Pioneer Rocketry

University of Wisconsin-Platteville

Team High Powered Rocketry Mentor: Adrian Guither

Team Faculty Advisor: Duane Foust

Student Team Lead: Jacob Ellenberger

Members: Jacob Napp, Adam Nielsen, Grant Oberhauser, Jane Dickler

Midwest Rocket Launch Competition

2015 – 2016

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Executive Summary:

Going into our fourth year, Pioneer Rocketry is experiencing its busiest year yet. The ongoing academic year has been a turning point in the history of Pioneer Rocketry. We started the year off strong 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 for the club to reach new heights both figuratively and literally.

On another note, Pioneer Rocketry has continued to emphasize the spreading 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 the boy scouts 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 in order to launch rockets. Instead of traveling several hours to launch at Richard Bong State Recreation Area, cooperation with the University and FAA allowed us 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 ease of launching nearby and the flexibility of managing our own launch site has allowed us to launch much more frequently. In this Academic year alone, we have launched well over 20 rockets which is much more than the nine rockets launched last year.

Pioneer Rocketry is thankful for the opportunity to compete in this unique event, the Midwest High Powered Rocket Competition. The challenge of the active drag system has been very complex, but we have enjoyed putting all our skills and strengths to the test to make it all work. We look forward to spending the time with fellow rocketeers and seeing what the competition has to offer.

Jake Ellenberger

President of Pioneer Rocketry

Rocket Design:

General Design:

The goal of the competition is to use an active drag system to accurately control apogee. An initial flight will be launched to set an apogee baseline, and the drag system will then be utilized in a subsequent flight to reach a height that is 75% of this baseline. To achieve this goal, the rocket "Skybreaker" was designed. Due to the complex nature of the rocket, a prototype airframe was designed and constructed. This rocket used parts that were readily available and allowed for a test platform to be constructed. This prototype is the same shape and size as the final design but differs only in materials selected to build the rocket. With a successful flight of this prototype completed, the design and advanced construction techniques have been verified, which provides confidence that final rocket can be built successfully. The final rocket is due to be completed by April 2nd.

Nose cone:

The nose cone selected for this rocket is a 20in ogive nose cone. An ogive was selected due to its simplicity and good aerodynamic properties. The nose cone is made from PLA plastic that has been 3D printed. As a team, Pioneer Rocketry has extensive experience with 3D printing nose cones, and they have proven to be very strong. To ensure the nose cone has sufficient strength, it has been covered in a layer of fiberglass and filled with Tap Plastics X-30 expanding foam. The nose cone has an aluminum tip with a threaded hole for the quick swapping of pitot tubes. The Pitot tube has threads so that if it gets damaged during the landing of the rocket it can be replaced quickly.

Body Tube:

The body tube selected for this rocket is 4in diameter fiberglass. The fiberglass was chosen for many reasons. The strength and rigidity of the fiberglass provide high tensile strength and resistance to elastic deformation. In addition, its weather resistance and dimensional stability are beneficial. A material like Blue Tube is highly sensitive to humidity and will expand and contract causing alignment issues. Fiberglass was chosen over the more exotic carbon fiber because it does not impede the radio waves needed for the telemetry system.

Airbrakes and Avionics Bay:

The airbrakes and avionics are housed together in the middle of the rocket, inside a single piece of coupler tube. The avionics bay starts at the separation point for the upper and lower sections of the rocket. Refer to the sections for the avionics and airbrakes under the Payload System Design for a more complete description of their design and functionality.

Recovery:

The recovery system on this rocket is a dual deployment system. The drogue parachute is a 24in, hemispherical parachute, and the main parachute is 72in and also hemispherical. The shock cord selected for this rocket is 0.25in diameter Kevlar with a breaking strength of 3600lb. To help absorb the shock of parachute inflation, the shock cord has an elastic cord attached. To ensure the parachutes are ejected properly, a redundant altimeter setup was utilized. Two Stratologger CF's were used in this system. The primary system deploys the drogue at apogee and the main at 700ft while the backup deploys the drogue at apogee plus one second, while the main is deployed at 500ft. The ejection charges were ground tested, and the rockets separation was verified.

Fins:

The fins on this rocket are made of 0.125in thick G10 fiberglass. The shape of the fin is a symmetric trapezoid and dimensioned to maximize durability and prevent damage on landing. The symmetric fin is 3.5in tall with a tip that measures 3in and a base that is 5in. The fins have a relatively high aspect ratio (height/width) as this creates both better stability forces and positions the center of pressure farther back on the airframe. The fins were placed above the tail cone to reduce the chance that the rocket lands on its fins.

Camera Pod:

To visually verify the deployment of the airbrake system, a camera pod was designed to attach to the side of the rocket. This component was 3D printed using PLA Plastic, and was fixed to the top of the rocket to allow for a better view of the airbrakes throughout the flight.

Rocket Diagrams

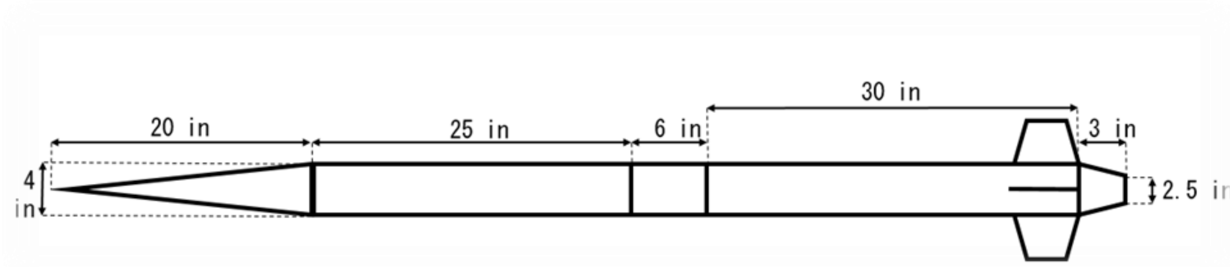

Figure 1: Dimensional drawing of Skybreaker

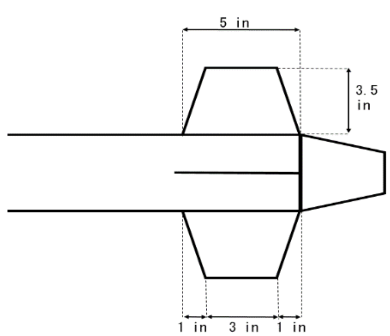

Figure 2: Dimensions of the fins.

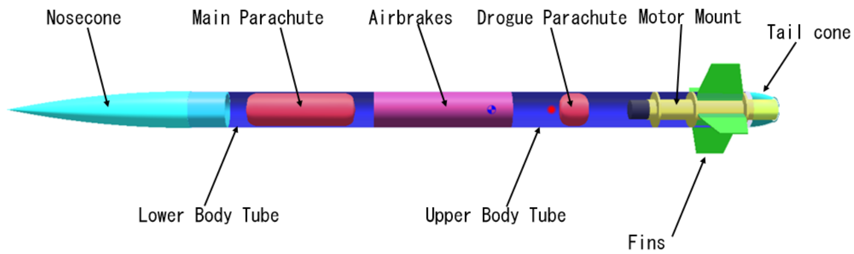

Figure 3: Layout of Skybreaker.

Stability Analysis

Based on the OpenRocket model, the stability of Skybreaker is 1.6cal. This increases to 2.8cal after motor burnout. The rocket was designed with additional stability so that the rocket remains stable even under the influence of the airbrake system.

Propulsion Specifications

Pioneer Rocketry will be launching Skybreaker on a Cesaroni K2045. The motor is 54mm in diameter and 404mm in length. The motor contains 4-Grains of Vmax propellant and has a total burn time of 0.7s. The motor will produce a total impulse of 1407.6 Ns, a maximum thrust of 2231.2N. The Vmax propellant is a good choice for several reasons. The competition requires that the airbrakes come out after motor burnout. Because the Vmax Motor has a short burn time, the airbrakes can be deployed earlier in the flight meaning more control over the rocket's acceleration and altitude. Another benefit of a Vmax motor is that it has a large velocity off the rail. This higher velocity, reduces the effect of wind on the path of the rocket thus making the rocket more predictable and easier to control. See Figure 4 below for the thrust curve for the K2055.

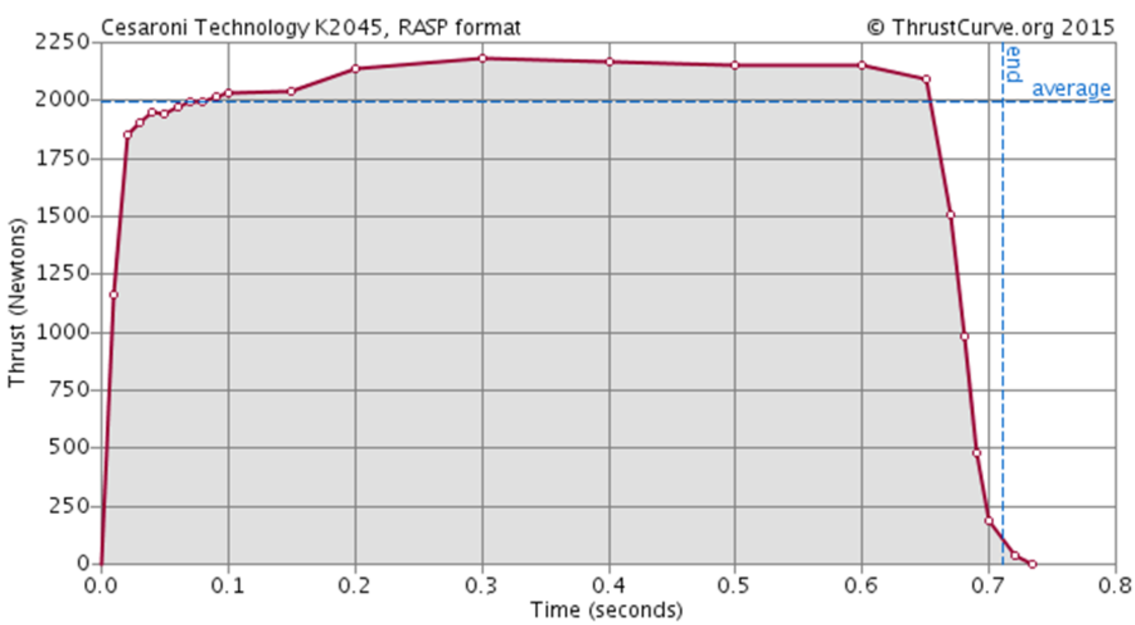

Figure 4: Thrust Curve for the Cesaroni K2045.

Rocket Tracking and Location

Previously, various electronic methods using sonic-locators and GPS modules have been met with good success for quick and efficient rocket recovery. Last year, the team developed new procedures for recovery teams. A minimum of two recovery teams are deployed from the launch pad prior to the launch event and move to pre-specified longitude and latitude coordinates. Once in position, the teams radio-in to the launch pad and confirm they are prepared to visually track the rocket's trajectory. A minimum of two persons are required for each recovery team so that there is a reduced chance of one team losing sight of the rocket. Each team is equipped with a data entry sheet, binoculars, and a compass. The compass is especially important because it is used to record the descending rocket's last known bearing from the recovery teams' fixed positions. The combined data from the recovery teams is then used to triangulate a possible landing location of the rocket using an aerial map. It is hoped that as the team progresses into more advanced rocket designs and launch operations that the recovery teams will also progress into a comprehensive suite of ground support duties.

Materials Testing

The design of Skybreaker relies on several custom made 3D printed parts such as the nose cone, tail cone, and support material in the avionics bay. Pioneer Rocketry has relied extensively on 3D printed components in the past and has been impressed by their durability. A boosted dart descended from an altitude of around 4,000ft without a parachute and imbedded itself close to 10in into the ground. All the paint was chipped off of the cone, but the actual nose cone itself was completely intact. This club has flown nine other successful flights with 3D printed nose cones, centering rings, or tail cones. Because of these past successes, the team is confident in the strength of 3D printed components.

Rocket Construction

The main design philosophy in the design of Skybreaker is to make the rocket as durable as possible. This was achieved with various new construction techniques. To test these new techniques, a Blue Tube prototype was created to be as similar as possible to the final fiberglass rocket.

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 the fins 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. To ensure that the fins are straight, the slots cut into the body tube were cut using a Bridgeport milling machine. The figure 5 below shows slots being cut on the mill. The fins are then reinforced with internal and external fillets. The open volume in the fin can section was then filled with X-30 expanding foam to lock the assembly together. The fin can was finished with a layer of fiberglass that runs from fin tip to fin tip.

Figure 5: Milling the fin slots on the Blue Tube prototype.

While in the past 3D printed parts have proven to be very strong they were also reinforced for this rocket. Both the nose cone and tail cone of the rocket have a layer of fiberglass on the surface of the part. This fiberglass was form fitted to the surface of the part using a vacuum food saver. Using the vacuum, even pressure could be applied to all areas of the part and force the fiberglass cloth to conform to the surface of the part. Parts such as the nose cone that would normally be left hollow were filled with the tap plastics x-30 foam.

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 where 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. This is similar to the Arduino Mega. However, it was designed with an ARM Processor which 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.

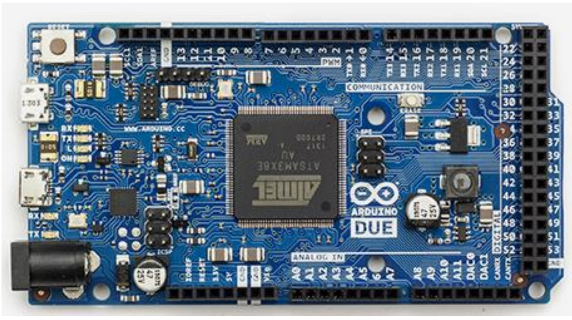 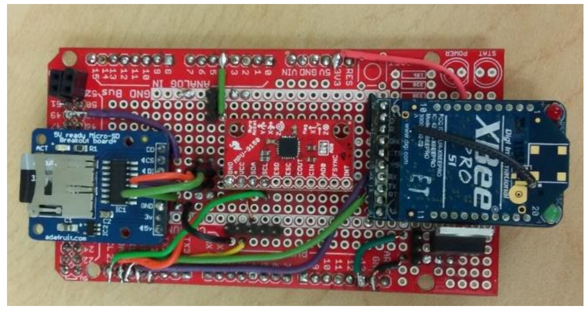

Figure 6: Left is the Arduino Due. Right is the custom shield created for this competition.

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 adjust 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.

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 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.

Figure 7: Pitot tube attached to tip of nosecone.

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 where connected with each other using JST connectors which 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 allowed 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. LEDs above these switches also provide visual feedback of the current state of the rocket.

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.

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 of all, an XBee Series 1 Pro was attached to the rocket.

Figure 8: XBee Radio module.

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

Airbrake Requirements

To determine the size of the airbrakes, a way of simulating the system was needed. To accomplish this, Simulink, a part of MATLAB, allows for the creation of a model and simulation. This Simulink simulation took drag data from an OpenRocket simulation and thrust data from ThrustCurve. This model allowed for the testing of airbrakes at various stages of deployment as well as the control loop needed to achieve the desired apogee.

Before any actual design of the airbrake system could be started, the requirements of the system needed to be known. The competition specifies an apogee reduction of 25% when the airbrakes are deployed. To allow for variation in the impulse of the motor and allow headroom for the airbrake control loop, a target apogee reduction of 37.5% was used.

To find the size and speed requirements of the airbrake system, a simplified model was created and implemented in the Simulink simulation. This airbrake model would start opening at one second and increase linearly with a set opening time. In addition, the airbrake had a set area. 170 simulations were then run to see what the effects of opening speed and area had on the apogee reduction as well as the peak drag force experienced by the brake. Table 1 below shows the data from that study.

Table 1: Apogee Reduction percentage as a function of airbrake area and opening time. Red Indicates a failure to meet the 75% goal. Green is the desired range. Blue is a reduction deemed excessive and unneeded..

		Airbrake Area [cm^2]									
		0	25	34.11	46.53	63.48	86.6	118.1	161.2	219.9	300
Rise Time [s]	0.25	0.00	25.53	30.76	36.26	41.77	47.06	51.95	56.34	60.14	63.38
	0.5	0.00	24.44	29.42	34.72	40.03	45.14	49.90	54.19	57.96	61.19
	0.75	0.00	23.42	28.21	33.31	38.46	43.43	48.09	52.32	56.07	59.33
	1	0.00	22.46	27.12	32.04	37.03	41.88	46.45	50.65	54.39	57.68
	1.5	0.00	20.74	25.08	29.74	34.46	39.14	43.59	47.73	51.49	54.86
	2	0.00	19.21	23.36	27.70	32.23	36.77	41.12	45.23	49.02	52.47
	2.5	0.00	17.87	21.76	25.91	30.31	34.65	38.95	43.04	46.86	50.38
	3	0.00	16.66	20.36	24.31	28.53	32.80	37.03	41.10	44.95	48.54
	3.5	0.00	15.57	19.08	22.91	26.99	31.14	35.29	39.35	43.23	46.89
	4	0.00	14.55	17.93	21.63	25.53	29.61	33.69	37.77	41.67	45.39
	4.5	0.00	13.66	16.91	20.42	24.25	28.27	32.29	36.33	40.26	44.03
	5	0.00	12.89	15.95	19.34	23.10	26.99	31.01	35.04	38.97	42.78
	6	0.00	11.49	14.29	17.49	21.00	24.76	28.72	32.67	36.68	40.56
	7	0.00	10.34	12.95	15.95	19.27	22.91	26.74	30.70	34.72	38.65
	8	0.00	9.32	11.81	14.61	17.80	21.31	25.08	29.04	32.99	36.97
	9	0.00	8.55	10.78	13.53	16.59	19.97	23.68	27.50	31.46	35.48
	10	0.00	7.85	10.02	12.57	15.51	18.76	22.40	26.16	30.12	34.14

The results of the simulations gave clear indication of what the airbrakes needed to do. There are two main design philosophies for the airbrake system: a quick opening brake with a small amount of area and a large area with a slow opening airbrake. The first of these designs explored was the slow and large airbrake system using flaps that open up and outwards, which will be discussed further in the following section.

Flap Style Airbrake

One of the first steps to understand how the flap brakes would perform and what actuator would be needed to open them is to run a series of Computational Fluid Dynamic (CFD) simulations. The simulations looked purely at the flaps and the aerodynamic drag created. The airbrakes were tested from 10 to 60 degrees opening in increments of five degrees at a rocket velocity of 200 m/s. Figure 9 below shows the results from that simulation. It can be seen that the airbrakes have a roughly linear relationship of drag coefficient to the deployment angle.

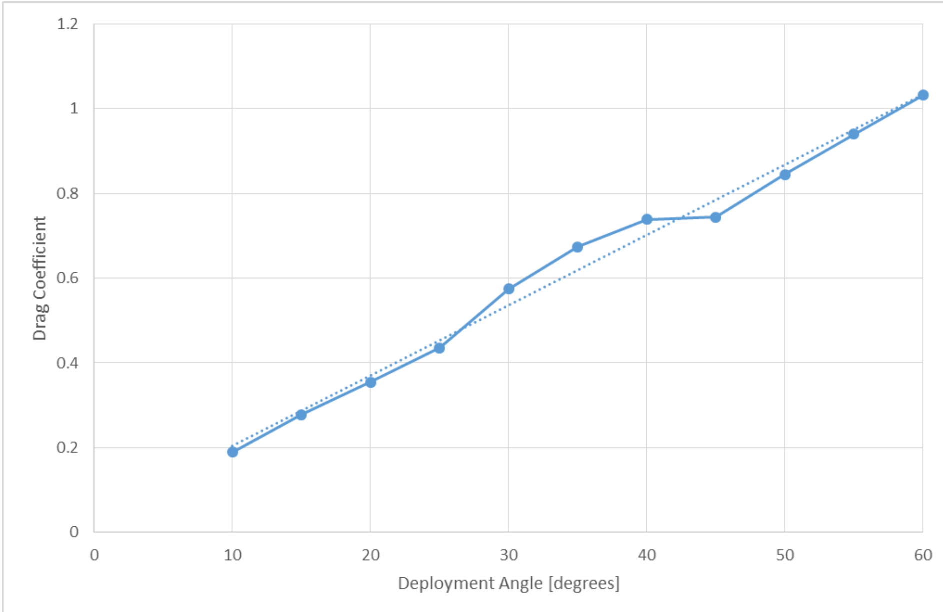

Figure 9: Plot of Drag Coefficient vs Deployment Angle.

To actuate the airbrake system, a mechanism needed to be designed. A key requirement for safety is that all flaps attached to the mechanism are mechanically linked. This prevents a single flap opening more or less than other flaps, which would cause the rocket to fly off course or to tumble out of control. To achieve this, a mechanism similar to a crank slider was created. This mechanism would drive four flaps simultaneously and be driven by a Firgelli linear actuator. The configuration with the highest gear ratio was selected to ensure the actuator had adequate force to open. The flap brake was constructed primarily using polycarbonate plastic that was machined on a Tormach CNC mill. Polycarbonate was chosen as it exhibits a high strength to weight ratio. Figure 10 shows the constructed mechanism.

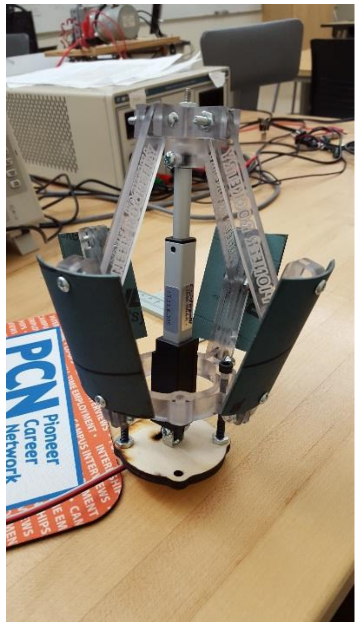

Figure 10: Original air brake design using a linear actuator.

In practice, this airbrake design had many design flaws. The first was that the actuator had to bear almost all the force of drag to open, which requires a strong and slow actuator. The other problem was the mounting and alignment of the mechanism. The brake required the external tube to have four slots precisely cut into body tube. If these slots were misaligned at all, the brake would bind and catch on the tube causing the brakes to either get stuck closed, open unevenly, or fail to close. The slots that needed to be cut for the linkages also reduced the strength of the tube quite significantly. The mechanism needed the actuator to be extended in its weakest position for the brake to be closed. These problems showed themselves during a test flight where the rocket landed hard on a drogue parachute resulting in the tube surrounding the airbrake and the actuator to break. See test flight section for details on the test flight.

Plate Style Airbrake

The next revision of the airbrake takes the alternate design philosophy of fast and small. The airbrake would extend plates perpendicular to rocket's body tube. This style made use of a high speed servo to drive the mechanism. A benefit of this design is that the actuator does not have to directly oppose the force of drag to open thus allowing a faster acting airbrake.

The initial design for the plate brakes was to have the plates slide as part of a crank rocker system that would extend the plate straight out. When creating this design, it was apparent that the mechanism would not fit inside the body tube when extended and it would leave the plates cantilevered out the side of the rocket with little to no support. This led to the final design for the plate brake system. The plates rotate around steel shafts outward into the airflow. To transmit the torque from the central servo to all four plates a system of gears was used. This system worked by transmitting the servos power to a central gear which then rotated the plates outward. The system was designed so that the 90° of motion of the servo corresponded to 120°

of plate rotation. At this point, the exposed area of the plate is maximum. The plates and gears ride on ball bearings to minimize the friction.

Since the brake is completely dividing rocket, as there is no continuous tube going past the airbrake, the system both the mechanism and its mounting had to be very secure. This was achieved by machining the components of the brake out of aluminum. The base plate of the brake is made out of 0.25 in aluminum and serves as the backbone of the system. The system was held rigidly in the coupler tube through use of a 3D printed shoulder that the coupler tube fit into and was secured with two bolts. This method proved to create a strong connection that provided rigid support of the airbrakes. This method was verified with the latest test flight and performed perfectly.

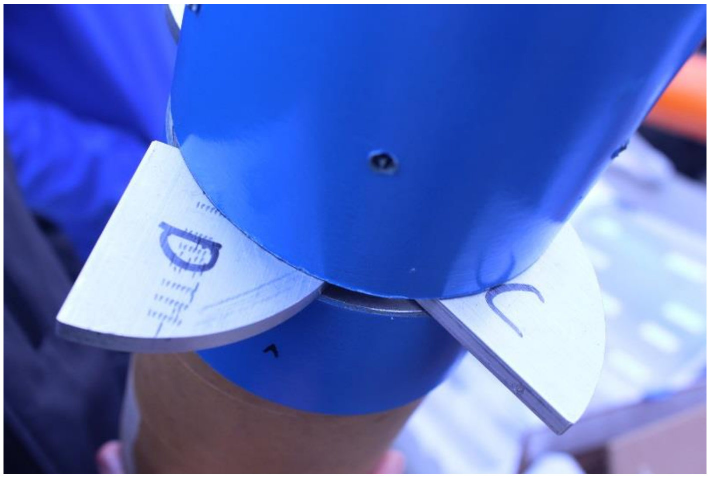

Figure 11: Completed plate style airbrake on the Blue Tube prototype rocket.

Anticipated Performance

To determine the anticipated performance, a Simulink simulation was created. This simulation is discussed in the Payload Mechanical Section. These simulations do not match the OpenRocket simulation exactly but show clearly the effect that the airbrakes have on the rocket and its flight characteristics. Three different scenarios were run. The first was a simulation with no airbrakes. Then it was a simulation of PID controlled airbrakes. Table 2 below shows the anticipated performance with various simulations. Figures 12 through 15 show drag, altitude, and velocity data.

Table 2: Table of Simulated Performance

Parameter	OpenRocket No Brakes	Simulink No Brakes	Simulink Controlled Brakes
Apogee [m]	1803	1818	1368
Max Velocity [m/s]	262	303	340

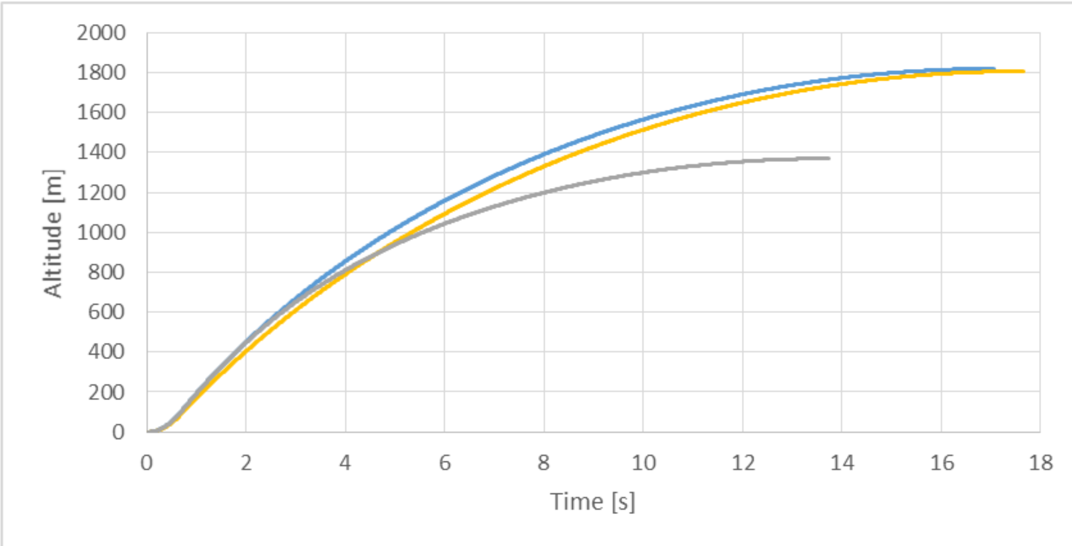

Figure 12: Altitude vs Time. Blue Line is Simulink Model. Yellow is OpenRocket Model. Grey is the Simulink model with the airbrake active.

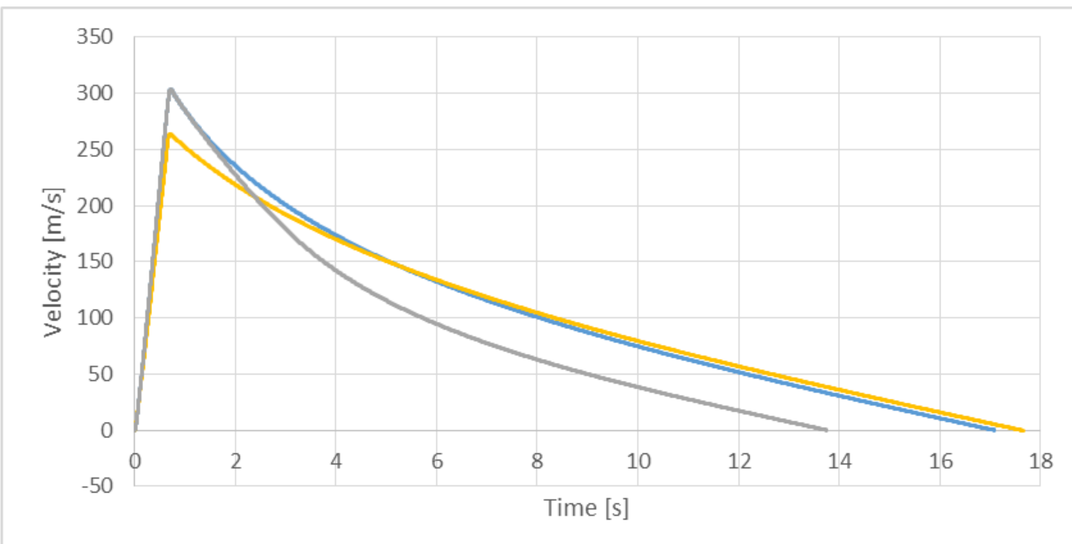

Figure 13: Velocity vs Time. Blue Line is Simulink Model. Yellow is OpenRocket Model. Grey is the Simulink model with the airbrake active.

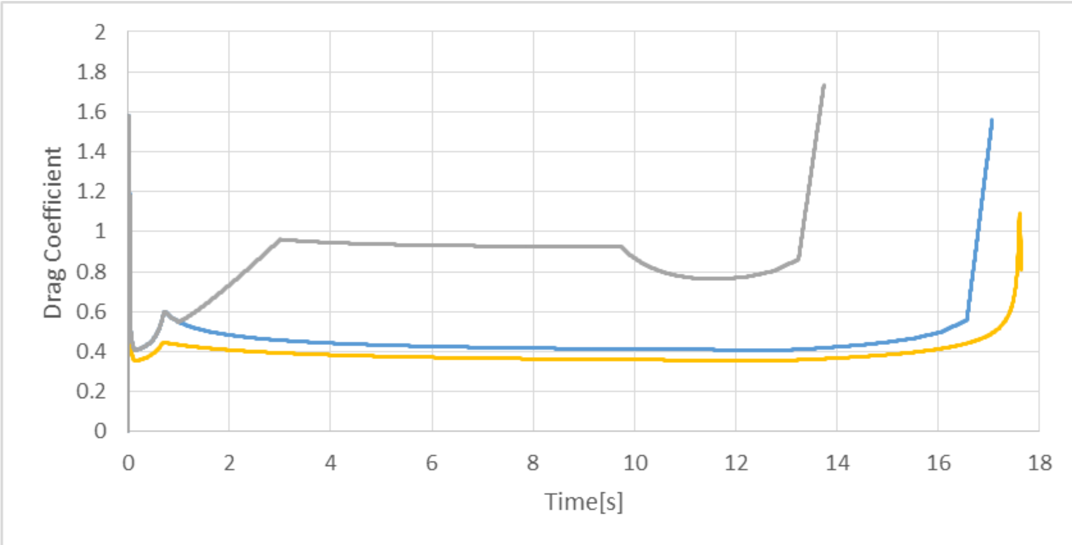

Figure 14: Drag Coefficient vs Time. Blue Line is Simulink Model. Yellow is OpenRocket Model. Grey is the Simulink model with the airbrake active.

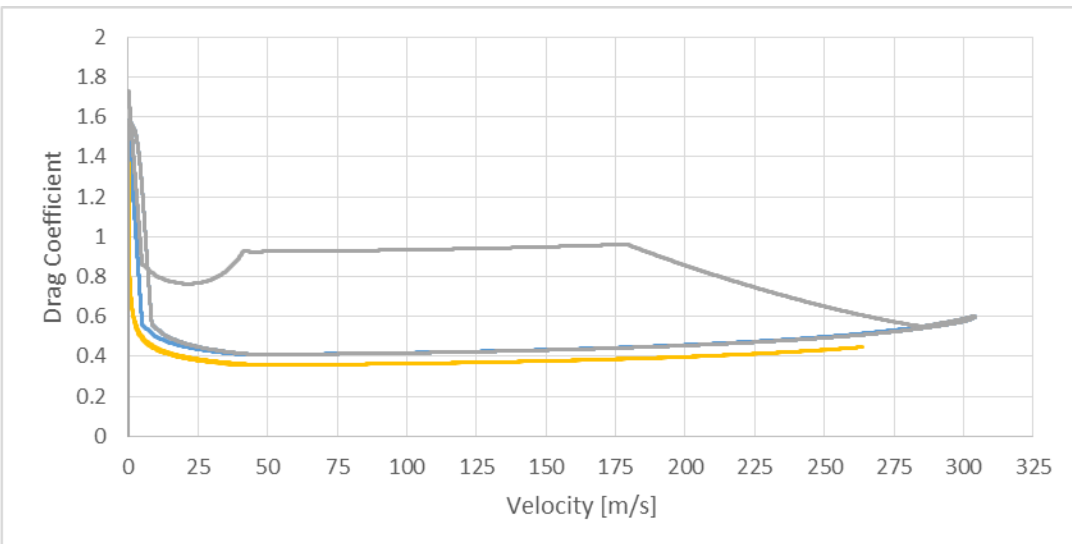

Figure 15: Drag Coefficient vs Velocity. Blue Line is Simulink Model. Yellow is OpenRocket Model. Grey is the Simulink model with the airbrake active.

Safety

Material Handling Procedures

The sport of rocketry requires the use of hazardous and volatile materials. Therefore, steps must be taken to ensure that these materials are handled with utmost care and stored in a proper manner to minimize risk to members. Highly flammable materials such as black powder, motors, and aerosol paints are stored in locked fire-resistant cabinets, and lithium-polymer batteries are stored in PVC battery-bags. Any members that are handling toxic materials, such as epoxy and spray paint, are required to wear protective nylon gloves to protect from the risk of skin contact and other inadvertent contact with any materials that might get on their hands. When any member is using hazardous materials that can get into the air, such as sodium silicate and aerosols, all members that are present in the same room are required to wear filtering face masks to protect them from inhaling small particles that could be airborne. Before any member can use any piece of equipment, they must receive the proper training on how to use the equipment safely. The faculty advisor Duane Foust teaches members how to use equipment such as the CNC Mill, Horizontal Ban Saw, and Laser Cutter. Experienced members of the team teach other members how to use the other equipment such as drills, rotary tools, and soldering tools.

Rules and Regulations

As rocketeers, it is critical to adhere to the safety guidelines established by state and federal governance, and organizations such as the National Association of Rocketry (NAR) and Tripoli Rocketry. Safety codes such as the *High Power Rocketry Safety Code* provided through the NAR website.

Launch Locations

A majority of flights performed by the University of Wisconsin-Platteville take place at Pioneer Farm. Pioneer Farm is the agriculture-research and animal science center located outside of Platteville. Due to the location of the Platteville Municipal Airport close to the farm, and the altitude reached by the rockets being launched, special waivers were obtained from the FAA that allows launches to occur at Pioneer Farm. Additional launches occur at locations that have also obtained FAA waivers.

Launch Controller

The launch controller was designed with two arming switches wired in series. The first switch is a key switch and the second is a safety toggle switch. Once both switches are armed, there are two momentary switches. When the first momentary switch is held, the controller sends a continuity check trough the igniter. Once continuity is confirmed, both momentary switches must be held to ignite the motor.

Checklists

There are procedural checklists for both preflight and post flight operations. These checklists include rocket assembly, prelaunch and launch procedures, and recovery procedures. See appendices 1, 2, and 3 for the actual checklists.

Empirical 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. These test flights allow the testing of 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 5th, 2015. This test flight was done on a rocket test platform known as the PRX-1 codename Iguanodon. This test flight was primarily focused 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 30th, 2016. This test flight was also launched using the Iguanodon test platform. This flight was a test of the electronics as well as a test for the airbrake mechanism. This first airbrake mechanism was a flap style brake. This flight suffered 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 second problem was due to a wiring failure where the Arduino lost power and failed to record data or deploy the airbrakes. This flight still provided a lot of useful data however. This flight showed 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 break in half. Because of this a more robust airbrake system was needed.

The third test flight took place on March 12th 2016. This flight was testing more complete electronics payload, the new Skybreaker prototype, and a newly designed airbrake system. This flight was a successful test of the new construction techniques as well as the general design of the rocket. The airbrake and avionics system were not as successful. An anomalous power loss occurred after the system had been powered on for several minutes. All attempts to replicate this problem have failed.

The next test flight is planned on April 2nd. This flight will implement some more advanced features of the program. It will actively record data from the flight, and deploy the air brake shortly after burnout to ensure that the brake design actually produces as much drag as modeled.

Conclusion

Pioneer Rocketry is eternally grateful to everybody that has made this team and our exploits 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 year's 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 to this unique problem. We are thrilled to bring Skybreaker to this competition. We look to the future for more challenges to overcome and more rockets to send skyward.

We would like to thank Duane Foust for being our faculty advisor and beloved mentor to our team. Duane taught us how to use the mills and laser cutters that we use to build our rocket parts and it is with the 3D printers in his shop that we make several of our parts. We would like to thank the University of Wisconsin-Platteville for hosting our team and allowing us to use their farm for a nearby rocket launch site. We would like to immensely thank the Wisconsin Space Grant Consortium for their continued support of our team. Last but not least, we would like to thank each and every member of our team. Without all our hardworking and dedicated members, Pioneer Rocketry would be nothing more than an idea.

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Appendices

Appendix I: Rocket Assembly Checklist

Electronics Assembly Checklist

- Stratologger
  - Ensure all four terminals are connecting
  - Switch on all Stratologgers before attaching charges or closing avionics bay
- Batteries
  - Ensure battery JST connectors are attached
- Jolly Logic
  - Ensure adequate battery supply (more than 50%)
  - Ensure securely attached
- Servo
  - Ensure Servo connected to Arduino
  - Ensure none of the wires are frayed or damaged
  - Ensure Servo begins activates
- Pitot Tube
  - Ensure Pitot tube is connected to the Arduino
  - Ensure none of the wires are frayed
- SD Card Writer
  - Ensure SD card is inserted into SD writer
- Arduino
  - Turn on Arduino
  - Ensure SD Writer begins to flash
  - Ensure computer receives telemetry
- LEDs
  - Ensure Arduino is connected to LED

Rocket Assembly Checklist

- Avionics Bay
  - Ensure both caps are secured
  - Ensure small blue ring is screwed onto the Avionics bay
- Shock Cord
  - Ensure shock cord is attached to both ends of the Avionics Bay
  - Ensure Parachute is attached to the shock cord
- Charges
  - Ensure Ejection charges are properly attached to the terminal blocks
  - Ensure Parachute is protected by dog barf or Nomex
- Connectors
  - Ensure shear pins and rivets are connected
- Motor
  - Ensure motor delay is properly set

Appendix II: Pre Flight Checklist

Pre Launch Checklist

- Is the rocket stable?
    - every flier should have CG and CP marked before coming to the RSO
        - both stages must be stable for multi stage rockets
- Are the fins solid?
- Any imperfections in the airframe?
    - Any cracks/dents?
- Is the parachute securely attached?
    - Is the shock cord fireproof?
    - Is the parachute protected against the ejection charge?
        - Nomex or Dog barf
- Will the parachute deploy at the right time?
    - Motor ejection has delay cut
    - Altimeters are configured correctly
        - Have ejection tests been done?
    - Are points of separation not too loose or too tight?
        - Good test is to hold the rocket upside down. if it separates, its too loose
    - Shear pins are required for dual deploy rockets
    - A vent hole is required for rockets going over a mile (5280 ft)
        - ⅛-3/16 inch hole
- Is there a large amount of flex in the rocket?
- Is motor sufficient to propel rocket?
    - Launch rail exit velocity >45mph? (20m/s)- can be less if no wind
    - NAR minimum 3:1 thrust to weight ratio (Average)
- Rail Guides properly secured
    - Adequate distance between rail guides?
    - Should be close to CG, not a must
- Is the motor properly secured?
    - Motor retention for both boost and ejection
- Will the rocket break the ceiling?
    - 3,500ft at Pioneer farms
    - 10,000ft at Bong
    - 15,000ft at Princeton
    -

Appendix III: Post Flight Checklist

- Pre Launch
    - Rocket Name
    - Description
    - Static Margin
    - Length
    - Liftoff Mass
    - Motor
    - Launch Site
    - Wind
    - Temp

- Launch Site GPS Coordinates

- Flight Analysis
  - Successful Flight?
  - Basic Description of Assent
  - Describe Recovery System
  - Single Deploy (Motor Ejection)
  - If Dual Deploy, which altimeter(s)?
  - Was recovery Entirely Successful? Explain
  - Flight Data Analysis
  - Altitude
  - Max Velocity
  - Max Acceleration
  - Any Abnormalities in Data? Explain
- Failure Report:
  - Suspected Cause of Failure
  - What steps can be taken to prevent this in the future?

Appendix IV: Budget

	Item	Company	Unit Price	Qty	Shipping	Total Cost
	Jolly Logic Altimeter	Apogee Components	$139.90	2		
11/9/2015	Sandisk MicroSD 2GB Memory Card	All-Out Mobile	$4.98	1		
11/9/2015	Pigtail Cable for DTx U	PerfectFliteDirect	$2.51	3	$7.51	$7.53
11/9/2016	Cable	Digi Key	$20.00	1		
	Breadboard Solderless 300 Tie	Digi Key	$4.50	1		
	Logic Level Converter	Digi Key	$2.95	2		$5.90
	Solder 1MM	Digi Key	$6.50	1		
1/11/2016	Screw Switch	Featherweight Altimeters	$5.00	6	$10.00	$30.00
1/11/2016	MicroSD Card	Adafruit Industries	$14.95	1	$13.79	$14.95
1/11/2016	Pitot Tube Kit	Eagle Tree Systems	$9.99	1	$8.00	$9.99
1/11/2016	Threaded Rod	MSCIndustrial Supply	$7.08	1		$7.08
1/11/2016	Zippy Flightmax 350 mAh	Hobby King	$3.19	4		$12.76
	Zippy Flightmaz 1000 mAh	Hobby King	$6.14	2		$12.28
	IMAX DC Charger	Hobby King	$15.58	1		$15.68
	Turnigy Nano Tech 750 mah	Hobby King	$3.10	2	$27.35	$6.20
1/13/2016	Arduino	Digi Key	$36.35	1		$36.35
	Sensor	Digi Key	$16.09	1		$16.09
	Wire Jumper	Digi Key	$3.06	1		$3.06
	Breadboard Solderless 300 Tie	Digi Key	$4.50	1		$4.50
	Bergstik	Digi Key	$1.44	4		$5.76
	Conn Header	Digi Key	$3.76	4		$15.04
	Kit LED	Digi Key	$15.60	1		$15.60
1/22/2016	Adata Micoshc	RadioShack	$49.98	1		$49.98
	9V 2 Pk Batteries	Menards	$3.99	3		$11.97
2/8/2016	Adapter Kit	Digi Key	$10	1		$10

	IC Reg LDO	Digi Key	$1.20	3		$3.60
	Mega Protoshield	Digi Key	$17.95	1		$17.95
	Conn Rcpt	Digi Key	$0.18	25		$4.46
	Conn Plub	Digi Key	$0.15	25		$3.52
2/23/2016	Foam	Tap Plastics	$29.95	1		$29.95
2/23/2016	SM Connector Series	Digi Key	$8.69	1		$8.69
	SM Connector Series	Digi Key	$0.07	50		$3.30
	RCY Series	Digi Key	$0.07	50		$3.45
	G12-2.1-24 - 54mm G12 Fiberglass Tube (2 feet)	Wildman Hobbies	28.8	1		28.8
	G12-4.0-60 - 98mm G12 Fiberglass Tube (5 feet)	Wildman Hobbies	116.725	2		233.45
	G10-1/8 - 1/8 INCH G10 FIBERGLASS SHEET 1 SQUARE FOOT	Wildman Hobbies	18	4		72
	G12CT-4.0-12 - 98mm G12 Coupler 12 inches long	Wildman Hobbies	31.2	3	$49.91	93.6
3/4/2016	Aluminum Threaded Standoffs	Servo City	1.49	1		1.49
	Flanged Ball Bearing 2 pack	Servo City	2.4	5		11.95
	16 Tooth 32 Pitch Gearmotot Pinion Gears	Servo City	8	5		39.95
	1/4" Precision D-Shafting	Servo City	1.09	5		5.45
	16 Tooth 32 P Futaba Metal Gear	Servo City	15	2	6.99	29.98
3/8/2016	New Turnigy		13.37	2		26.74
3/8/2016	1/4"-20 Rod	Menards	2.38	1	0.13	2.38