Pioneer Rocketry

2016 Midwest High-Power Rocket Competition

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Abstract

The objective of the 2016 Midwest Rocket Competition was to use an active drag system to control the altitude of the rocket. The rocket was to fly twice, once with the system deactivated then again with the system active. The goal was for the active drag system to get the highest altitude of the second flight to be 75% of the un-deployed flight. The electric system onboard needed to both control the drag system as well as record the data necessary to estimate the drag coefficient throughout the flight. At competition, the rocket was flown a total of three times and performed as expected. The third flight was done for a second attempt at improving flight score. The rocket was able to achieve a reduction of 78% thus placing Pioneer Rocketry third in the competition.

The following report details the design and construction of Pioneer Rocketry's rocket Skybreaker, along with information regarding Pioneer Rocketry's growth as both an educational and professional organization here at UW- Platteville.

Executive Summary

This is the fourth year for Pioneer Rocketry, and it is the busiest one yet. The ongoing academic year has been a turning point in the history of Pioneer Rocketry. The new academic year has been a turning point in the history of our club; we started strongly in Fall 2015 with a rocket-building workshop we named TREX (Team Rocketry Educational eXtravaganza). The purpose of TREX was to teach new and veteran members design, construction, and launch procedures for high-powered rocketry. We spent the first eight weeks of the semester teaching lessons pertaining to general high-powered rocketry, rocket physics and design, use of laser cutters and 3Dprinters, and the construction of the rockets. Competing in TREX were eight teams of three to four members; teams were divided such that experienced members were distributed among the newer members to give each team guidance. At the conclusion of TREX, the teams successfully built and launched eight high-powered rockets.

In addition, Pioneer Rocketry decided to enter into two separate competitions for the first time. We have a team competing in the WSGC Collegiate Competition as well as the Midwest High Powered Rocket Competition. This marks a key point in the growth of Pioneer Rocketry as the expansion of member participation, experience, and skill will allow the club to reach new heights both figuratively and literally.

On another note, Pioneer Rocketry has continued to emphasize the dissemination of our knowledge, excitement, and passion of rocketry and engineering through outreach events. This year, Pioneer Rocketry taught boy scouts about rocketry in order for them to earn their Space Exploration merit badge. Our team spent several hours over a weekend to teach them about space exploration; after the teaching session, the Boy Scouts applied what they had learned by designing and building rockets.

Last year, Pioneer Rocketry was able to reduce the traveling distance to the rocket-launching site. We used to travel several hours to launch at Richard Bong State Recreation Area. In cooperation with UW-Platteville and the Federal Aviation Administration, we got the permission to launch at Pioneer Farms, which is just three miles from campus. The drastic reduction in traveling distance has saved the club a lot of money and time. The proximity of the new location permitted us to have both the flexibility of managing the site and the possibility to launch much more frequently. In this academic year alone, we have launched over 20 rockets, significantly more than the nine rockets launched last year.

Competition Requirements

The goal of the 2016 Midwest Rocket Competition was to design and construct a high-power rocket with an active drag system that would reach a max altitude greater than 3000ft. The rocket was to fly at least two flights with the first being a benchmark flight and the second one using the active drag system to reduce the altitude by 25%. Teams were to construct a data system that would estimate the rockets coefficient of drag over time and use an on-board video camera to document the state of the drag system.

Rocket Construction.

The main philosophy in the design of Pioneer Rocketry's rocket "Skybreaker" is to make it as durable as possible. The main area of focus was the fin can section. The cantilevered nature of fins makes them prime locations for damage during flight. To make them as strong as possible, the fins are *through-the-wall* style with the tab of the fin sliding into a slot that is cut into the centering ring. This slot ensures that the fin is aligned and perpendicular to the body tube. The slots into the body-tube were cut using a Bridgeport milling machine to make sure that the fines would be straight. The (Fig. 1) below shows slots being cut on the mill. The fins are then reinforced with internal and external fillets.

Fig. 1: Milling the fin slots

The nose and tail cones of the rocket were both 3D printed. Although in the past 3D printed parts have proven to be very strong, they were additionally reinforced for this rocket. Both cones of the rocket have a layer of fiberglass on their surface. This fiberglass was form-fitted to the surface of the part using a vacuum food saver; thus, even pressure could be applied to all areas of the part forcing the fiberglass cloth to conform to its surface.

Payload System Design

Electrical System. The complicated electronics used in Skybreaker have been a challenge for the Pioneer Rocketry Team. The electronics being designed for this competition were much more advanced than anything developed in the past, and required a great deal of commitment and dedication from all members of the team.

Physical components of Avionics Bay. The basis for the electronic payload was an Arduino Due shown in (Fig. 2). This is similar to the Arduino Mega. However, it was designed with an ARM Processor that is more than 5 times faster than the traditional processor meaning the air breaks will be better able to adjust to any changing conditions during the flight. The Arduino is powered by a 2 cell Lithium Polymer Battery, and all components interfacing with the Arduino were soldered to the perf-board Arduino shield to ensure that they are adequately secured throughout the flight.

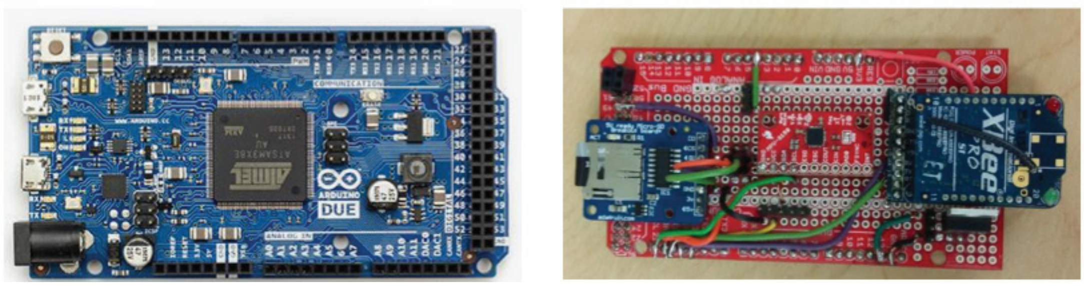

Fig. 2: Left is the Arduino Due. Right is the custom shield created for this competition.

The airbrakes employ a flat design (described in greater detail in the Mechanical System section), so they are able to be powered using a high torque, high speed, all metal gear servo. The Arduino actively adjusts these to ensure that the correct altitude is reached. A self-contained sports camera is fixed on the side of the rocket and provides video of the entire flight, including any airbrake activity.

Fig. 3: Pitot tube attached to tip of nosecone.

Redundant Stratologger CF altimeters are used to deploy the drogue and main parachutes. These altimeters run entirely independently to prevent a single point of failure. One of these is attached to the Arduino and provides altitude data over a wired serial connection.

Several other sensors are also incorporated into this design to provide a highly accurate flight data throughout the entirety of the flight. A pitot tube as shown in (Fig. 3) is attached to the nose cone of the rocket. This provides highly accurate velocity data. Due to the fragile nature of this design, it is designed to the capability of being replaced quickly if damaged.

A BNO055 nine degrees of freedom absolute orientation sensor also was used to provide acceleration data. One of the special features of the BNO055 is that it provides acceleration data with acceleration due to gravity removed. Because this sensor calculates its absolute orientation, the acceleration due to gravity can be correctly obtained even when the sensor is being rotated around all three of its axes.

Any of the electronics that could not be soldered down were connected with each other using JST (Japan Solderless Terminal) connectors that significantly decreases the time it takes to assemble the electronics between launches.

Finally, the last unique feature of the electronics is the avionics bay ring. It has screw switches that allows for easy arming of all the electronics and prevents the need to relying on twisted wires to power the devices. One of these switches was also used as the means to turn on and off the airbrakes.

Skybreaker's Software. Close to two thousand lines of code have been written to run all of the electronics. It took a considerable amount of time and effort to design, implement, and test. The main control loop has five unique states namely, launch/landed, engine burning, ascent, and descent. Each of these states are coded with unique behavior. For instance, after apogee, the velocity measured from the Pitot tube will no longer be providing relevant data. Thus during this stage, the displacement and time interval is used to estimate the velocity of the rocket instead.

Because the inherent noise from the sensors, the rocket implements a Kalman Filter to smooth the data. The Kalman Filter predicts the behavior of the rocket. It then compares this prediction with the sensor data. From this, it actively extrapolates the reliability of the sensors and the predictions. This smooths the data of unnecessary noises and actively merges the three main sensors being used, namely the altimeter, Pitot tube, and accelerometer. By utilizing this filter, the code can determine key events in the launch with greater sensitivity without having to fear that a bad reading could inadvertently trigger a state change such as lift off or burnout.

This code also automatically records the apogee of the rocket. It is stored for the next flight, but if this information were to be corrupted, it can be changed remotely. The specifics to how this works are detailed below in the data section.

The last, and likely the most important, feature of the electronics code is the algorithm that controls the air breaks. A specialized equation was designed to take the mass, velocity, and displacement of the rocket and predict the apogee of the rocket. It makes use of a PID (Proportional Integral Derivative) control loop that actively controls the deployment for the airbrakes to reach a target apogee.

Fig. 4: XBee Radio module.

Recorded Data. Previous attempts to record flight data using home built electronics have been largely unsuccessful. At the 2014 Collegiate Rocketry Launch, the design was faulty causing a complete loss of data. At the 2015 competition, the microSD card was physically destroyed. With this in mind, a redundant data collection system was developed for this year's competition. First, an XBee

Series 1 Pro was attached to the rocket.

It has a one-mile line-of-sight range, and provides live data throughout the entire flight. It also allows remote input. For instance, the user can change the apogee goal remotely from a computer even when the rocket is being powered on the launch pad if necessary. If a critical failure were to occur, however unlikely, and the avionics bay where to be destroyed, this method would ensure that the flight data would not be lost. As a back up to this system, a microSD card was also attached to the Arduino. In the event that the XBee were to fail or to go out of range, this also records all the data from the launch.

Mechanical system design of air brakes

Design Overview. The airbrake system designed used four plates that rotate outward into the airflow around the rocket and obstruct the airflow around the rockets. The benefit of using plates that rotate normal to the airflow is that the forces generated by the airbrakes plates are not acting to open or close the airbrake system. Because of this, the actuator that is used to open the airbrake does not need to be that strong and the airbrakes can open quickly. It was found during design that a quick opening airbrake is much more effective due to the higher velocities at full extension as well as being able to be active for more of the coast period. The quick acting airbrake also has the benefit of being able to adapt quickly to any disturbance.

Airbrake Mechanism design. To both ensure that all brakes open simultaneously and to drive the system with a single input all of the plates were geared together. Due to the size constraints present inside of the rocket, this gearing was accomplished by using a central gear to drive four pinion gears that are attached to the plates. This central gear is made up of two tiers. The lower gear meshes with the four plates and the upper gear meshes with a pinon on the servo motor. (Fig. 5) below shows a render of this mechanism with different parts indicated in different colors. The gears indicated with pink are the pinions linked to the plates. The blue central gear meshes with the plates. The red gear is driven by the servo motor and is attached to the lower gear. The cyan gear is attached to the servo motor.

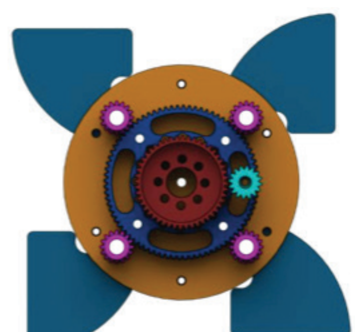

Fig. 5: Render of the Airbrake Mechanism

To make the mechanism as robust as possible the airbrake is made almost entirely of aluminum. To make the parts needed accurately in this mechanism a Tormach CNC mill was used. The plates that extend into airflow are made from .25in thick aluminum plate. These plates are held onto a steel shaft and secured with a set screw. These steel shafts are supported by two ball bearings each that go into the center bulk plates. These bulk plates are also made of aluminum with one of them being .25in thick and the other being .1in thick. To fix the airbrake system to the rocket's tube, large 3D-printed shoulder pieces were used. These shoulders slide firmly into the fiberglass coupler used for this rocket and ensure a rigid connection. To solidify the whole system two bolts and two tie rods go through the airbrake module and secure it together. Since the bulkheads completely divide the upper and lower sections of the rocket, the bolts used to secure the rocket together have hole bored through them to allow wires to pass through.

Testing

To accomplish the goals needed in this competition, Pioneer Rocketry has utilized our access to the launch site at Pioneer Farms to do a series of test flights at various stages of development of the airbrake system. Pioneer Rocketry has completed three test flights with various amount of success.

The first test flight launch was on December 5, 2015. It was done on a rocket test platform known as the PRX-1 codename Iguanodon. The primary focus was on testing the telemetry systems to be used on the competition rocket. This flight went flawlessly and provided confirmation that the telemetry system had the range needed to transmit its data throughout the entire flight.

The second test flight took place on January 30, 2016, using the same Iguanodon test platform. This was a test of the electronics and the airbrake mechanism. This first airbrake mechanism attempted was a flap style brake. This flight experienced several failures resulting in significant damage to the rocket. The primary failure was due to faulty ejection charges that caused the rocket to not deploy its main parachute. The secondary problem was due to a wiring failure; the Arduino lost power and failed to record data or deploy the airbrakes. The flight still provided a lot of useful data however as it revealed the vulnerability of the initial airbrake design. When the rocket landed the area around the airbrake completely broke and the side load on the linear actuator caused it to split in half. Because of this, a more robust airbrake system was needed.

The third test flight took place on March 12, 2016. It tested a more complete electronics payload, the new Skybreaker prototype, and a newly designed airbrake system. This flight revealed that the new construction techniques as well as the general design of the rocket were successful. The airbrake and avionics system, however, underwent anomalous power loss after several minutes of operating the system. All attempts to replicate this problem have failed.

At the Wisconsin Collegiate Rocketry Launch event, our team aimed at testing the general design of the Skybreaker rocket and its airbrake system. A safety check was performed on the rocket to ensure it was correctly assembled and ready for launch. The flight was successful and provided a great deal of information. Off the launch rail, the rocket began to turn but quickly corrected itself and was flying nearly perfectly straight after about 100 feet. Unfortunately, the main parachute deployed at apogee. It appears that this occurred because of the high mass of the nose cone; its steel weights, the Pitot tube, and the small electronics bay were a bit of an overload. When the ejection charge for the drogue separated the rocket, the nose cone at this point apparently had enough momentum to break the shear pin thereby deploying the main parachute at apogee. To remedy this situation, a second shear pin will be inserted to keep the nose cone attached. The rocket floated much further than was desired, but luckily landed in trees completely undamaged. After the launch the rocket was examined and all of the data was retrieved from the sensors."

"The peak altitude was considerable lower than anticipated. Because of this, the air brake did not need to open as early or for as long as had been hoped. It flew to roughly 80% of the predicted altitude.

Results

Airbrake Performance. 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 0.39 value to 1.15, thus tripling the normal drag of the rocket. The data also showed that this occurred in a timespan of 300ms, which matches the opening speed of the servo used.

Drag System Report. The airbrakes opened at 353 feet instead of the goal of 240 feet. This was triggered by the method used to determine the burnout event. The method was overly cautious in ensuring 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. (Fig. 6) shows the airbrakes functioning in flight.

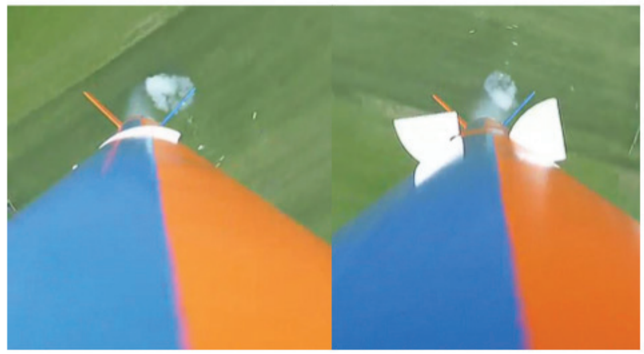

Fig. 6: The image on the left shows the onset/initiation of air breaks deployment. The image on the right shows the airbrakes fully deployed.

Unfortunately, the airbrakes closed prematurely at 2590 feet. This occurred because the velocity read by the Pitot tube was too granular. There was not enough resolution on our analog to digital converter reading in the pressure from the Pitot tube. The velocity read by the Pitot tube jumped from 0 ft/s to 133 ft/s 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 2740, and the air brakes only had a 22% reduction. 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.

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

Conclusion

Pioneer Rocketry is grateful to everybody that has made this team and our projects possible. We have worked closely with our friends, our mentors, and our school to help make this team into what it is today. Moving forward, we will continue to expand our knowledge and experience with high-powered rocketry. We will continue to grow our team with the express purpose of sharing the wonderful and fascinating world of rocketry with anyone who is eager to learn. We hope to one day become more than just a team of wayward rocketeers. We hope to become a vector of learning and experimentation in the larger rocketry community.

This presently built Skybreaker rocket is only one small step in one of many directions of rocket design and engineering. The implementation of active airbrakes was certainly a challenge, but it was a challenge that encouraged us to come up with creative and innovative solutions. We were thrilled to bring Skybreaker to this competition. We look to the future and the challenges it brings.

Ad Astra