan to the rocket remotely. To do this, a flight plan is generated and verified on the control computer, made possible by the parser being written in pure C++ to enable it to run across platforms. Then, the plan is transmitted over the radio to the rocket which will verify it. Should the flight plan fail parsing on the rocket, the default plan will be used.

Communication

The rocket and the control computer use XBee radios to pass information back and forth. The rocket's XBee is connected to an Arduino microcontroller and the Arduino SoftwareSerial library, which allows reading and writing bytes of data at a time. The control computer connects to the XBee through a USB adapter and is configured using the Digi XCTU software. Every message sent between the rocket and ground is prefixed with a single character to identify the source. Messages without Kent State's identifier are ignored. The communication with the rocket is split into three sections: pre-launch, ascent, and descent. Each stage uses the radio connection differently, and the rocket controls the current stage.

During the pre-launch phase, after a valid flight plan that verifies on the control computer, the file is sent to the rocket. The communications device parses the plan and reports back to control device with a success or failure message. The launch can be delayed until the rocket confirms a correct flight plan. Otherwise, the rocket uses a preset flight plan.

While the rocket is ascending, sensors attached to the Arduino report at ~100Hz. When there is a sensor update, that data is passed to the ground station. To reduce the overhead of parsing messages from the ground, communication during ascent is one way.

After the rocket reaches apogee, two-way communication resumes with the control station sending problems for the rocket to solve. The rocket sends responses once the result has been computed. A simple interface is provided on the communications device to pass the raw message to the routine that solves the problem. This allows the implementation of problem solver to be done at a later time.

Flight modes

The behavior of the software varies based on the phase of flight (pre-flight or post-flight) the rocket is in at the time. To accomplish this, the phase of flight is recorded as an integer (the flight mode) starting from 0 for the preflight phase, then 1 for powered flight, then 2 for the coast until near apogee (the part of the flight where the roll is actively controlled) and so on. A switch statement is used to control the actual branching, ensuring that only the code intended to run during the rockets current phase of flight actually executes. A check is performed within the switch statement to determine if the next phase of flight has started (e.g. the rocket has a strong vertical acceleration and the launch rail is no longer present indicates that the boost phase has started). If it has, the flight mode is incremented.

Roll Control

The actual roll control algorithm runs on the control device. The design philosophy of the roll control system itself is to make the rocket behave as though it were a critically damped harmonic oscillator along its roll axis (i.e., obeys the equations $I\ddot{\theta} + c\dot{\theta} + k(\theta - \theta_g) = 0$ and $c^2 - 4Ik = 0$ with θ_g being the target roll (as provided by the flight plan)). In this way, the rocket quickly and smoothly returns to the target roll after being disturbed from it, without overshooting.

In order to accomplish this, a ω is chosen on the ground to achieve a quick return to the target roll without exceeding the capability of the software to update or the roll control system to provide adequate torque. From this (and the rockets roll moment of inertia (I)) values for c and k will be calculated. In flight, the software uses the target roll provided by the flight plan, as well as the current roll and roll rate provided by the sensors, to calculate the torque necessary to make the rocket obey the aforementioned equation of motion (in other words, $\tau_g = -c\dot{\theta} - k(\theta - \theta_g)$).

The rocket is expected to be under some torque due to its passive aerodynamics, which is expected to be a function of its roll rate and speed relative to the air (denoted as $\tau_i(\dot{\theta}, v)$). Subtracting that torque from the target torque gives us the torque that must be provided by the control system ($\Delta\tau(\tau_g, \tau_i) = \tau_g - \tau_i$).

Finally, the torque provided by the control system itself is expected to be a function of the airspeed of the rocket and the physical inputs to the system (e.g. the angle of the control surfaces), inverting this function with respect to the physical input allows us to calculate what that input should be in order to achieve the desired torque (e.g. $\varphi(\Delta\tau, v) = \tau^{-1}(\Delta\tau, v)$). This value is used to control the servos or similar devices, ultimately controlling the physical roll control system.

Bang Bang Control System

A simpler alternative roll control system has been devised due to delays in developing the full system. This system functions by choosing between three fixed deflections. One for when the roll is greater than the target roll, another, equal in magnitude but in the opposite direction for when the roll is less than the target roll, and zero for when the roll and the target roll are equal. While simple to implement, this system has a tendency to overshoot.

Planned improvements

Additional refinements are planned for the bang-bang control algorithm. Pending test flight, the damped motion algorithm may also be used.

Findings & Future Work

Key Findings

Our analysis of the test flight videos indicates that we need to debug the program to more effectively actuate the servo. During test flights 7, 9, and 10 we noticed that the canards did not seem to be affecting the roll of the rocket as much as we hoped. This is a result of the program and the surface area of the canards. The program we used for the system is going to be updated to increase the deflection angle of the canards to add more rotational force.

Potential Design Improvements

Our current design only allows for 30 degrees of deflection in the canards due to the physical limitations of the disk. We can design a better servo disk that will allow the canards to deflect further. We can also create larger canards that will have a greater impact on the rotational force while at the same time moving the 1/8th inch piano wire closer to the center of pressure. Moving the piano wire closer to the center of pressure on each canard should reduce the torque necessary to rotate the canards.

Budget: Predicted vs. Actual

Table 5: Budget to Date

Proposed Budget Delegation ($10,000)			
Delegated Component	**Estimated Budget [$]**	**Budget Percent [%]**	**Actual Budget to Date[$]**
Travel/Lodging	3,800.00	38.00	2,800.00
Lab Space/Overhead	0.00	0.00	0.00
Prototyping	100.00	1.00	80.45
Instructor Mentorship	1,200.00	12.00	0.00
Reports/Documentation Supplies	100.00	1.00	0.00
Propulsion	1,200.00	12.00	936.98
Structures	1,100.00	11.00	836.17
Data Acquisition Components	1,600.00	16.00	887.77
Registration Fee	400.00	4.00	400.00
Hardware/Software	400.00	4.00	0.00
Misc.	100.00	1.00	793.74
TOTAL	10,000.00	100.00	6,735.11