inVenTs High-Power Rocketry

Virginia Polytechnic Institute
and State University

Student Team Lead	Nicole Gouhin, ngouhin@vt.edu, (919) 444-4657
Faculty Advisor	Dr. Kevin Shinpaugh, kashin@vt.edu, (540) 231-1246
Tripoli Mentor	Dr. Pat Artis, hartis@vt.edu, (970) 731-3273
Student Team Mentors	Payleigh Behan, Aaron Brown, Nicolas Bulzoni, Jeremy Gross, Kyle Sakmyster, Sara Schlemmer, Caitlyn Stone, Riley Ulven
Team Members	Sean Buono, Nicolas Gutkowski, Casey Hall, Ian Harnett, Brody Northrop, Inga Schlier, Michael Snellings, Yen Truong, Nathan Wagner, Ryan Yankey

Wednesday, May 9, 2018

Table of Contents

Executive Summary

The objective of the NASA Space Grant Midwest Rocket Competition for the 2017-2018 academic year is to successfully launch and recover a single stage high-power rocket designed to fly on a J800 motor. The rocket will feature an aileron system to minimize roll during the first flight and meet certain roll angle orientations during the second flight. A series of commands will be performed through the use of an on-board data collection sensor package to send commands to the rocket during the second flight as well.

During the test launch on April 29, the rocket performed as expected with minor setbacks. Due to a wiring issue between the servo motor power source and the motors used to turn the ailerons, the aileron system did not actuate correctly, causing the ailerons to open and never retract. This caused the rocket to reach an altitude of approximately 2,100' as opposed to the predicted 3,100'. The Jolly Logic chute deployment method also failed, causing the main chute to open at apogee instead of 700' as originally set. This caused the rocket to land in a tree next to the launch site on the property of a United States Army ammunition plant. Due to the 30 hours it was stuck in the tree and the complex process of retrieving it, the top of the rocket was damaged as well as several of the aileron rods were bent. Since then, the aileron rods have been replaced, the rocket design has been modified to cut the top damage off the rocket, and simulations have been rerun with the intent of maximizing performance during the competition flight on May 20th. *Figure 1*, to the right, shows the completed inVenTs High Power Rocketry team rocket following repairs and modifications.

Budget

The inVenTs High Power Rocketry Team has currently spent $2,842 toward the design and construction of the rocket as well as initial trip costs. The remainder of the trip costs are estimated to cost roughly $2,000. Since the team is traveling from Virginia, roughly 3,000 miles roundtrip, the largest remaining trip cost is expected to be the cost of gas. Both the initial and remaining trip costs are detailed in *Figures 2* and *3* below.

Estimated Expenses and Spendings

Component	Cost		Date
Subteam Supplies	$	293.85	17-Oct
Registration Fee	$	400.00	2/2/18
Nose Cose, Rail Buttons	$	75.48	2/12/18
Coupler Tube	$	73.90	2/15/18
all-thread, nuts, steel rods, plastic clips	$	12.53	2/18/18
PowerBoost 1000 Charger	$	34.27	3/3/18
1/4" 2' x 2' Oak Wood	$	6.59	3/6/18
3 eye screws	$	2.15	3/18/18
epoxy, threaded rods, nuts	$	19.38	3/16/18
Mechanical Parts	$	48.41	3/17/18
XBee Pro 60mW Wire Antenna	$	47.53	3/15/18
Batteries	$	14.92	3/27/18
Tops, Shock Cord	$	18.94	3/27/18
Mechancial Parts	$	11.94	3/25/18
Mechanical Parts	$	25.44	3/26/18
Tenergy 6V-9V Battery Pack Charger	$	17.99	4/4/18
North Branch Hotel - Rodeway Inn	$	1,443.19	4/5/18
X	$	24.51	4/6/18
Tenergy 2000mAh 6V NiMH Battery Pack	$	21.98	4/6/18
Outreach Activity Materials	$	15.61	4/6/18
Wood and Epoxy	$	12.13	4/10/18
Outreach	$	4.93	4/11/18
Screw Posts, Zip Ties	$	5.06	4/23/18
Jolly Logic, grease	$	161.50	4/25/18
Random Parts	$	12.19	4/24/18
Servo Screws	$	8.99	5/2/18
Electrical Connectors	$	12.89	5/8/18
Mechanical Connectors	$	15.32	5/6/18
Total	**2841.62**		

Figure 2: Up to date expenses

Item	Cost
Gas	$ 1,000.00
Tolls	$ 200.00
Hotels (Wednesday)	$ 148.73
Hotels (Thursday)	$ 164.97
Hotels (Tuesday)	$ 151.26
Emergency Parts	$ 300.00
Total	**$ 1,964.96**

Figure 3: Estimated Remaining Expenses

SUMMARY OF ROCKET DESIGN

The following sections present a brief review of the rocket designed by the inVenTs High Power Rocketry Team.

Aileron Design

Three 2"x4" ailerons control the roll of the rocket. Each aileron is connected with an 1/8" steel rod to a servo motor, and the rotation of the servo motors is translated to the ailerons. Each aileron is epoxied to and rotates about a 3/16" steel shaft. One bearing on the fin and one on the inner surface of the body tube hold each steel shaft in place. Each of the servo motors are mounted with metal servo mounts to a wooden bulkhead located above the rocket motor. A 6 volt battery to power the servo motors and a servo driver are also mounted to the bulkhead. The aileron system is designed to be easily adjusted and replaceable in the event of a component failure. A cut in the rocket just above the servo motors allows easy access, and the lowest centering ring is removable so that the bearings can be replaced. There is a spacer for each aileron, and when removed, the ailerons slide out and can be replaced. *Figure 4* shows the aileron system undergoing static testing in the inVenTs lab.

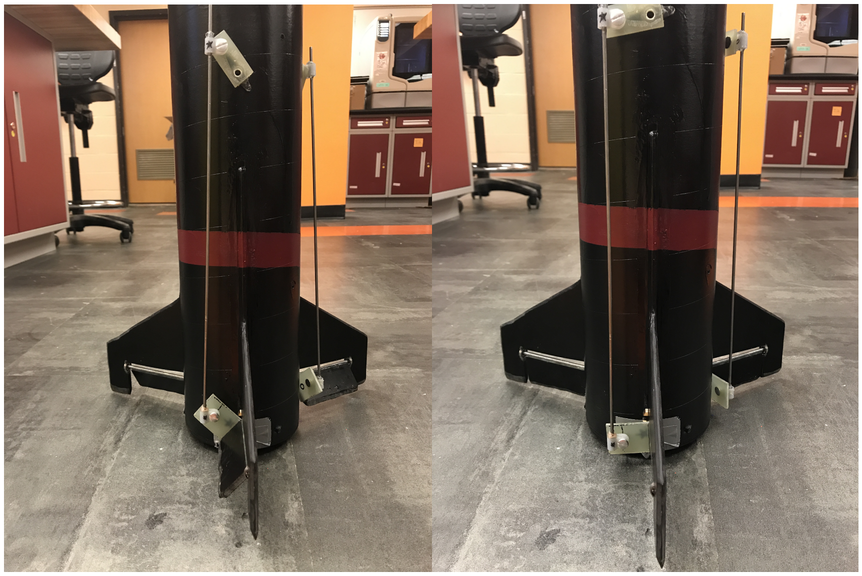

Figure 4: The ailerons being tested in the design lab.

Construction Techniques

The body of the rocket is comprised of blue tube with fins made out of 1/4" G10 fiberglass and a plastic nose cone. A design was etched on the fins with a laser cutter and then carefully cut out with a bandsaw, appropriate safety measures were taken each time to ensure bluetube and G10 fiberglass particles were not inhaled. Once the fins were cut out, the aileron rectangles were measured and cut out using the same techniques used to cut the fins. A dremel tool was then used to create an airfoil shape on the fins, as shown in *Figure 5*. From there, holes were drilled in the rocket body and G10 fiberglass attachments were made in order to attach the aileron rods to the connector pieces shown in *Figure 4* above. The base of the avionics bay is a sheet of 1/4" G10 fiberglass epoxied to two wooden bulkheads. It is designed to easily slide in and out of the coupler tube in the middle section of the rocket with minimal effort. All bulkheads and centering rings were cut out using a laser cutter and sanded down to fit within the rocket body tube.

Figure 5: Team members use a dremel to create the airfoil on the fins.

Stability Analysis

To allow for the rocket to properly turn along a specific axis, a control loop was implemented to increase and decrease the overall amount of rotation that the system experiences during flight.

Constructed for Safe Flight & Recovery

The rocket was constructed so the team could safely recover it in flyable condition. Although the original plan was to use a dual-deployment method with black powder charges to deploy the main chute out of the nose cone and the drogue chute out of the lower section, it was later decided that it would be optimal to use a Jolly Logic for chute deployment instead. When this change was made, the lower section was screwed into to the coupler tube for added support, hooks were screwed into the top of the avionics bay, and black powders charges were used to blow the parachutes out of the top section under the nose cone. The parachutes were deploy at apogee with the main chute opening at 700’ via the Jolly Logic.

Avionics Bay Design

The avionics bay has a simple to use, yet durable design. Two epoxied 1/8” pieces of G10 fiberglass serve as the base for the electrical equipment in order to allow for greater forces during ascent. The top and bottom of the G10 fiberglass plate is epoxied onto two wooden bulkheads, each with eye-hooks to connect the parachutes and shock cord and blast caps for black powder charges. Four pieces of threaded rod support the avionics bay and secure the bulkheads in place. This design is easy to slide in and out of the rocket as well as provide a secure fit once screwed into the coupler tube during launch. The batteries, Arduino, and XBee Radio Components are zip tied onto the G10 fiberglass board for easy access and secure placement.

Discussion of Changes Since Preliminary Design Report

The parachute deployment was changed from a dual deploy to a single deploy system using a Jolly Logic chute release. Since wires needed to be run from the electronics bay down to the servo motors, located above the rocket motor, it was easier to use a single deploy system with a cut above the electronics bay instead of using breakaway wires between the upper and lower sections. The original data logging method was also changed from a BeagleBone to an Arduino. Initially, there was not a secure way to hold the battery used to power the servo motor in place during launch. A bulkhead has since been added to the lower section to eliminate the chances of the battery shifting during launch. Four small screws through the outer body of the rocket hold the bulkhead in place while allowing for it to be easily removed.

ROCKET OPERATION ASSESSMENT

The following sections detail the analysis and assessment of the test launch of the rocket on April 29, 2018.

Launch and Boost Phase Analysis

Upon ignition of the J800T motor, the rocket is propelled upward with a maximum acceleration of 517.78 ft/s, given by the flight characteristics of the motor.. The rocket clears the launch rod at approximately t+0.25 seconds, as noted in the flight video, reaching a maximum velocity of 560.0 ft/s. Stability at launch is 1.59 cal. The motor was estimated to have burned out at t+1.6 seconds.

Coast Phase Analysis

The rocket coasted from t+1.6 seconds to approximately t+13.65 seconds, reaching an apogee of 2,210 ft. During this time, maneuvers with the active roll control were performed. Aileron deployment time requirements were calculated using a Mathematica function that takes maneuver start time, aileron deployment angle, and desired roll angle as inputs, calculates the forces on the ailerons based on the upward velocity of the rocket, and outputs the time the ailerons need to be deployed to attain the desired roll angle.

Recovery System and Descent Phase Analysis

A 36” drogue parachute is deployed via gunpowder ejection charge at apogee. The 84” main parachute also exits the rocket body with this charge but is kept folded by a Jolly Logic parachute release until the rocket descends to 700 ft above ground level (AGL). During descent, due to an issue with the Jolly Logic, the main parachute deployed at apogee instead of at 700’ AGL. The early deployment of the main parachute caused the rocket to drift farther than anticipated due to lower descent velocities.

Pre- & Post-Launch Procedure Assessment

The pre and post launched procedures have not drastically changed since the Preliminary Design Report. With the addition of a Jolly Logic to the recovery system, parachute packing procedures were updated to reflect the use of the Jolly Logic chute deployment method. Post-Flight Procedure 5.a.ii was updated to reflect a more logical course of action.

Pre-Launch Procedure

1. Pack and secure parachute and drogue chute as follows:
   Parachute Packing Procedure
   a. Unhook parachutes from shock cord (if applicable)
   b. Untangle shroud lines
   c. Sling/Run with parachutes to evenly open the chute before folding
   d. On a flat surface, with one person holding the shroud lines firmly, a second person extends the upper part of the parachute by gently tugging on the outside center of the parachute, extending the parachute to a semicircle as flat and spread out as possible. Overall length of the folded parachute will be determined by the widest portion of the semicircle.
   e. Once the chute panels have been aligned, apply baby powder to aid in the prevention of the fabric sticking together from moisture.
   f. Starting from the base of the parachute, roll in part of the shock cord into the parachute
      i. This is to help in chute deployment
   g. Tightly roll the parachute, applying additional baby powder as needed, to achieve the desired thickness of the chute roll to ensure fit into the rocket airframe
   h. Place it on top of the blast shield and secure the Jolly Logic
   i. Carefully insert it into the top section of the rocket
   j. Insert Shear Pins
   k. Do a second ground test
2. Ensure the electronics are activated and are secure in the rocket
   a. Turn on and test tracking beacon
   b. Set delay
   c. Turn on and secure both competition altimeters

    d. Turn on and secure camera
    e. Download the flight program to the microcontroller, ensuring everything is connected and working properly
    f. Secure the microcontroller system
3. Ensure mechanical's motor bearings need to be tightened
    a. Do not overtighten; ensure flaps open and close quickly
4. Test mechanical system for functionality
5. Test security of the motor in the rocket
6. Verify that the correct amount of black powder is in the ejection canisters
    a. 5.0 g for upper section
    b. 5.0 g for lower section
7. Verify mechanical fin system is functional
8. Place flame resistant wadding (dog barf) to separate the ejection charge devices from the payload components in the rocket subsections
9. Inspect fin connections for damage.
    a. Repair if needed with JB Kwik Weld
10. Verify that nose cone is secured to top of rocket, using shear pins if needed
11. Verify that all sections of the rocket are properly connected, aligned and secured
12. Verify correct motor has been installed properly into the rocket
13. Have the Range Safety Officer (RSO), inspect and approve the rocket for flight
14. Mount rocket on launchpad
15. Activate microcontroller
16. Ensure transmitter is activated
17. Arm the recovery devices
18. Toggle electrical systems on with key switches for ignition
19. Launch

Post-Launch Procedure

1. Wait for RSO to declare the area clear
2. Recover rocket using tracking beacon, if needed
3. Ensure all components were recovered
4. Take photo and video of the landing site
5. Examine the rocket for possible damage
    a. Determine if Repair is viable if the rocket is damaged
        i. If Yes: proceed with repairs
        ii. If No: ascertain the extent of the damage and document what components of the rocket failed/broke for reference for future teams
6. Download video from camera
7. Download flight data from microcontroller
8. Deactivate camera, microcontroller, and beacon

9. If rocket is in flyable condition, prepare for next flight
    a. Repeat *Pre-Launch Procedure* for subsequent flight

TEST LAUNCH ACTUAL VS PREDICTED PERFORMANCE

The following sections detail what actually occurred during flight versus what was expected of the flight from OpenRocket simulations.

Peak Altitude Comparison to Expectations

Based off of simulations, the rocket was expected to reach around 3,100'. The dual altimeter system registered apogee at 2,166' and 2,168'. This result was expected as the rocket did not travel vertically due to one aileron not being set to zero degrees at time of launch and wind present at the time of launch. The rocket, instead, pitched off to one direction. As a result, more of the energy from the motor was directed in a horizontal direction, as opposed to vertical. Examining the code after launch, there was no clear explanation as to why the aileron was not set to zero degrees. There is a high probability that something was accidently pushed out of place when setting it up on the launch pad. Extreme care will be taken in the future to ensure this same mistake is not repeated in future launches. *Figure 6*, below, shows the simulated altitude of the rocket compared to the actual recorded altitude of the rocket.

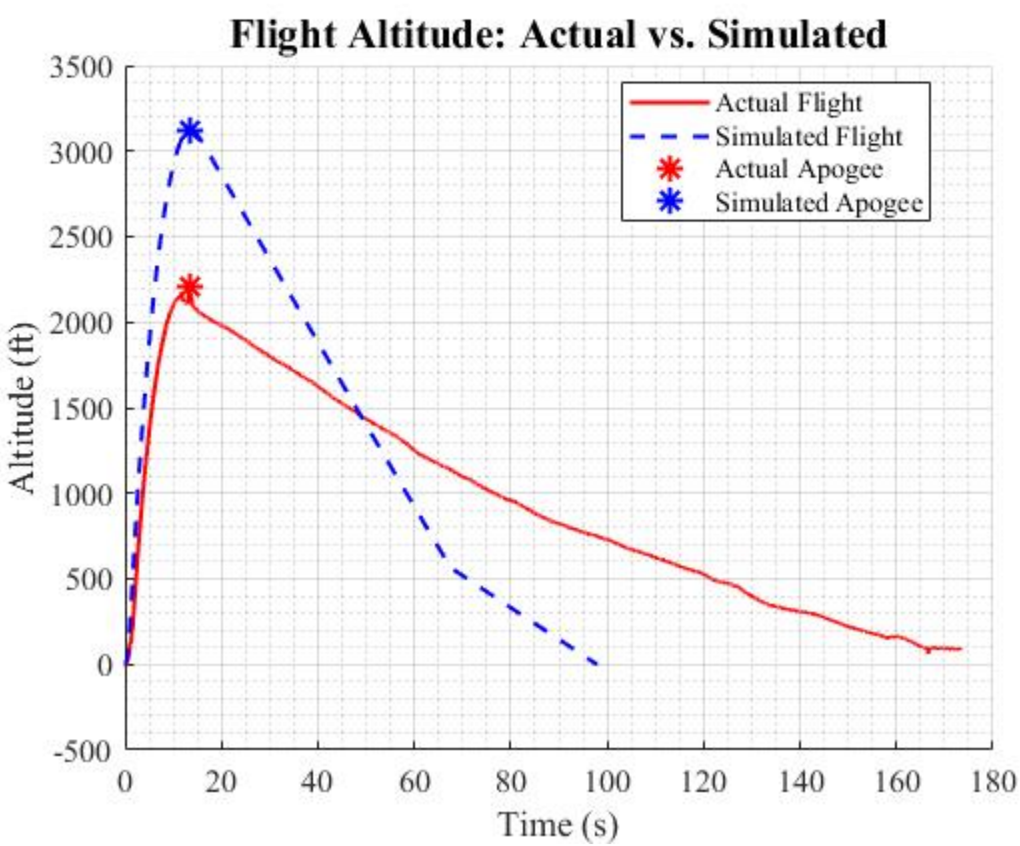

Figure 6: Comparison of the recorded flight altitude data and the simulated altitude data from OpenRocket.

Peak Velocity and Peak Acceleration Comparison to Expectations

Velocity performance of the rocket was within expectations of the flight simulation. Maximum actual flight velocity was calculated to be approximately 560.0 ft/s whereas simulated max velocity was noted to be at 511.5 ft/s, per the simulation data in OpenRocket. Primarily, recorded flight velocity follows the same general trend as that of the simulation. The primary exception being in the noted velocity spikes. This can be explained as possible lapses in the altimeter used in flight logging. Total velocity performance is given below in *Figure 7*.

Actual flight acceleration data was not obtained due to a limitation of the altimeters used in the system.

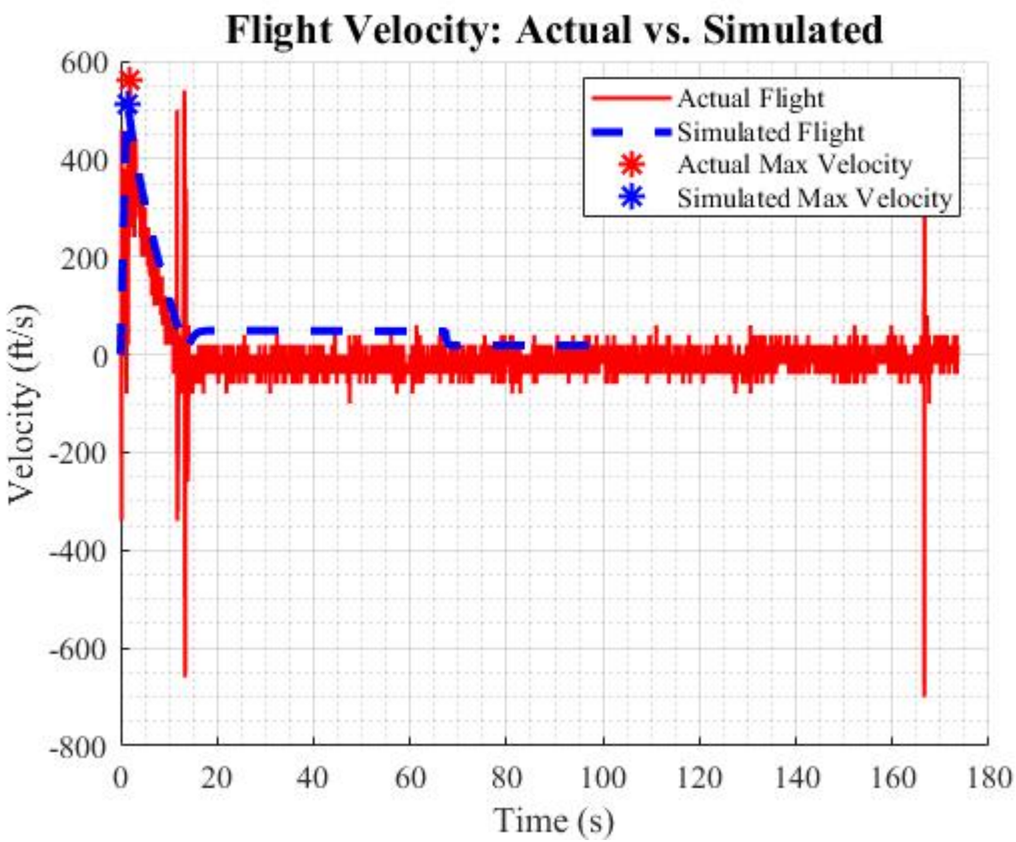

Figure 7: Comparison of the recorded flight velocity data and the simulated velocity data from OpenRocket.

Recovery System Performance Comparison to Expectations

The black powder charges split the rocket at the expected height and the drouge and main chute both ejected properly. However, the Jolly Logic misfired and released the main chute just after apogee, which made the rocket drift nearly a mile away into an army ammunition plant. Based on a comparison of the velocity data made in *Figure 7* is estimated to be approximately the same as was noted in simulations during descent.

Video Results vs Data Logging of Rocket Orientation Angle

While the team did not have any data logging to capture the results of our rolling or orientation during flight, analysis of the video, as documented in *Figure 8*, allowed for determination of whether or not the program worked as intended. Examining the footage, one of the ailerons appears to have been at an angle from the beginning, which caused the rocket to pitch after leaving the launch rail. The ailerons appear to move out to the angle to start rolling, but there is no evidence that they returned to zero degrees or changed to be the opposite angle in order to counter the roll of the rocket. After further inspection, the counter roll was disabled due to a power disconnection from the power supply in the bottom of the rocket.

Figure 8: Video footage screenshots from the launch showing ascent, turning, and apogee.

Performance and Comparison to Expectations

Based off our simulations, the code was written to start rolling the rocket ten seconds after launch. At this time, the angle for the ailerons would be set to 30 degrees for 0.78 seconds to roll the rocket clockwise. Afterwards, the angle would be set back to zero degrees, then changed to -30 degrees for 0.78 seconds to counteract the roll initiated earlier. In addition to the roll control code, there were three LEDs, which indicated different conditions. One LED would light after launch is detected. Another LED would be lit while the rocket is rolling clockwise. The third LED would be lit while the rocket is rolling counterclockwise.

The plan is to fix the implementation of the control system that was destroyed before the launch. The system will now be implemented using a Arduino Due A000062. The overall control logic is the same as before. When there is an initial state (no rotation), the rocket will go to whichever way that is set based on the equation.

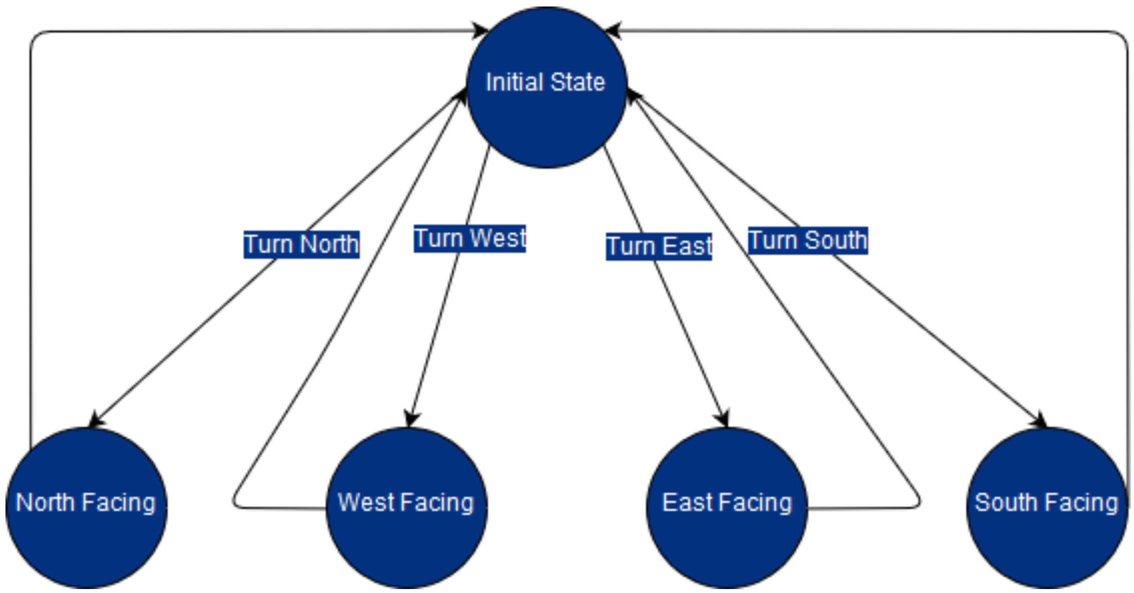

Figure 9: Flow chart outlining the logic behind the operation of the aileron system.

FINDINGS AND FUTURE WORK

The following sections outline the findings from the test launch and the future work the team will need to undertake prior to launch later in May.

Key Findings

During the test launch, three major design issues were encountered. During the launch, the drogue deployed at apogee as it was supposed to, but the main chute also opened at apogee instead of at 700'. This caused the rocket to drift across the river and land in a tree on the property of the Radford Army Ammunition Plant, owned by the US Army. Due to it being on a military property, the team was unable to recover the rocket for over 30 hours. However, when it was recovered, it was in fairly good condition. When it was recovered, the battery in the lower section used to power the servo motors had become detached and several of the aileron rods were bent. There is some uncertainty as to whether this was from the actual launch, the result of it hitting the tree, or the process of removing it from the military base. Because of the uncertainty, it was deemed best to assume the damages happened during the flight so that future launches can have the best possible chance at optimal success.

Potential Design Improvements

In accordance with the above findings, measures have been taken to ensure that the Jolly Logic chute release performs as expected for subsequent flights. It was likely user error which caused the chutes to open at apogee during the test launch as opposed to 700' All team members will fully understand how to set the Jolly Logic and parachutes up in the future so that this error is not repeated. As mentioned above, a lower section bulkhead has also been added to ensure that the battery attached to the servo motors stays firmly in place. New ailerons rods have also been constructed as well as a backup set of rods in case the first set bends during the first flight. As a result of the servo battery detaching during flight, the ailerons did not perform as they were expected and stayed open the entire flight. This caused the rocket to lose roughly 1,000'. When the rocket hit the tree, there was some damage to the top section. To counteract this, the top two inches of the rocket was cut off, also adding expected height to the rocket during future launches. The ailerons will be tested extensively in the coming weeks to ensure they are performing as expected. Unfortunately, the LED code was not working in time for the test launch so prior to the competition launch, a new code will be written to ensure the most accurate roll control data from the flight can be obtained.

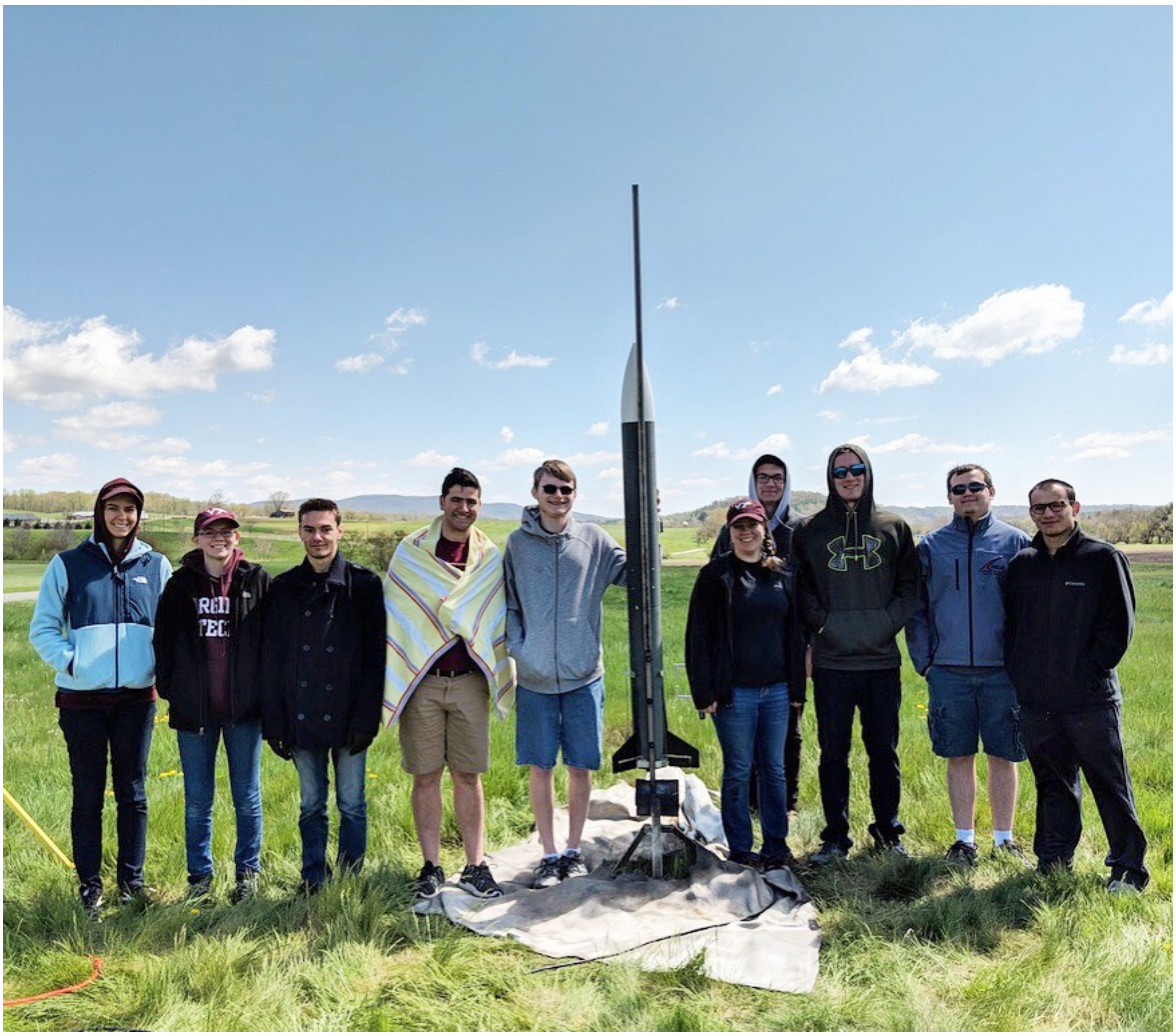

Figure 10: The team assembled before the test launch..