Pioneer Rocketry

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Midwest Rocket Launch Competition

2015 – 2016

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Introduction

The Midwest High-Power Rocket Competition required a great deal of work and dedication from the Pioneer Rocketry team to design, build, and test the rocket Skybreaker. It was an incredible learning experience for everyone involved, and we were honored to be able to compete at this competition. The countless hours spent designing the systems of Skybreaker, the seven test flights that incrementally tested various aspects of the competition, and the hard work and dedication of the team paid off at the competition where the rocket flew three times before noon.

Rocket Operation Assessment

In-Flight Recovery System Analysis

The only significant flight anomaly occurred when the shock cord broke during the first flight. Although the upper section of the rocket did fall freely until the main parachute deployed, the flight was still considered a success because both sections landed on a parachute and were recovered with no damage.

At apogee the 1500lb kevlar shock cord snapped in half at the point where the parachute attaches. After examining the video, the ejection event did not happen significantly after apogee. This means that the force on the shock cord should have been well below the 1500lb breaking point of the cord. Thus, the most logical conclusion would be that the Kevlar was weakened from the knot in the cord and fatigued by multiple test flights. To help minimize this in the second and third launches, the new shock cord was folded and wrapped in masking tape at several places. To fully extend, the cord would have to tear through the tape minimizing the shock on the cord.

Either the new cord was less damaged from repeated use, or the masking tape shock mitigation system worked because the shock cord was undamaged during the second and third flight both of which had flawless duel deployment. In the future, an elastic shock mitigation system will be used to help reduce the shock experienced by the cord.

Propulsion System Assessment

The K2045 performed perfectly, and the properties of the Vmax motor provided several benefits toward the success of the flight. The short burn time allowed the Airbrake system to deploy earlier, and the high velocity increased the efficiency of the brakes. There were no significant anomalies when the rocket launched, and the motor performed as expected.

Flight Path Assessment

The flight path of the rocket was remarkably straight. Thanks to the Vmax motor the rocket has a high velocity off the rail so the effects of wind are minimized. Also do to the short burn time there wasn't much of an opportunity for the rocket to propel itself sideways after turning into the wind. All three flights the rocket flew very straight with only minor weather cocking.

Rocket Location and Ground Recovery

Skybreaker was designed from the ground up for a quick and easy recovery. Standing 7ft tall the rocket tall and would be easily spotted when landed. The recovery system was also tailored to a quick recovery. The drogue parachute chosen was 24in in diameter as this ensured a quick descent and minimal drift. The main parachute was also minimal as it measured only 60in in diameter. The rocket was built to be tough to handle the increased landing force. This methodology paid off as the rocket never drifted more than 1000ft. Recovery was also aided by the good visibility at the launch site where a landed rocket can be easily spotted from thousands of feet away.

Pre and Post Launch Procedure

The pre and post flight procedure checklist was followed before and after all launches and it worked exceptionally well. This was extremely helpful especially between launches when the team was rushing to get the rocket ready. It was placed on a smartphone to allow for easy access. This method was far superior to a clipboard. Unfortunately, the team was still required to fill out a physical copy for the post flight review of the rocket. While this did not cause any real issues, it was frustrating. This method was used on all three launches and there were no issues with this method during any of them.

Data Collection

Drag System Report

The Airbrakes opened at 353 feet instead of the goal of 240 feet. This was caused by the method used to determine the burnout event. This method was overly cautious to ensure that the airbrakes did not deploy while the motor was still burning. While the delay was only 0.149 seconds long, the rocket was still moving fast enough to travel close to 100 feet in this time.

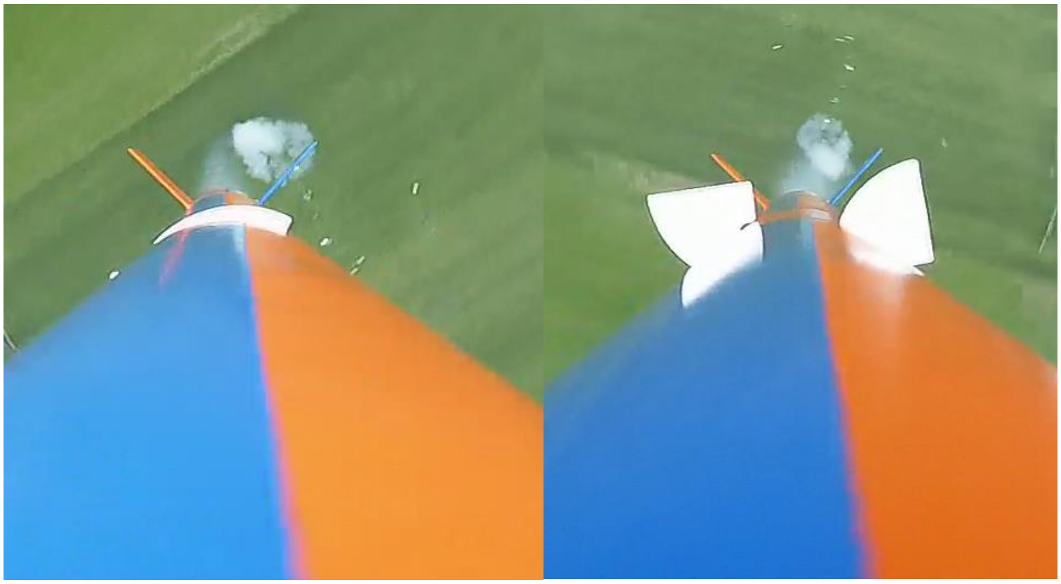


Figure 1 has two images of the airbrakes being deployed. The image on the left is when the air brakes first begin to deploy. The image on the right shows the airbrakes fully deployed.

The rocket was designed with the potential for a late air brake deployment, and the airbrakes had the potential to reduce the flight by more than the 25% required by the competition. Combined with the flight predication software, the rocket was able to actively control the air brakes throughout flight to reach the desired apogee.

In order to prevent over braking, the coefficient of drag for the non-braked flight was set slightly higher than that of the actual rocket. This meant that the airbrakes closed for short periods of time throughout the flight. The rocket then would have a higher velocity over time than anticipated, and the airbrakes would once again reopen.

Figure 2 shows a flutter in the airbrakes. At several points of the flight, the airbrakes began to close only to quickly open again. The images above show the most significant of these events. The image on the left is when the airbrakes are being held open. The middle image shows the airbrakes at their most retracted state. The image on the right shows the airbrakes once they were fully reopened.

Unfortunately, the airbrakes did close prematurely at 2590 feet. This occurred because the velocity read by the pitot tube appeared to be too granular. This occurred because there was not enough resolution on our analog to digital converter reading in the pressure from the pitot tube. In future flights, two pressure sensors will likely be utilized to remedy this problem. One sensor will be used at low velocities and the other will be used at higher velocities. This should prevent a similar error from happening. Since this system was not implemented in the competition launch, the velocity read by the pitot tube jumped from 0 fps to 133 fps and back. There were no intermediate readings. Thus the brakes closed too early and could not make any fine adjustments for the last 257 feet or 4.66 seconds before apogee. Thus the rocket flew to 2847 feet instead of 2734, and the air brakes only had a 22% reduction.

Furthermore, all of the readings from the flight were recorded to an SD card. These readings included the time in seconds since the last recording, the raw displacement, velocity, and acceleration values, the displacement, velocity, and acceleration data modified by the Kalman filter, and the percentage that the airbrakes were set to. All of these were used to analyze the flight.

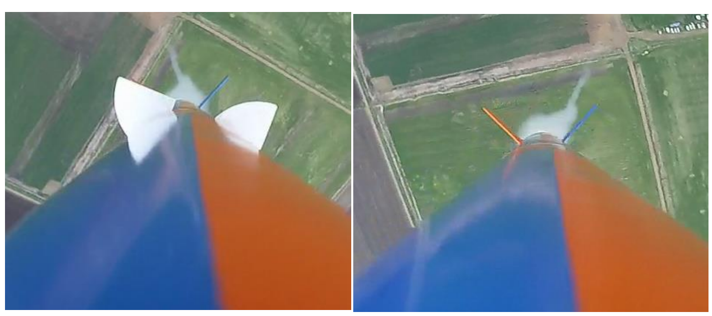


Figure 3 shows the airbrakes retracting before apogee. This occurred 8.779 seconds after liftoff. The image on the left shows the air brakes beginning to close, and the image on the right shows the airbrakes fully retracted well before apogee.

It is interesting to compare the values read from the Jolly Logic against the accelerometer, Stratologger, and pitot tube for the benchmark and the scoring air brake flight. The top speed has a difference of 34 fps. Considering the granularity of the pitot tube readings, this is surprisingly close. Similarly, the apogee has a difference of 6 feet and the coast to apogee time has a difference of .1 second. The thrust time recorded by the Jolly Logic is noticeable shorter than what was recorded by the Stratologger. This is likely caused by a delay in the Jolly Logic's recording of the rocket's launch.

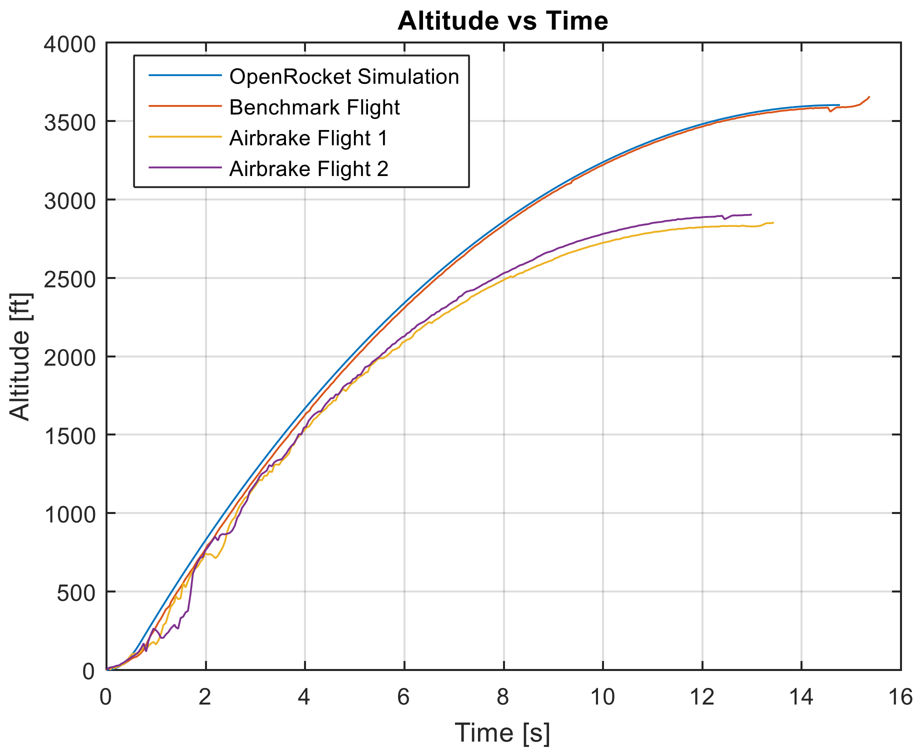
The accelerometer is the most problematic sensor. It appears as though it was unable to completely initialize. This means that the accelerometer would have provided acceleration data based on the boards axis instead of using the chips absolute orientation abilities. If this were the case, other axes would have spikes in acceleration at the time of liftoff. Once all three accelerometer readings where compared, the highest acceleration was found to be 97.9 ft/sec^2. Still this is much smaller than the 753 ft/sec^2 recorded by the Jolly Logic. It appears as though the accelerometer was fully saturated and could not read the high acceleration seen during a rocket launch. Because of this, the acceleration measured by the Jolly Logic would appear to be the more accurate of the two at accelerations exceeding 2Gs.

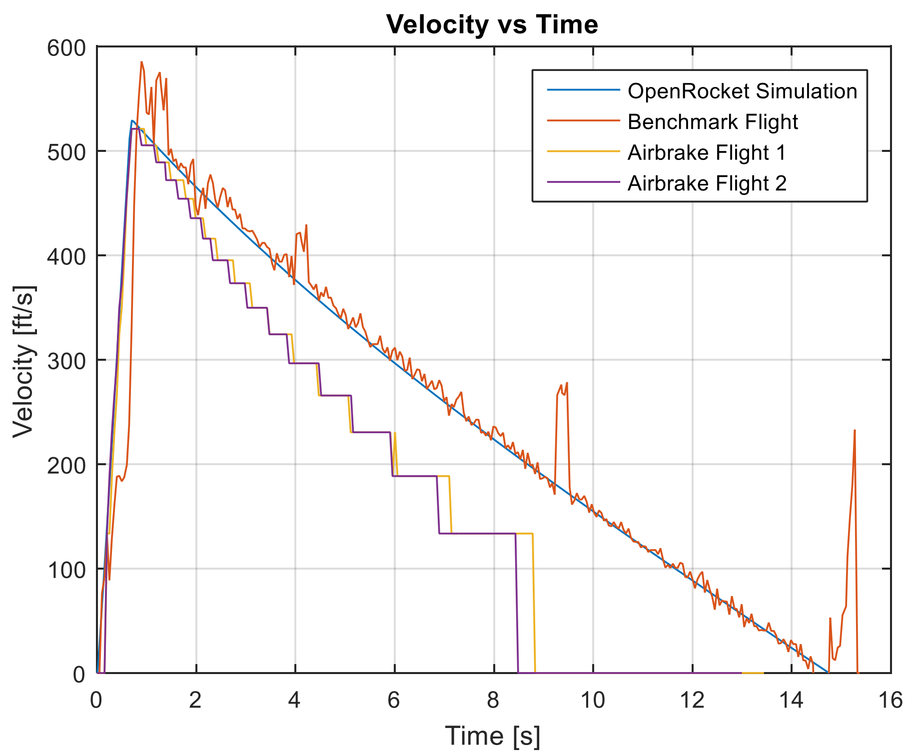
Table of flight characteristics

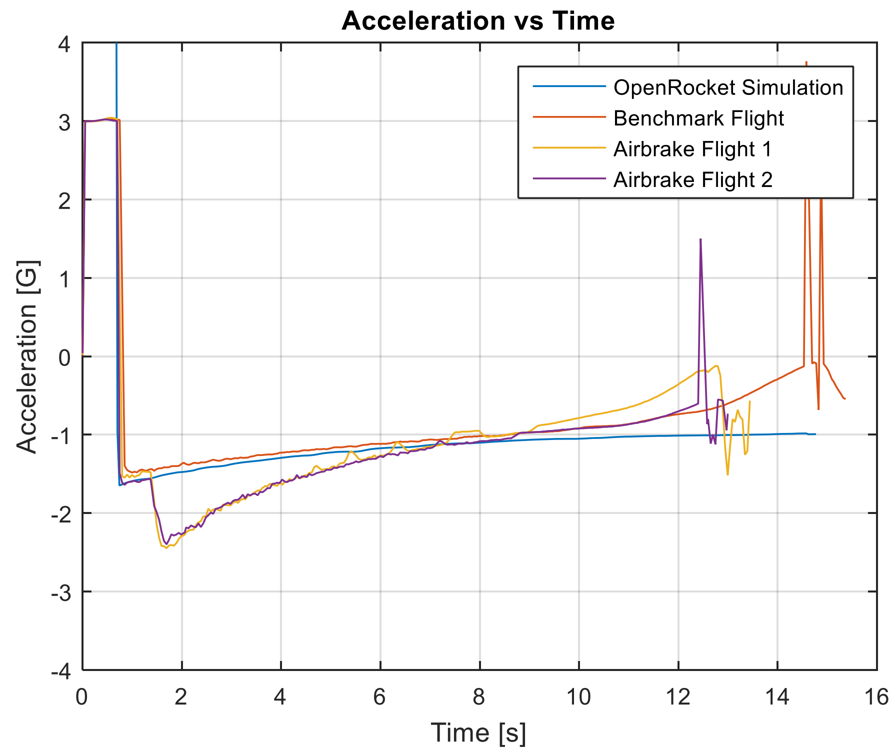
Flight	Measurement [units]	Jolly Logic #1	Jolly Logic #2	Sensor System	OpenRocket Simulation
Benchmark Flight	Apogee [ft]	3646	3644	3658	3617
	Max Velocity [ft/s]	546	418	586	529
	Max Acceleration [G]	24.3	24.4	3.06	25.6
	Time to apogee [s]	14.9	14.7	15.4	14.7
First Air Brake Flight	Apogee [ft]	2850	2847	2853	N/A
	Max Velocity [ft/s]	487	138085	521	529
	Max Acceleration [G]	23.4	26.2	16.2	25.6
	Time to apogee [s]	12.8	13.4	13.2	N/A
Second Air Brake Flight	Apogee [ft]	2906	2900	2853	N/A
	Max Velocity [ft/s]	>407	242	521	529
	Max Acceleration [G]	>40.6	24.8	3.29	25.6
	Time to apogee [s]	12.9	13.0	13.0	N/A

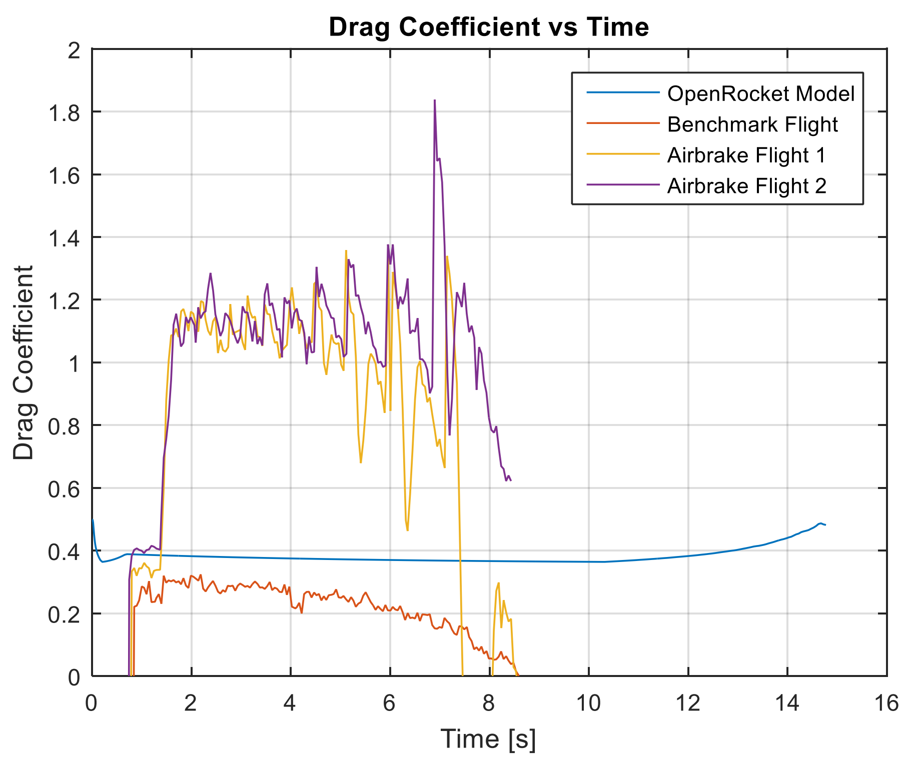
Graphs of data captured during flight.

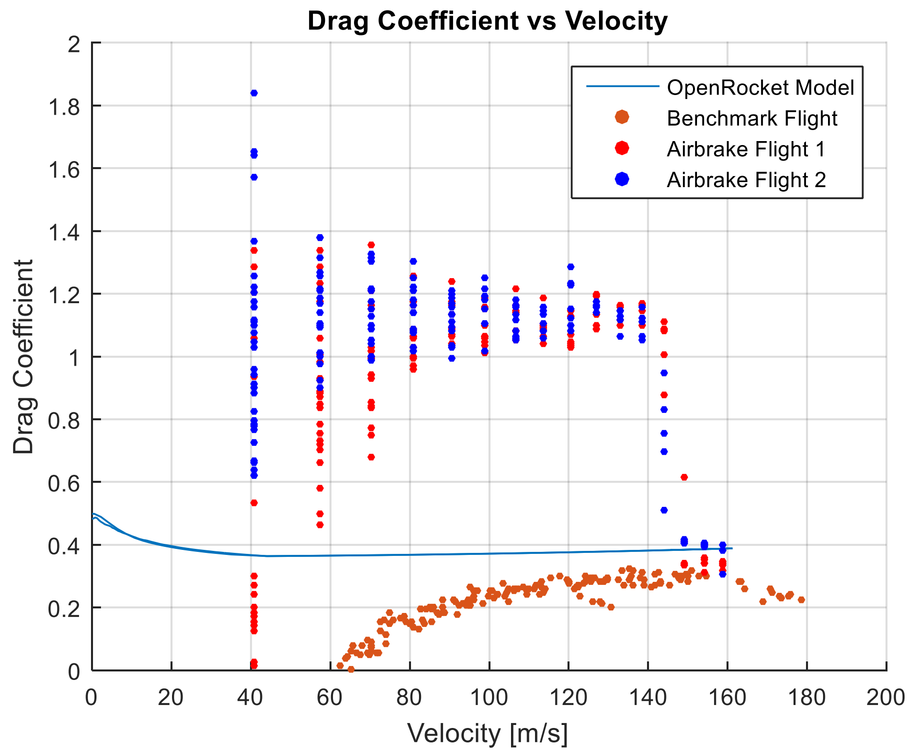
Shown below are graphs of the data captured by the flight data collection system. These include graphs for displacement, velocity, and acceleration. Graphs for drag coefficient vs time and velocity as well as commanded airbrake position vs time are also shown. Note the velocity for the benchmark flight was found by taking the derivative of position. This was due to the pitot tube being swapped with a solid rod to prevent damaging the primary tube.

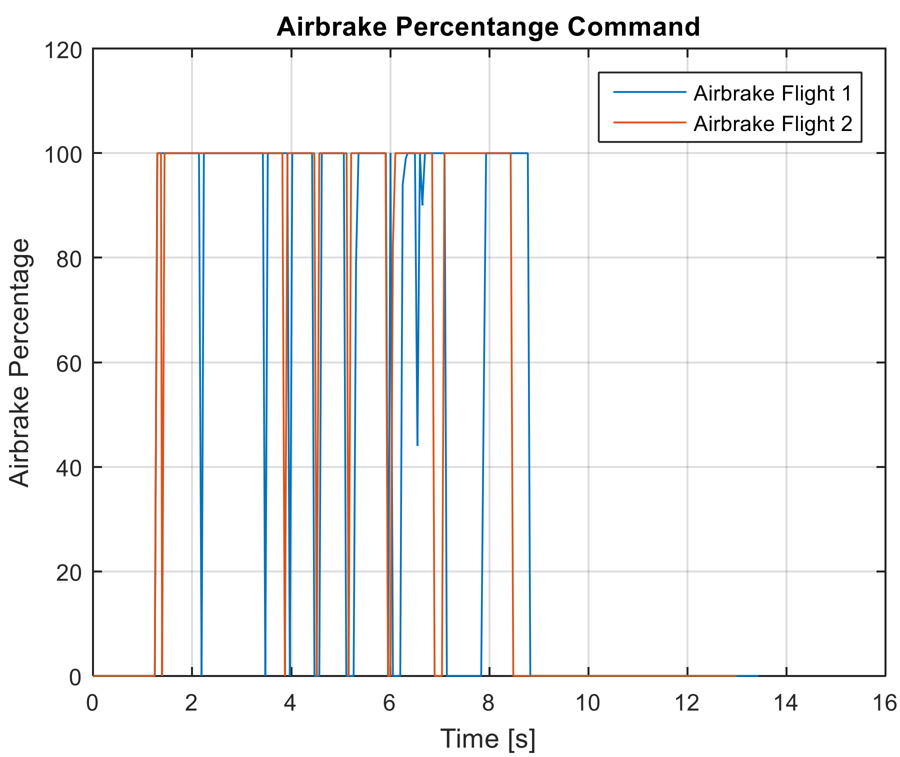

Altitude vs Time
OpenRocket Simulation
Benchmark Flight
Airbrake Flight 1
Airbrake Flight 2
Altitude [ft]
4000
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
16
Time [s]


Velocity vs Time
OpenRocket Simulation
Benchmark Flight
Airbrake Flight 1
Airbrake Flight 2
Velocity [ft/s]
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
Time [s]


Acceleration vs Time
Acceleration [G]
Time [s]
OpenRocket Simulation
Benchmark Flight
Airbrake Flight 1
Airbrake Flight 2
4
3
2
1
0
-1
-2
-3
-4
0
2
4
6
8
10
12
14
16


Drag Coefficient vs Time
Drag Coefficient
Time [s]
OpenRocket Model
Benchmark Flight
Airbrake Flight 1
Airbrake Flight 2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16


Drag Coefficient vs Velocity
OpenRocket Model
Benchmark Flight
Airbrake Flight 1
Airbrake Flight 2
Drag Coefficient
Velocity [m/s]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
20
40
60
80
100
120
140
160
180
200


Airbrake Percentange Command
Airbrake Flight 1
Airbrake Flight 2
Airbrake Percentage
Time [s]
0
20
40
60
80
100
120
0
2
4
6
8
10
12
14
16

Comparison and discussion of Results

Apogee Comparison

The apogee that was predicted in simulation matched very closely with the benchmark flight. This is due to the method used to create an accurate simulation. After a test flight of this rocket parameters were tweaked in simulation to match the measured results of the flight. The result of this is an apogee that was within 1% of the measured value.

Velocity comparison

The Jolly Logic Altimeter proved a very unreliable measure of peak velocity. Two altimeters launched on the same flight had variations exceeding 100ft/s. On the first airbrake flight one Jolly Logic measured a velocity of 138085 ft/s. The pitot tube system on the other hand was very accurate. The peak velocity measured during the first airbrake flight before airbrake deployment was much more accurate measuring within 1% of the expected value.

Acceleration comparison

The peak acceleration measured by the two Jolly Logic Altimeters was pretty accurate. The values measured by the Altimeters were both within 5% of the simulated value. Peak acceleration could not be found with accelerometers used on the data collection system. This is due to the sensors saturating at 3G's.

Simulation comparison

Overall the data collected from the data collection system matched very closely with the simulated performance. The plots for displacement, velocity, and acceleration all match very closely with what was expected from simulation. This shows the usefulness of fine tuning the simulation to match test flight data.

Drag Coefficient comparison

The method used to calculate the real time drag coefficient had was inaccurate at low velocities. By measuring acceleration and velocity the drag coefficient can be solved for. This is causes problems as the square of velocity is in the denominator of the equation and at small velocities the drag coefficient can grow out of control with even the smallest of errors. At the most accurate point with the pitot tube active a drag coefficient of .360 was measured in the first airbrake flight and .393 was measured in the second airbrake flight. These numbers are within 5% of OpenRocket prediction of .386 these measurements were taken before the airbrake deployed and represent only the drag of the rocket.

Airbrake Performance

From the drag coefficient data it can be seen how effective the drag system was at increasing the drag on the rocket. When the airbrake was deployed there was an acceleration increase of approximately 1 G. This rapid increase of drag corresponds to the drag coefficient increasing from the nominal .39 value to a value of 1.15 tripling the drag of normal rocket. The data also shows that this increase took place in a timespan of 300ms which matches the speed of the servo used.

Conclusion

Pioneer Rocketry is thankful for the opportunity to participate in the 2015-2016 Midwest High-Power Rocket Competition. This competition provided a unique challenge and a great opportunity to be creative. We would again like to thank the Wisconsin Space Grant Consortium for supporting our team, and we would like to thank the Minnesota Space Grant Consortium for hosting this competition. We look forward to seeing what challenges this competition has in store in the upcoming years.

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