Pioneer Rocketry
2014 WSGC Collegiate Rocket Competition

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Society of Physics Students: University of Wisconsin-Platteville

Abstract

The objective of the 2014 Wisconsin Space Grant Consortium (WSGC) Collegiate Rocket Competition was to design a one-stage high-powered rocket that could accurately reach an apogee of 3,000 feet and then be recovered timely and safely and in a flyable condition. The competition also required two methods of determining velocity through the use of onboard electronics.

Overall, the performance in the 2014 WSGC Collegiate Rocketry Competition was a success. The rocket used for competition, ***Pioneer - I***, reached an apogee of 3094 feet. The time took to recover the rocket was approximately ten minutes. The apogee reached and recovery time, combined with our presentation, design report, post-flight report, and educational outreach services put us into first place for this year's competition[1].

The following report details the design, construction, and flight of Pioneer Rocketry's 2014 Competition Rocket ***Pioneer - I***. Pioneer Rocketry is composed of undergraduate students from the University of Wisconsin - Platteville. This report will detail:

- Competition Parameters
- Rocket Design and Construction
- Anticipated flight Performance
- Post Flight Results

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[1] WSGC 2014 Rocketry Competition Handbook

Pioneer Rocketry would like to thank Wisconsin Space Grant Consortium, the University of Wisconsin-Platteville, Duane Foust, and the Society of Physics Students-UW Platteville for their support through our many endeavors.

1.0 Competition parameters

According to the competition parameters handbook for the 2013-2014 WSGC Collegiate Rocket Competition, student teams will compete to design a one-stage, high-powered rocket that will as accurately as possible achieve an apogee of 3000 feet and be recovered safely and in flyable condition. The rocket shall carry onboard instrumentation sufficient to perform post-flight analysis in categories concerning the rocket's velocity, acceleration, and altitude. Teams will devise at minimum two methods by which the rocket will record these parameters during flight. The time to recover the rocket will also be used to calculate the results[1].

Flight Mission	● Capture flight performance using more than one type of measurement system ○ Speed vs. Altitude ○ Acceleration vs. Altitude More than one type of measurement system allows for cross-verification of the flight performance.
Flight Apogee Requirements	● Target Apogee 3000 feet ○ Max - 3500 feet ○ Min - 2500 feet
Parachute Deployment	● Electronic Dual-Deploy required ● Motor ejection charge backup required
Rocket Limits	● Body Diameter ○ Min - 4 inches ○ Max - 6 inches ● Length ○ Max - 84 inches
Rocket Motor	● Each team must select one of the following Cesaroni motors: ○ 38 mm I-540; J-285; J-316; J-357 ○ 54 mm K-400; K-445; K-454; K530

2.0 Rocket design and construction

This following section will go into details into the physical parameters of the rocket design as well as the components used in the rocket's interior.

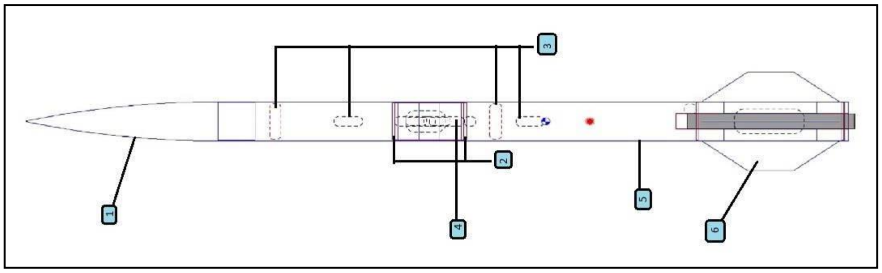

Figure 1: Pioneer-I Diagram

2.1 Nosecone The nosecone selected for Pioneer-1 was a 16.75 inch polypropylene design from Public Missiles Ltd. The shape of the nosecone is a tangent ogive. The tangent ogive nosecone was selected because it offers a good trade-off between stability and drag characteristics. We have previous experience using tangent ogive nosecones from other rockets which had been used as practice and verification platforms.

2.2 Control & stability systems Last year's rocket had mountable tube-fins that would be attached to the payload section of the rocket to increase drag and lower the maximum altitude. For this year's rocket it was decided not to control altitude using drag but rather through a system of interchangeable weights (or ballast). Using an interchangeable weighting system the weight of the rocket can be varied to control its flight. These weights will be attached to either the upper and lower avionics bay bulkheads. Through the process of placing variable weights along the interior length of the airframe, the stability and flight characteristics can be altered.

2.3 Recovery systems Per the competition parameters, Pioneer-1 operates on a dual deploy parachute system including one drogue and one main chute. Commonly, HPR parachutes are made from a single cut of ripstop nylon, which when deployed opens into a parabolic shape. A notable feature of our parachutes are that they are completely hemispherical, and also employ spill holes in their centers. "Squidding" is a term used for when a parachute fails to inflate fully, and instead ripples as the rocket falls. Though more expensive, hemispherical chutes should allow for a comparable descent rate relative to a parabolic chute, and reduce the chance of squidding. This is achieved by eliminating slack cloth, and allowing "through the chute" airflow by means of the central spill holes.

The drogue chute is to fire at apogee, and is housed in the booster section of the rocket. Safe recovery of high powered rockets mandates certain decent rates for each stage of parachute deployment in order to mitigate shock load while airborne, and impact trauma at landing. The drogue chute should allow the rocket to descend at approximately 55-60 feet per second (fps). Under both drogue and main chutes, the descent rate should slow to around 20 fps. Proper parachute sizing depends primarily on dead weight after motor burnout (6.7 lbs). Through this, along with experience from prior launches, the parachute sizes were determined. The shock cord which tethers the rocket after parachute deployment is made from a tubular nylon material with a nominal break strength of approximately 3100 lbs.

2.4 Avionics bay The avionics (AV) Bay is composed of a nine inch paper coupler tube and two birch plywood bulkheads. Housed inside the coupler is a birch-wood sled to which the electronics systems are mounted. Besides housing the electronics, the AV Bay also couples together the upper and lower rocket sections.

2.5 Airframe By using the J-357 motor, initial simulations predicted a significant overshoot of the target altitude. To increase the mass of the rocket prior to the addition of weighted rings, it was decided to make the rocket as large as possible by designing it to be just under the maximum length of six feet. For the airframe material, Quantum Tubing (QT) was selected from Public Missiles. QT is a proprietary material similar to PVC, and offers several preferable qualities that were felt to be ideal for the competition; mainly it's resistance to water damage, and relatively high fatigue and impact strength. Moisture resistance was especially important given the amount of marshland surrounding the competition launch zone.

2.6 Fins Pioneer-1 was designed to incorporate the use of four fins with a symmetrical trapezoidal rounded shape. This shape was adopted to reduce the possibility of damaging fins upon landing. Additionally, this shape helps with ease of assembly. To reduce the fin span and maintain the designed center of pressure (CP) the number of fins used was increased from three to four. The fins are designed as symmetrical trapezoids with a chord of 12 inches and a span of 3 inches. They are made of 0.125in aircraft grade birch plywood and are attached to both the motor tube and body tube. The connections between fins and the body tube are reinforced with thickened epoxy fillets and six ounce fiberglass fabric. This fin selection gives a dry stability caliber of two and a wet caliber of one. It is hoped that having this minimal stability caliber will help reduce the effects of weather cocking.

2.7 Weighting system In order to adjust the estimated altitude of the rocket, it is equipped with a system to adjust its overall weight and CG. This is accomplished using specially designed stainless steel plates which are attached to either ends of the avionics bay (figure 1). The plates were designed to not interfere with the various components inside the airframe. Plates with different weights are produced using a common shape but with various thicknesses. The plates were cut precisely using a CNC water jet table owned and operated by UW Platteville.

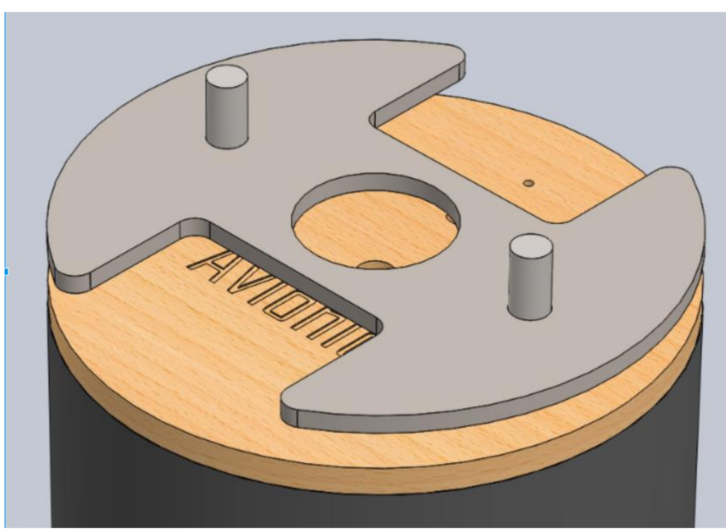

Figure 2: Pioneer-I Variable Weighting System

2.8 Rocket construction When constructing a rocket many things must be considered; most notably, the materials and fabrication methods used. To accurately attach the fins the *Tip to Tip Fin Jig* was used (http://www.jcrocket.com/tttjig.shtml). This jig both orients the fins with either 90 or 120 degrees of separation and provides a flat, supportive surface for applying a layer of fiberglass.

For this competition the team was granted access to the university's new laser cutter. This tool has provided the capability to rapidly prototype and test parts for the rocket. The laser cutter also provided the ability to make entirely custom parts which accurately fit the rocket body, most notably centering rings, bulkheads, fins and avionics sled. The ability to produce multiple designs proved especially beneficial when building the avionics sled. The laser cutter has proved very useful and we are looking forward to using to build future rockets.

Selection of a body tube material for construction is a critical decision which was made early in the design process. When building two previous rockets, problems were encountered with the standard phenolic tubing ripping and tearing at certain points such as rivet locations and shear pin holes. To combat this a product called Quantum Tubing marketed by Public Missiles was settled upon for the body tube. QT is resistant to the ripping and tearing that the phenolic tubing was subject to, but had its drawbacks; QT is nearly twice the price as phenolic tubing. It also expands and contracts with changes in temperatures. This in mind, much consideration was needed when designing some components in hopes that on launch day no material failures

2.9 Avionics The avionics bay on Pioneer-1 houses four systems including two of the teams own design, as well as the measurement system provided by the Wisconsin Space Grant Consortium for the Intercollegiate Rocketry Competition. The team decided to use the Raven III, Big Red Bee 900MHz, a Raspberry Pi, and a system built around the Freescale Freedom development board. The Raven III, which is the same device used by Space Grant to take their own measurements of our flight performance, will be our primary means of recording flight as well. This device is also used to deploy both of our parachutes. The team adopted the Raven III as compared to other systems such as the Adept, which was used in previous year’s competition rocket. The system was chosen for its ease of use and customizability. The Big Red Bee is a GPS coordinate transmitter designed for being used to track and locate rockets.

2.9.1 Secondary velocity measurement Our second method of data logging is a custom solution built around the microcontroller FRDM-KL25Z, a development board by Freescale. Last year the team used Flight Trac, a custom built data logger designed and constructed by team member Weston Woolcock; this year instead of refining that system the team felt that it would be advantageous to migrate to the freedom platform. The Freedom platform was chosen because of multiple advantageous qualities. The board has a 32-bit ARM processor, which is capable of running on a very low amount of power. This quality will help to reduce the amount of batteries we will need to fit in to our avionics bay. The board also has an Arduino compatible pin layout which allows developers to utilize the large amount of hardware for the Arduino platform. It is part of the Mbed platform which allows access to a wealth of code created by an active community of developers and a development environment all from within a web browser. Finally team member Luke Sackash already had experience with this board. In order to collect data, an electronic barometer is used to measure air pressure which is then used to calculate altitude with very low error. The Altitude is recorded with respect to time so that velocity and acceleration can then be calculated for Pioneer-1's flight.

2.9.2 GPS positioning The Big Red Bee sends the rockets GPS coordinates over a 900 MHz radio signal to a handheld radio device that is stationed at the launch site. Members of Pioneer Rocketry have developed software to interpret these coordinates and log them so that later a flight path can be reconstructed. The software developed also converts the coordinates received into a more user friendly format, allowing the team to briskly locate and retrieve the rocket. In preliminary flights the GPS proved extremely useful allowing for recovery of a rocket that would have otherwise been lost in the marshland of Bong Recreational Area.

2.9.3 Raspberry Pi and video

The final piece of hardware included is a Raspberry Pi and its camera peripheral to capture and store in-flight video. The raspberry pi is powered by a homebrew voltage regulated power supply. An SD card is loaded up with a Debian Linux distribution tailored specifically for the raspberry pi. At boot up, the camera module will begin to capture video. The captured video is then saved to the SD card. For next year's build there are hopes to take further advantage of the processing power the Pi for more advanced inflight data logging as well as exploring other possible uses.

3.0 Anticipated performance

Pioneer Rocketry's airframe designs depend heavily on the collection of empirical data. However following the current competition timeline it became impractical to construct and test the competition rocket prior to launch day. Because of this, PR has utilized simulation programs to help with design. The simulation program used was OpenRocket. This was the first time PR had used this program, and for this reason, we conducted three test flights prior to competition verify the software's accuracy. We tested a several different construction techniques and rocket designs, and referenced our flight data to the results given in OpenRocket (table 1). Data was taken for altitude, descent velocities, and acceleration.

There were a total of three test flights used to verify simulation results, two 38 mm Hi-tech rockets and one Torrent rocket. For the 38mm Hi-tech rockets one with a H-120 and the other with a H-152 motor, simulations were run in OpenRocket and the simulation data recorded. The rockets were then launched on Saturday, February 22nd, 2014 at Richard Bong State Recreation Area, and data was collected from those launches. The data from the Torrent rocket launch was deemed unusable due to a rapid unexpected disassembly (RUD). When comparing actual and simulated results, the predictions from our simulations matched the data collected on the launch day. Actual apogee was in both cases within a few hundred feet of predicted, proving that OpenRocket is a viable simulation program to use in the design of a rocket.

Rocket Hi-Tech H-45, 38 mm

	Predicted Data				Actual Flight Data		
Motor	Stability (Cal)	Apogee (ft)	Time to Apogee (s)	Flight Time (s)	Apogee (ft)	Time to Apogee (s)	Flight Time (s)
Cesaroni H120	1.72	3333	11.8	177	3168	26.5	111
Cesaroni H152BS	1.7	3363	11.6	174	3441	12.5	171

Table 1: Predicted Data compared to actual data of two test flights of both Hi-Tech rockets

4.0 Projected flight performance

A rocket must perform under strict parameters and is best built with experience and extensive testing as opposed to simulation. This said, we have extensively tested two practice rockets prior to construction of the Pioneer-1.

High powered rockets from previous team builds which had achieved apogees near 3000ft were used as models for this year's competition rocket. Given the anticipated weather conditions for April 5th 2014 Pioneer-1 was configured in the launch simulation software to overshoot the target altitude under perfect conditions. Our anticipated maximum altitude of 3256 feet is expected provided no wind and a vertical launch. To help us achieve the 3000 feet target accurately a weighting system was developed as explained above to help plan for changes in weather conditions. Estimates of peak acceleration from OpenRocket are about 13.2 G. We anticipate a peak acceleration of 34 G based on prior launch experience and the data recovered therein. Below is a graph showing the expected acceleration when compared to time from the simulation program OpenRocket and a graph showing the peak acceleration of a previous launch of the Super DX-3 rocket collected from a Raven altimeter.

4.1 Pressure and gravity diagrams By the insertion of weighted plates into the rocket airframe, the flight characteristics of the rocket can change on the fly. The ability to adjust the weight of the rocket allowed the team to achieve our target altitude under a variety of possible weather conditions. The weighting system allowed us to add ballast without significantly shifting the CG of the rocket.

5.0 Post-flight results

Our post flight data very closely matched what we had predicted from our simulations (figure 3); we had a few hiccups on launch day but we were able to quickly find solutions and apply fixes in the field.

Figure 1: Flight 2 Performance Characteristics Table

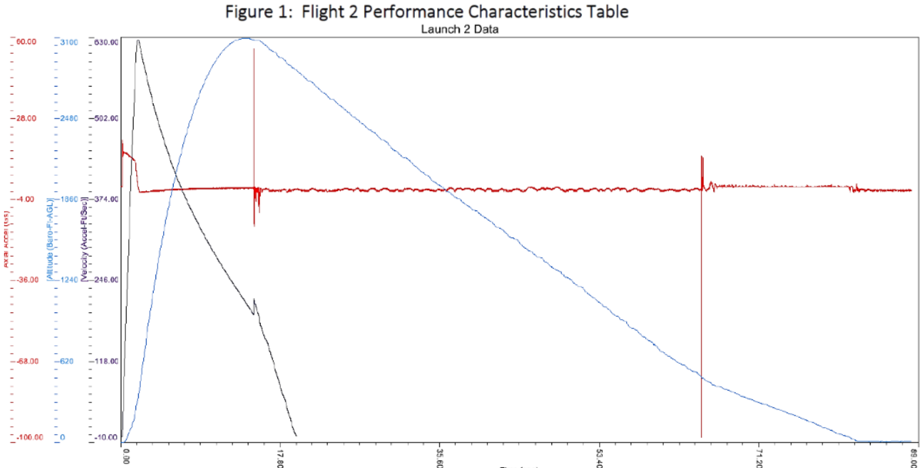

Figure 3: Flight 2 Performance Characteristics Graph

5.1 Data analysis & comparisons The predicted Apogee of 3018 feet was 76 feet below the measured apogee of 3094 ft from the second launch flight and the predicted maximum velocity was about 100 ft/s below the measured max velocity of 617 ft/s.

The predicted reasons for the discrepancy in apogee and maximum velocity may have been tied to the mass of the rocket. It is believed that there may have been a difference between the mass listed in OpenRocket and the actual mass at liftoff during flight-two. Changes were made to the mass of the rocket as a result of field repairs which took place after the first flight. It should be noted that the first launch (where mass was known) came in at an altitude closer to 3000 ft (2956 ft). Ballast was removed from the rocket for the second flight to compensate for the addition of epoxy and additional shock cord.

The predicted max acceleration was significantly different from the measured (table 2), overestimating by over 300 ft/s^2; in addition, the predicted acceleration curve on the graph is significantly different from the measured acceleration line on the measured graph, being much higher overall. This might be due to measurement error.

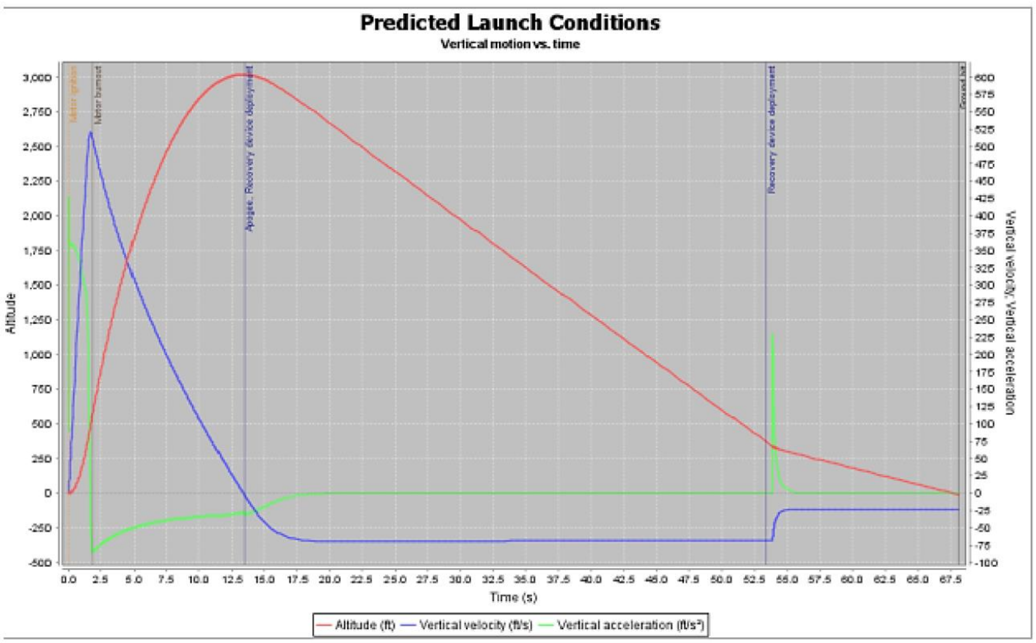

Figure 4: Flight performance characteristics from open rocket. The red line signifies the predicated altitude, the blue line signifies the predicated velocity, and the green line signifies the predicated vertical acceleration.

Predicted Data						Launch 2 Measured Flight Data			
Motor	Stability (Cal)	Apogee (ft)	Time to Apogee (s)	Max velocity (ft/s)	Max Accel (ft/s2)	Apogee (ft)	Time to Apogee (s)	Max velocity (ft/s)	Max Accel (ft/s2)
J357	1.14	3018	13.4	524	428	3094	17.73	617	55.61

Table 2: Flight performance characteristics

5.2 Performance of electronics systems

5.2.1 Expected outcomes The goal of our electronics bay was to capture in-flight video, log velocity and acceleration, and finally to send GPS coordinates our ground team. Our two methods of measuring velocity were intended to be our Raven III's accelerometer as well as a custom pressure logging system.

5.3 Actual outcomes

5.3.1 Overview From the start of the competition we noticed inconsistencies with our electronics bay. The GPS Board we had purchased was not being supplied a steady voltage and it was constantly restarting. Due to time constraints we were forced into our first launch without our active GPS system. By the time we had recovered our rocket we were confronted with the news that our in-flight video system as well as our pressure logging system had failed to log any data. Of the four systems we had on board, only one had properly functioned. As the rest of the team repaired the damaged rocket, the electronics team brainstormed solutions to fix the faulty avionics bay. We implemented a solution by rewiring the power supply of our failing in-flight video system to the GPS module. This was a big step in the right direction for our team. Not only were we able to secure a steady GPS signal, we also had a third method of calculating velocity secured. By the time our rocket was ready for a second launch; our GPS system was retrieving data properly (figure 5). The solution that we implemented ended up paying off. We ended up using the GPS coordinates as a velocity measurement, since the custom built system again failed to save coordinates.

5.3.2 Barometric measurement system Our secondary measurement system was supposed to log barometric pressure vs time to a flash memory chip which would then be sent to a computer via USB connection. The reason we used an external memory chip was to allow for the data to still be intact even if the board was power cycled (lost power). Our microcontroller could not write to its own memory. There was a problem in writing to and reading from the flash memory, however so no data was recovered from the device.

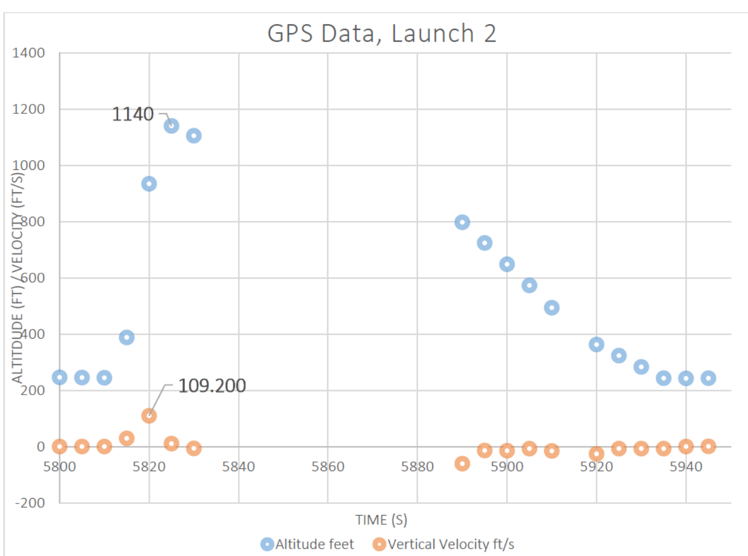

Figure 5: Flight-2 data as recorded by GPS system. The upper blue dots represent the altitude feet and the lower red dots represent the vertical velocity. Note the gaps between data packets, which in this case excludes data that would have marked flight-apogee.

6.0 Conclusion

The completion of Pioneer-1 brings a close to PR's second season as part of the WSGC intercollegiate rocketry competition. The challenge of designing a rocket capable of reaching the 3000 foot altitude while simultaneously logging data via a suite of onboard electronics has been met by the hard work and dedication of over twenty undergraduate engineering students. The larger airframe, extended avionics bay, additional data logging capabilities, and weight control systems integrated into Pioneer-1 are examples of our growth as a team, and our understanding in the fields of engineering and aerospace science.

PR's member base is not small, and for this reason is modeled differently than most contenders in this year's competition. Our intent is to become more than just an isolated group of rocketeers, but rather to be an integral part of our University's selection of student organizations. It is hoped that over the coming years PR will expand its membership, build more rockets, conduct more launches, receive more HPR certifications, and lend creditability to the use of aerospace applications as part of an undergraduate college curriculum. We are grateful to WSGC and Tripoli Rocketry for allowing us the opportunity to compete, and we look forward to the coming competition.

Figure 6: 2013-2014 Pioneer Rocketry Team