Flight Readiness Report

University of Wisconsin - Platteville

Pioneer Rocketry

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Rocket Design

University of Wisconsin – Platteville's 2018 MRL rocket has morphed three distinct times due to new design input and test flight data. The final rocket design will be outlined and explained, then the changes and motivations will be explained at the end of this section. The rocket's name is Mr. Rodgers.

Design and Dimensions

Ultimately, a 3-fin design was settled upon. This design decision allowed for multiple unique and beneficial characteristics. The primary benefit this provided the rocket with is the ability to control all three axes during flight with a minimum number of control surfaces. A custom control system is capable provides the capability of three axis control, which is discussed in a later section. Mr. Rodgers has five in diameter airframe and a stability of 1.22 caliber with the motor loaded. Using this relatively large diameter allowed for easy access to the AV Bay and the control surface driver section ("fin-can"). The stability takes into account the overridden mass and center of gravity determined from experimentation.

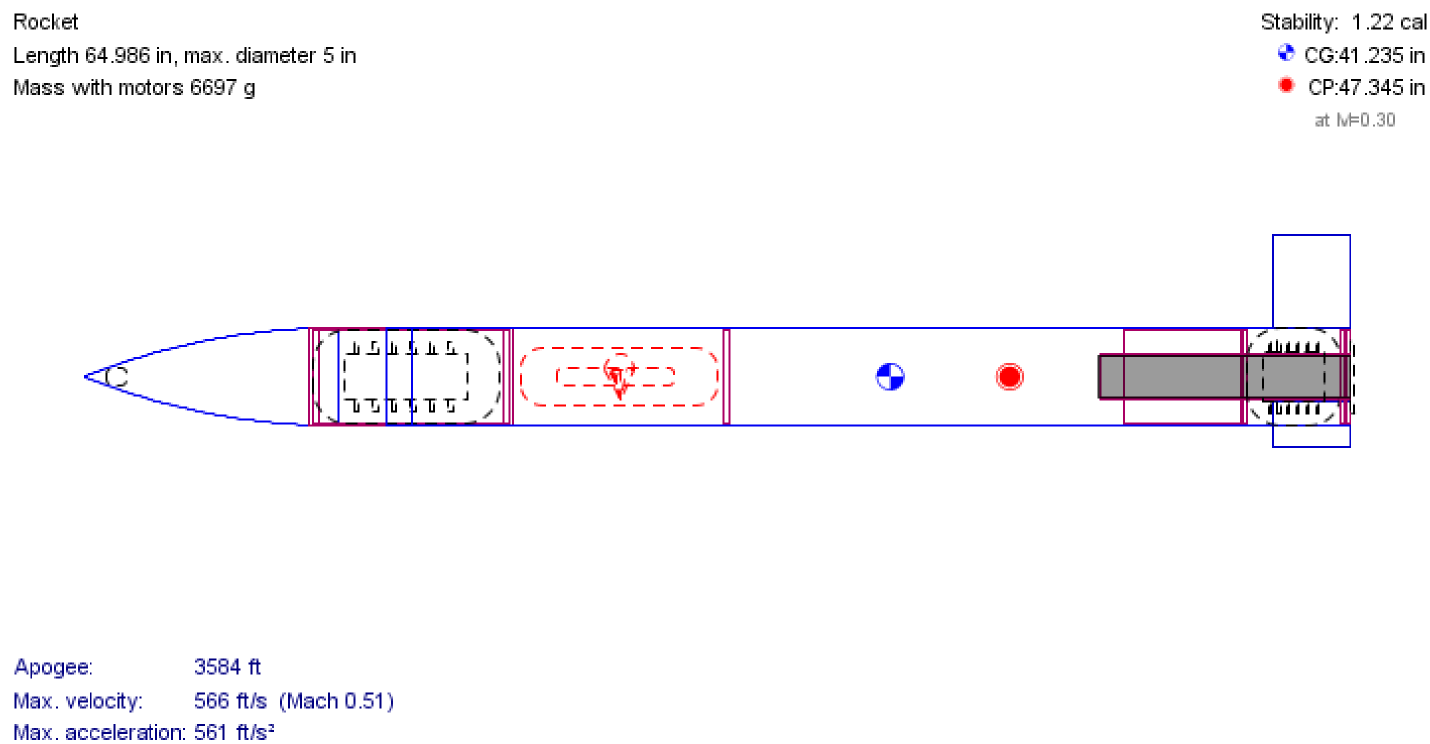

Figure 1: Open Rocket schematic of Mr. Rodgers

The goal has always been to mount the servos near the fins while having the control effort correspond to a 1:1 output of servo action to fin action. However, the servo was not to be directly linked to the fins. This would cause undue stresses on the motor connection, which would risk the motor disconnecting from the fin during flight. A 4-bar linkage between the servo and an axle fixed to the fin itself was designed and implemented to relieve these stresses.

Construction Techniques

When designing the final rocket, two goals were in mind: ease of repair and use. Almost every part on the rocket can be replaced. Permanent construction techniques were only used in places that required high strength. One such area that permanent construction techniques were used on is the motor tube. The motor tube is fixed to the top centering ring and four triangular struts using Rocketpoxy™ in conjunction with fiberglass strips for added strength. This centering ring was then epoxied to a coupler section that acts as a thrust ring. The coupler tube, centering ring, and motor tube assembly are screwed onto the body with four screws. This provides strong mechanical connections while still allowing the assembly to be removed for repair.

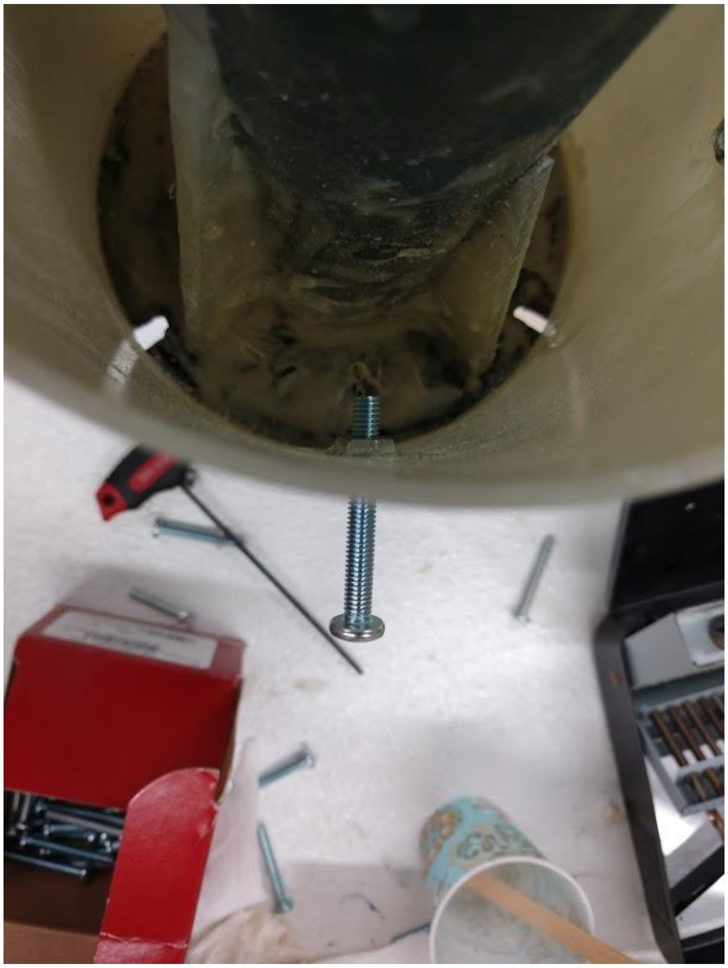

Figure 2 Triangle supports were used on the linkage between the motor tube and centering ring. The entire assembly is secured with four machine screws.

A fin-can that holds the three fins, servos, and linkages was designed in Solidworks. This fin-can was 3D printed by Midwest Prototyping using an SLS 3D printing technique. The fin-can was optimized for use with the initial rocket design, however with a change in design, some features became obsolete. For example, there are holes aligned on the top and bottom for threaded rods that secure the assembly to the rocket. Only the bottom holes are now used for securing the motor retention to the fin assembly.

Figure 4 Fin-can at Midwest Prototyping after being printed

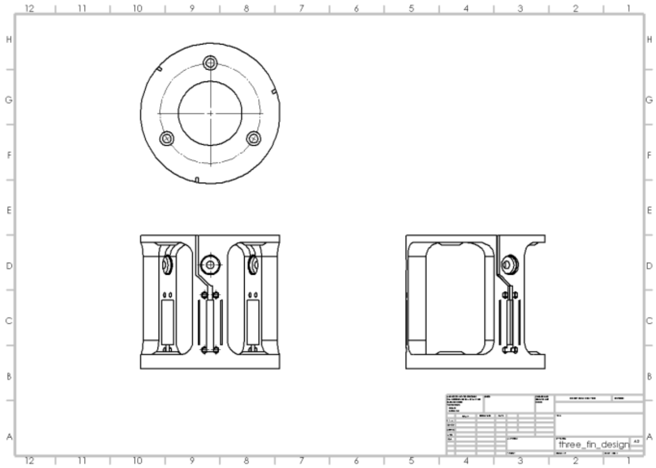

Figure 3 Multiview projection of the fin-can design from Solidworks.

Motor retention is commonly an afterthought when building a rocket. Generally it can simply be drilled into the bottom of the fin-can using wood screws. However, the fin-can on this rocket is an expensive custom part, and modifying the shape through drilling into it was to be avoided as much as possible. Therefore, a customer motor retention ring was designed and was fabricated from aluminum using a CNC. The process of using the CNC can be seen in Figure 4. The final product is pictured in Figure 5.

Figure 5 Using a CNC to fabricate an aluminum motor retention.

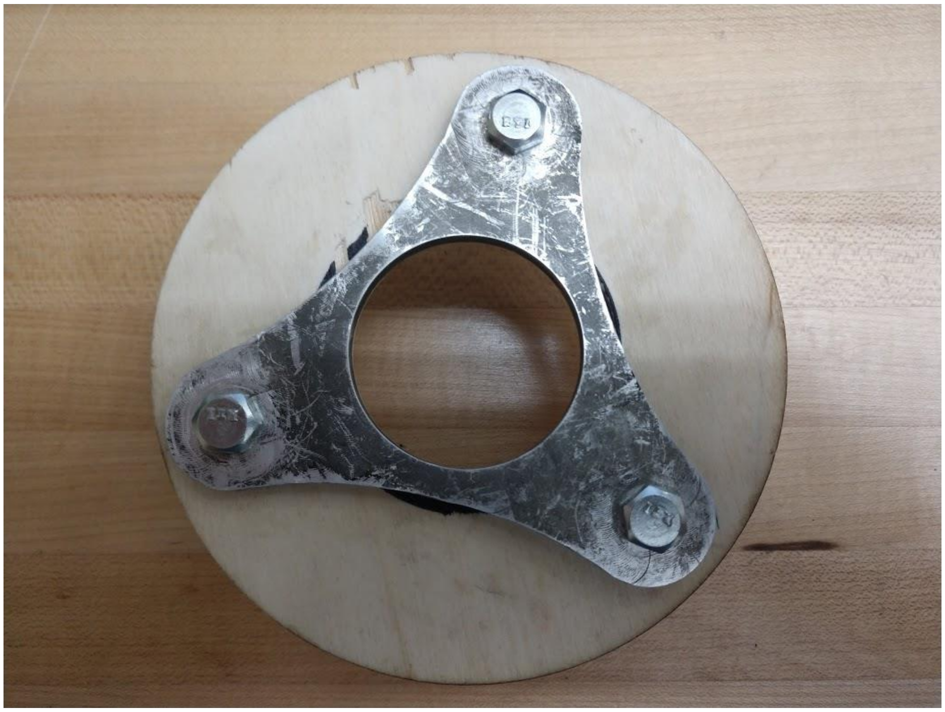

Figure 6 The finished and slightly used motor retention with bolts.

Stability Analysis

Stability is a major concern with every rocket. This is *especially* true with a rocket that does not have static fins. The stability of the rocket changes depending on the orientation of the fins. During burn time Mr. Rodgers' fins are locked in the vertical position and is statically stable with a stability of 1.22 cal. During the control phase Mr. Rodgers' control system is providing vertical stability assistance in addition to roll control. In the event of a control system failure, we programmed in a failsafe that will lock the fins back to vertical position to ensure a safe stability for the remainder of the flight.

Safe Flight & Recovery

Our prototype rocket flew on a CTI J280. The rocket was programmed to sway the two dynamic fins to positive and negative five degrees. The rocket was stable during the entire flight and safely descended into a nearby pond. Then we test flew the first iteration of Mr. Rodgers. Mr. Rodgers was programmed to sway all three of its fins to positive and negative 2 degrees. Mr. Rodgers was also stable throughout the flight. However, the StrattoLogger unexpectedly failed before apogee. The motor backup ended up deploying the drogue, and the main parachute slipped out of its chute release. The rocket was still recovered safely and intact.

E-bay Design

The nose cone in uniquely designed to house our electronics bay and a pitot tube. The nose cone is custom 3D printed to have a 1/4 in hole through the top that leads to a cavity that fits a 1/4 in hex nut. Epoxied to the hex cavity is a barbed hose fitting that has female 1/4 in threads on one end and a barbed 1/8 in hose connection on the other end. This allows us to replace damaged or clogged pitot tubes. To maintain access to the inside of the nose cone and the hose fitting we offset the electronics sled to one side of the nose cone's shoulder. Since we could not permanently put a bulk plate at the top of the shoulder to anchor the electronics sled, we instead made a ring that would be the anchor point for the sled. Figure 6 demonstrates the mounting ring for the E-bay. The nose cone shoulder also has a switch band for pressure holes and to arm the electronics on the pad. The pitot tube is also removable, as is demonstrated in Figure 8.

Figure 7 AV-bay section. This design features the opening to the upper nosecone for easy access to the pitot tube.

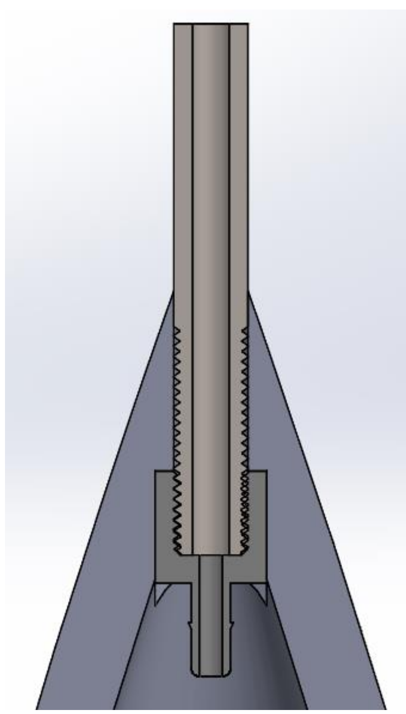

Figure 8 Pitot tube connection to the nosecone.

The electronics for the E-Bay are mounted upon a sled designed to slide on two of the rails installed in the nosecone. The sled is shown in Figure 9. Not pictured is the 2200 mAh battery that powers the servos. The wires with yellow, black, and blue tape are servo wires. The color of the tape signifies the motor every wire should go to.

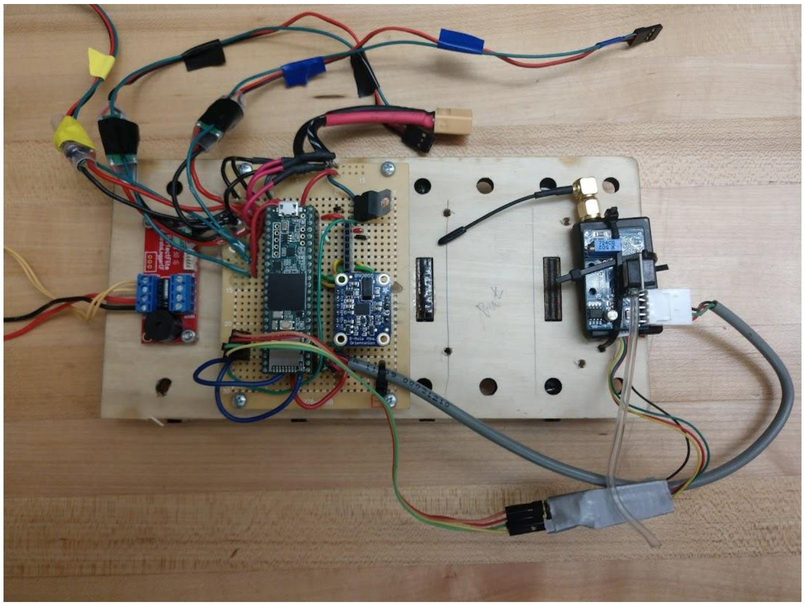

Figure 9 Electronics layout on the sled. Features Stratologger, Teensy 3.6 with BNO055 orientation sensor on protoboard. Pitot tube pressure sensor and radio module are packaged together on the right.

Changes since Preliminary Design Report

The design of Mr. Rodgers has changed immensely since the PDR was written. After reviewing the design and test launch video of the first launch, it was concluded that the connection to the servo was too weak and introduced flutter into the system.

Figure 10 Original servo connection. This design proved to be too hard to maintain.

During the test flight of the first rocket, a servo wire fell into the fin-can of the rocket. The process of retrieving the wire involved reaching all the way to the bottom of the rocket and fishing the servo wire through a very small hole. To prevent things like this from happening in the future we decided to design the rocket to be easily disassembled as well as strong.

The new fin assembly moves the servos completely into the body tube. Each servo is connected to a D-shaft axle via a control rod. Thus, only the axle and the fin are exposed outside of the rocket. We had a part custom manufactured to hold the servos and the D-shafts. The servo horns are connected to the D-shafts via collars and rotate freely on bearings. Since the fins are not static, there are no fin fillets. So to ensure the thrust of the motor could be transferred to the body, we had two 0.71 in. thick centering rings epoxied to the motor tube. There were three treaded rods through both centering rings that the fin assembly would slide onto and be attached with hex nuts. However, we did not foresee how much weight this design added to the rear of the rocket. Thus our static stability was only 0.7 cal and our predicted altitude was only 3,017 ft.

To mediate this problem we consulted with Tim "Wildman" Lehr. Tim suggested a redesign of the main body section of the rocket. We purchased a lighter body tube and coupler piece, and redesigned the motor mount to eliminate the need for the large centering rings and threaded rods. The new design transfers the thrust of the motor to the body via the fiberglass centering ring and thrust ring assembly discussed earlier.

The fin assembly is completely removable from the rocket. This allows us to easily repair or replace broken pieces to the fins, servos, or servo wires. The fin assembly is held into the rocket at the top by the aforementioned centering ring assembly. At the bottom there are two wooden centering rings that screw into the body tube to prevent the assembly from falling out.
The final version of the rocket grew to be 5 in. in diameter and shrunk to 65 in. long. The AV bay was moved into the nose cone and we added the Pitot tube.

Rocket Operation Assessment

Launch and Boost Phase Analysis

On launch the fins are locked to vertical position providing a static stability of 1.22 Caliber off the pad. The J800 pushes the rocket to 60.3 ft/s velocity of the pad and peaks at 566 ft/s. The J800 has a peak thrust of 1001 N and a total impulse of 1229 Ns. The maximum acceleration of the rocket is 572 ft/s^2. After 1.8 seconds the motor burns out and the rocket enters the coast phase.

Coast Phase Analysis

During the coast phase is when the control system is active. The system was modeled and simulated in Simulink. The controller design is a non-linear feedback linearizing system. To develop the controller three steps were taken: modeling the rotational dynamics, modeling and simulation using MATLAB and Simulink, and redesign and tuning. The system was analyzed to show that this method can be applied. The full Simulink model can be seen below in Figure 11.

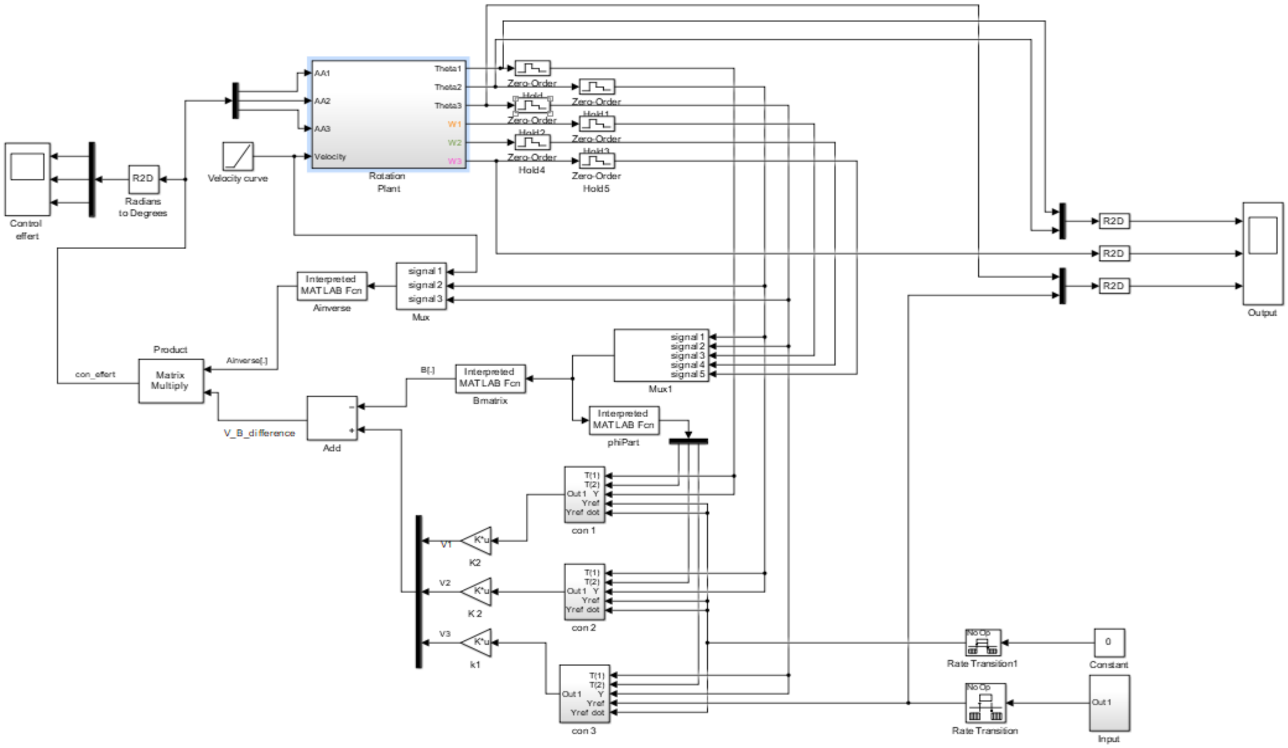

Figure 11 Full Simulink model of the feedback linearization control system.

The main advantage of the feedback linearization is that the system removes the dependence of velocity allowing the system to be valid over the full range of the rockets flight. There were two main assumptions made in this design. The first being that the rocket would be within 10 degrees of vertical. The second being that the air is static. The simulation does have a linearly decreasing velocity input and will model the rotational velocity and orientation in terms of Euler angles.

The input to this system was a series of step inputs to test the system under different conditions. Simulations showed that the initial design using state feedback did not meet our requirements so it was redesigned to a Proportional-Integral-Derivative (PID) controller. This controller is designed based on the linearized system. The full system response can be seen in Figure 12 through Figure 14. The system was designed to have a settling time of 0.3 s and an overshoot of 10%.

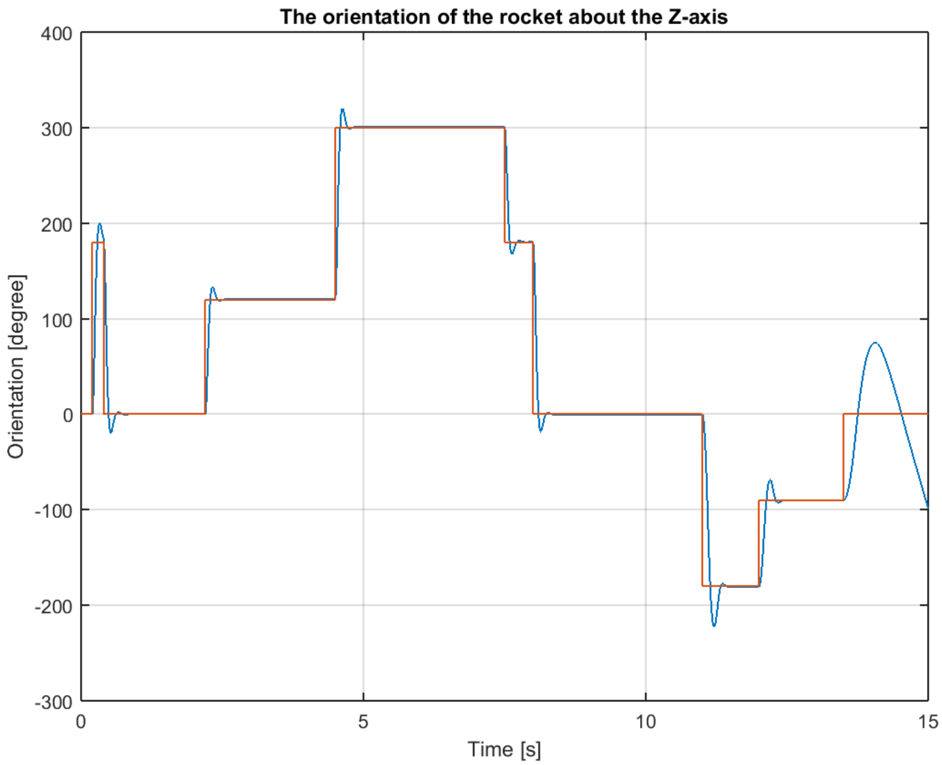

Figure 12. Full system response to a series of commands over a 15 sec flight time. The velocity of the system is linearly decreasing function starting at 350 m/s

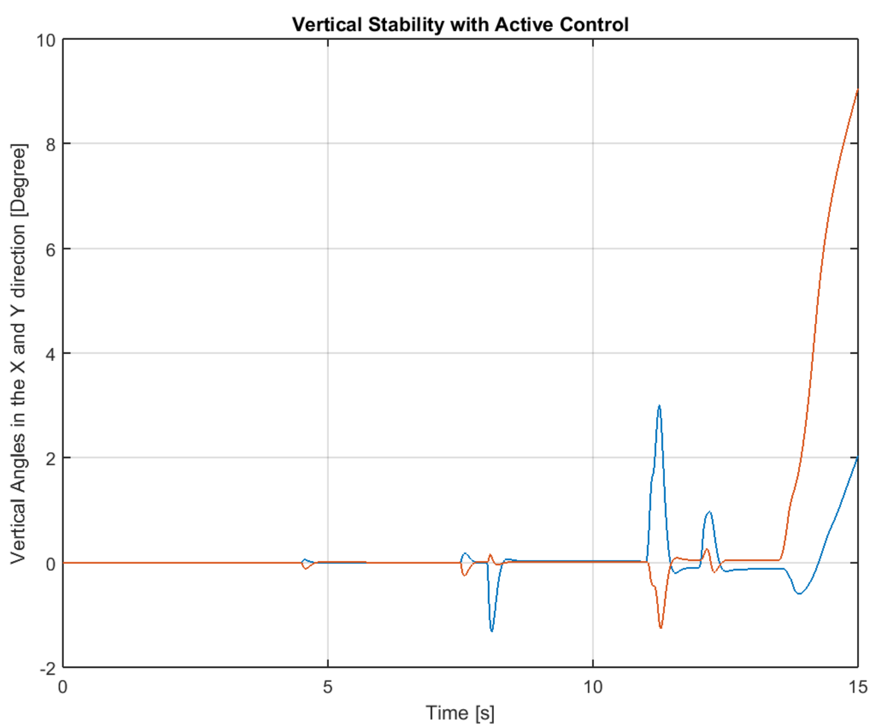

Figure 13. The angles off of vertical Z-axis of the nose.

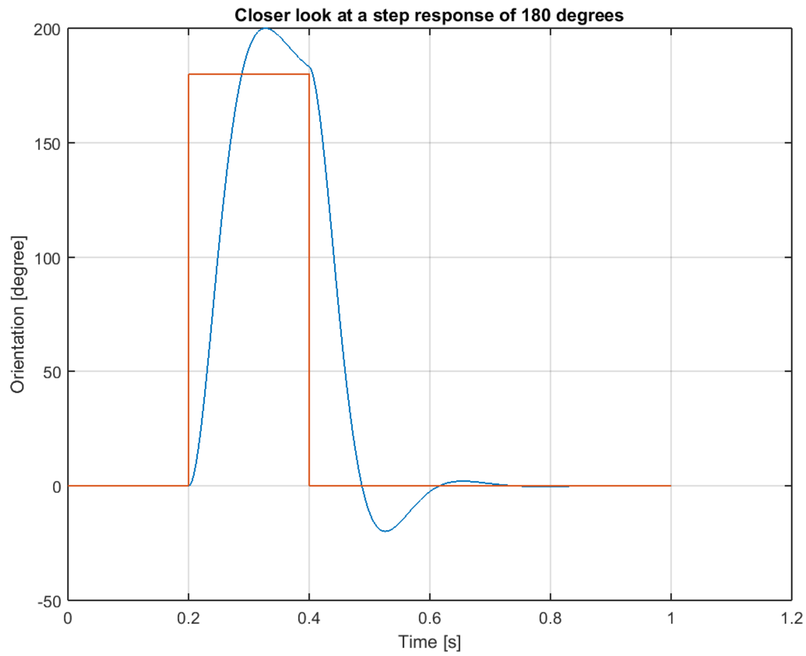

Figure 14 Step response of 180 degrees. Settling time .3 sec. Overshoot 11%

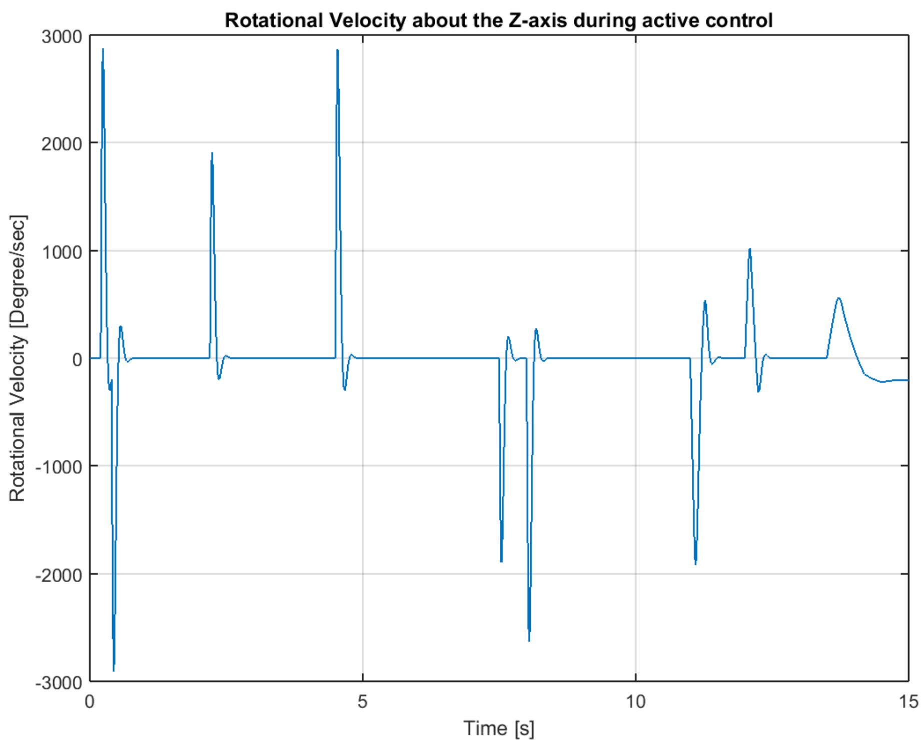

Figure 15. Rotational velocity of the rocket about the vertical Z-axis. The large spikes are due to the simulation assuming that the fins can be snapped to

Another concern that was addressed is limiting the maximum angle of attack of the fins. One of the reasons for this is that the coefficient of lift and drag have a linear region of ±10 degrees. The second reason is that the system can hit a catastrophic failure if the angle of attack approaches 90 degrees. The plant of the system included this limit of ±10 degrees. The control effort with the limitation can be seen below in Figure 13.

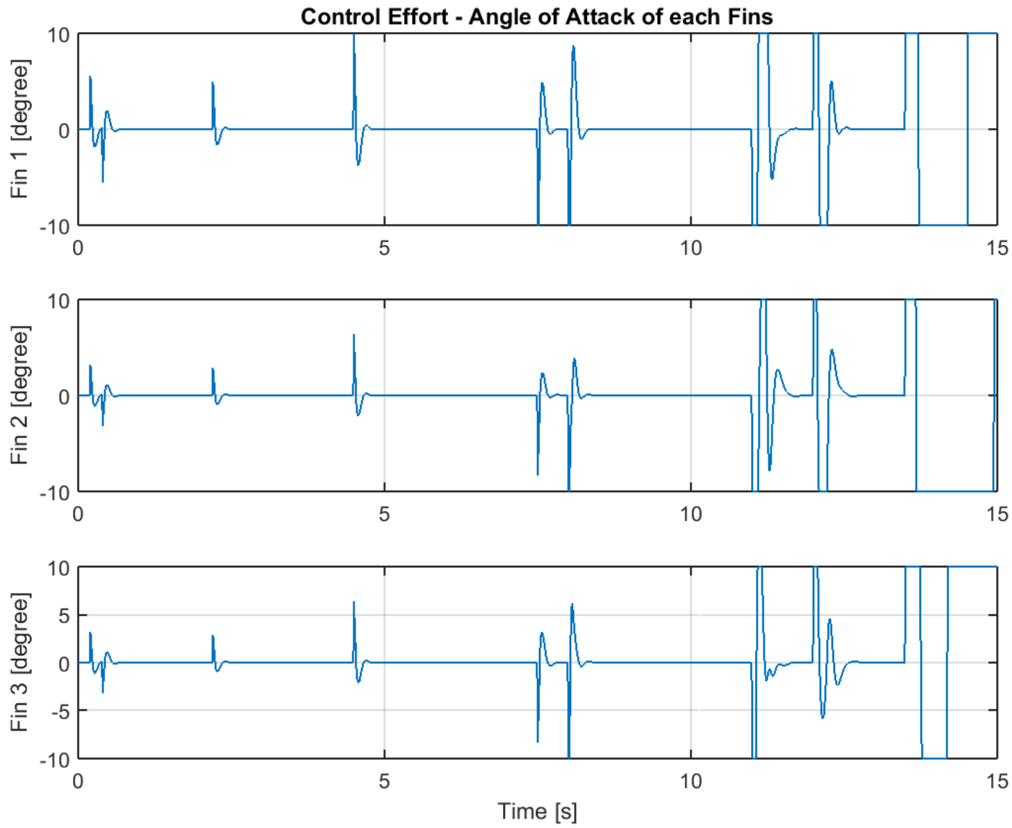

Figure 16. The output of the control system. The control effort is the angle of attack that the fins need to be moved to.

The last thing to note is the loss of stability in the last two seconds of the simulation This shows that the system will not be able to maintain control for the velocities under 20 m/s.

Recovery System and Descent Phase Analysis

The recovery system consists of a 46 in. drogue parachute and a six foot main parachute. A PerfectFlite Stratologger deploys a 3g black powder charge at apogee. The motor provides a 2g backup charge in the event that the primary charge fails to separate the rocket. After descending on drogue to 400 ft. a Jolly Logic chute release will release the main parachute. This slows the rocket to a ground hit velocity of 21 ft/s.

Pre- & Post-Launch Procedure Assessment

The pre-launch procedure begins with zeroing the fins. This involves setting the servos to their zero position, and then manually adjusting the servo horns and tuning the length of the control rods until the fins are vertical. Additionally, if it is necessary we can set servo offsets in the control code to assist in zeroing.

The next step is assembling the airframe. This involves sliding the fin assembly onto the motor tube and thrust ring assembly while feeding the servo wires through the cut slots in the fiberglass centering ring. Then, the servo wires are connected to the extension wires that run the length of the body to the AV bay's bulkhead. Then, that whole assembly is carefully slotted into the back of the rocket and the motor tube and thrust ring assembly is bolted to the body. The wooden centering rings attached to the bottom of the fin assembly are screwed into the body tube wall as well.

Next, the parachutes are packed in Nomex and we check to make sure that all linkage points of the shock cord are secure. Then, the packed parachutes and the primary ejection charge are inserted into the upper section of the body tube. Then, the extended servo wires are plugged into the wires that penetrate the bulkhead and the ejection charge wires are attached to terminal blocks which lead to wires that also penetrate the bulkhead. Then, the electronics sled is assembled, programmed with the first set of requirements, and secured into the nose cone shoulder. The servo and ejection charge wires are connected to the servo controllers and StratoLogger respectively, and the bulkhead is bolted to nose cone.

Then, we insert the nose cone and run a full system test of the control system. Once the test is satisfied, the nose cone is secured with a sheer pin and the Aerotech J800 is assembled for flight. Then the rocket is ready to go to the pad. Once on the launch pad a button inside the switch band is pressed to activate the StratoLogger, and when the StratoLogger's boot sequence is complete the rocket is ready for flight one.

The post-flight procedure begins with recovery. The onboard tracker will assist in locating where the rocket landed. Then, a picture will be taken to document how the rocket was found. Then, the rocket will be brought back to our work station and repaired if necessary. At the same time the electronics sled will be removed and the data from the onboard SD card will be collected. Then the control code will be updated for the second flight with the new requirements. Once the reprogramming and repairs are completed, the airframe is reassembled, repacked, and the next motor assembled and loaded. Then Mr. Rodgers is ready for round two.

Test Launch Actual vs Predicted Performance

Two test launches have been completed. The goal of the first test launch was to test construction and implementation of the active control surfaces. The second launch was to gather data to preform system identification. However no usable sensor data was recovered from either launch.

Test flight one was launched and recovered however the rocket landed in a small pond near the launch site. This caused several electrical components to fail and the SD card to become corrupted. The second test flight did work however the StratoLogger failed midflight for unknown reasons, we due suspect that it’s age and was a factor. The SD card was recovered, however when inserted to retrieve the data the system wiped the card and all sensor data.

Figure 17 Video of test launch of test rocket.


Figure 18 Video of test launch of Mr. Rodgers

Peak Altitude Comparison to Expectations

Due to a lack of recorded date we cannot perform a comparison

Peak Velocity and Peak Acceleration Comparison to Expectations

Due to a lack of recorded date we cannot perform a comparison

Recovery System Performance and Descent Velocity

The recovery system performed exactly as expected. The StratoLogger deployed the 2.5g ejection charge at apogee releasing the 46in drogue. This allowed the rocket to descend at a rate of 35ft/s until 400ft. Then the chute release deployed the 6ft main which slowed the rocket down to 21ft/s.

Video Results vs Data Logging of Rocket Orientation Angle

Due to a lack of recorded date we cannot perform a comparison.

Findings and Future Work

Key Findings

Some of the key findings we discovered throughout this project is the importance of maintainability. Being able to easily access the sensitive components of the rocket is paramount when those components need to be repaired or replaced. Another key finding is reducing complexity. The control system is very complex and a lot of effort was needed to verify and validate the control code. When there was a bug in the system it almost always took several hours to correct.

Potential Design Improvements

The design could be improved my moving the servos further up the rocket. This would push the center of mass forward and increase static stability. The design could also be improved to use more modern servos. Replacement servos were expensive and hard to find because we designed the fin-can around outdated servos we already had on hand.

Budget

The budget has changed a lot since the PDR was written. First, all of the required electronic components were priced out. This also required replacing all of our sensors that we had initially. The airframe was also changed to a 5 in airframe, which had to be purchased.

Name	Quantity	Unit Price	Total Price
Teensy 3.6	1	$36.88	$36.88
Xbee Pro 60mW Module	2	$32.00	$64.00
Xbee Pro 60mW Connection	1	$24.95	$24.95
SparkFun 9DoF Sensor Stick	1	$14.95	$14.95
Adafruit MPL3115A2 BAROMETER SENSE BOARD	1	$9.95	$9.95
DC-DC converter	4	$9.95	$39.80
5V Regulator	3	$0.45	$1.35
Female headers for teensy	5	$1.37	$6.85
Female headers for 9DoF	5	$0.45	$2.25
Female headers for XBee	5	$0.65	$3.25
Female headers for Altimiter	5	$0.61	$3.05
Male headers (50 pin)	1	$3.11	$3.11
Standoff for 9DoF and board	8	$0.72	$5.76
Screws for standoff (M3 100 ct)	1	$5.94	$5.94
JFET	5	$0.52	$2.60
Communications Specialists Tracker	1	$50	$50.00
CTI J280	1	$71.25	$71.25
G-12 5.0	1	$180	$180.00
G12CT-5.0	3	$43.10	$129.30
FCBP5.0	3	$7	$21.00
FBP5.0	3	$7	$21.00
Aerotech Casing	1	$100	$100.00
J800-T	2	$94.99	$189.98
Fee for expensive motor	1	$100	$100.00
Bearings	10	$5.85	$58.50
Collars	10	$1.07	$10.70
D-shafts	2	$15.19	$30.38
Good Servos (estimation)	3	$50	$150.00
Travel	1	$600	$600.00
		Total	**$1,936.80**

Conclusion

In summary the Rocket is built and ready to fly physically, however there are areas for improvement, mainly the code and a real-world test of the control system. However, enough time and effort has been put toward the control system that has also been tested via software for possible failure cases, and extreme conditions that we feel confident in our ability to have a successful flight come competition day.