Pioner Rocketry
2016 WSGC Collegiate Rocket Competition

Adrian Guither, Bryan Reyes, Christina DeVries

Society of Physics Students: University of Wisconsin-Plattevile

Abstract
The objective of the 2016 Wisconsin Space Grant Consortium Collegiate Rocket Launch Competition was to design and build a "true scale model" of any real world rocket or missile. We selected to bring a scale model of the Orbital ATK Pegasus XL to this year's competition. We had three flights during the competition, all of which were successful, meaning that the rocket flew as intended and sustained no damage, and the apogees were close to our expected values.

This, as well as our documentation, earned us first place in this year's competition. The following report details the design and construction of Pioneer Rocketry's 2016 competition rocket, along with information regarding Pioneer Rocketry's growth as both an educational and professional organization.

Year in Review

Our fourth competition year was a year of exponential growth for Pioneer Rocketry, both in terms of membership and activity. During the fall of this year, we hosted an in-house contest named TREX (Team Rockery Educational eXtravaganza) to promote our club, as well as teach all new and returning members the basics of high power rocketry. 8 teams of 3 or 4 members worked together to design, build, and fly a basic high power rocket. They competed against each other to achieve an altitude as close as possible to the target altitude of 1500ft. Building on that experience, several members pursued their high power certifications. Five of our members achieved their level one certification, and four members achieved their level two certifications this year.

Fig. 1: All club members posing with their rockets prior to our TREX launch.

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Fig. 2: Various members with their cerfitication rockets.

This year was also the first year that Pioneer Rocketry has competed in more than one competition, competing not only in the Collegiate Rocket Launch, which we will talk about here, but also in Minnesota Space Grant Consortium's Midwest Rocket Launch, where we placed third in the nation.

In a short period of time, we've greatly expanded our team and our knowledge. We've come a long way from the original rag-tag group of enthusiastic amateur rocketeers who founded this team a few short years ago. With the foundation they laid, we've grown into a respectable team with a large amount of rocketry experience . We're excited to continue our path of exponential growth and creating new rocketry adventures!

Fig. 3: The MRL team with Skybreaker, our airbrake rocket

Adrian Guither
Pioneer Rocketry WSGC CRL 2016 Team Lead
Vice President, Pioneer Rocketry

Rocket Design

Competition Overview. The goal of this year's collegiate rocket launch competition was to construct and accurately model a scale model of any real world rocket or missile. The competition was scored based on the accuracy of our predictions. For this competition, we chose to build a scale model of the Orbital ATK Pegasus XL.

Orbital ATK Pegasus XL. The Pegasus rocket was originally created by Orbital ATK as a low cost way to send payloads into space. The feature on the Pegasus rocket that makes it unique is the triangular wing that is on the body tube of the rocket. To launch, the rocket is attached to an L-1011 aircraft where it is released at an altitude of 12,000 ft and its first stage ignites. Pegasus has been active since 1990 and has flown 42 missions as of June, 2013.

General Design

With such a unique rocket, the design required careful consideration. The design had to be altered to maintain the stability of the rocket. The first of these alterations was to make the wing removable. The wing can be removed by simply unscrewing 2 bolts. This allows for the rocket to be flown in higher wind speed, and not be greatly impacted. We also increased the stability of the rocket with a modular weight system. Weights have been water jet cut out of stainless steel, and are designed to be attached to the base of the nose cone. The rocket supports up to 1Kg (2.2lb) of additional weight.

With the objective of the competition being to build the most accurate scale model possible, several features not found on traditional rockets had to be designed. The most obvious is the wing, which was precisely laser cut to the exact scaled dimensions. Another key feature is the fins, which have 3D printed profiles to accurately portray the airfoil of the fins on the Pegasus XL. Also of note is the wing attachment point and nose cone, which have been 3D printed to the exact scaled dimensions.

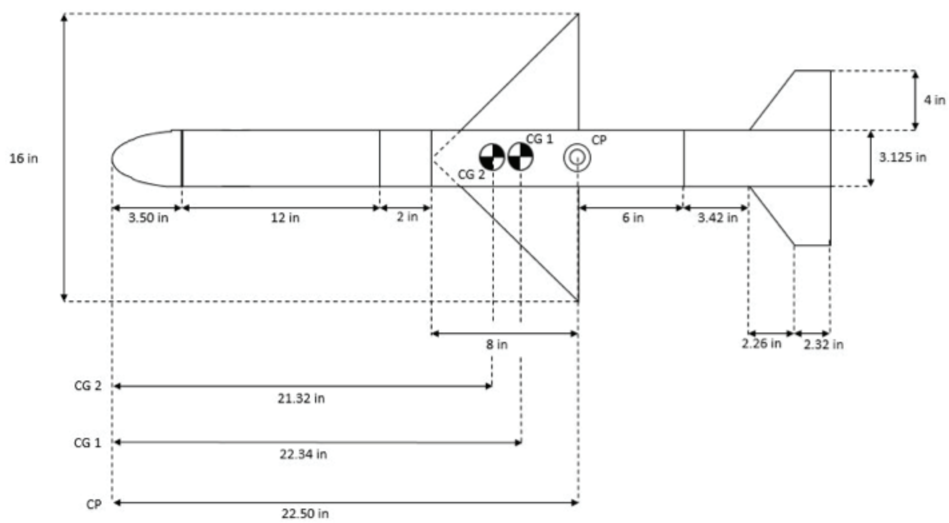

Fig. 4: Dimensioned drawing of our Pegasus XL rocket

Stability Analysis.

With such a unique design, stability was one of our key concerns in dealing with this project. Several different approaches were taken in order to asses the stability of the rocket. The first approach was to run a basic simulation in openrocket. This basic simulation gave us a stability of just over 1 caliber. The next step was to build a lower power scale model, as will be discussed in a future section. With the simulations confirmed by the performance of the low power scale model, construction began on the final competition vehicle.

The competition handbook [1], as well as Tripoli safety codes [2] require the rocket to have a stability of above one. With the final vehicle constructed, the stability was shown to be 1.01 Calibers in openrocket, however, the stability was shown to be a much higher (2.6) in RockSim. It is unknown why these two simulation programs provided a different result, as they both claim to use the same equations, originally developed by James S. Barrowman. The data and pictures from our test flight shows that the rocket flew straight and true, with very little wind. Our consensus it that the rockets stability is above one, and very safe to fly, even with the wing attached.

Construction

For our model of the Pegasus, the majority of the components were made out of fiberglass for added strength, heat resistance, low weight, and low cost compared to carbon fiber. The body tube, coupler, and centering rings are all made of fiberglass; while the nose cone, and wing mount were 3D printed out of PLA plastic. The fins were made of carbon fiber and their profiles were 3D printed with PLA. The wing itself is made of 6mm plywood and bolted to the mount.

The nose cone was fiberglassed with 6oz fiberglass cloth to provide extra strength to the 3D printed PLA. Ballast was added to the nose - a series of water jetted steel weights- before each flight to provide stability.

The fins were an interesting endeavor. Strength was key, so making them out of carbon fiber and through the wall was the clear choice. Then there was the dilemma of making the fins appear correct to the original Pegasus rocket. The fins began as flat, 3/32” carbon fiber. To accomplish the minute bends and curves of the fins, 3D printed PLA fin profiles were epoxied to the either side of the fins and then fiberglass cloth was applied to seal everything together.

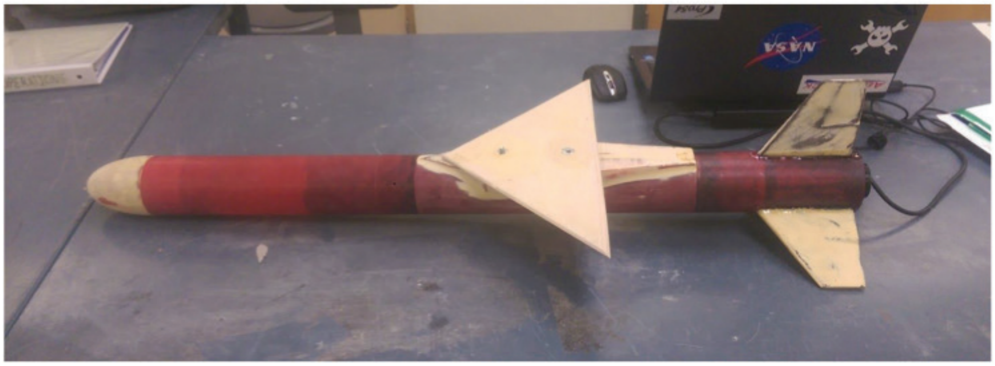

Fig. 5: The completed rocket ready for painting.

To test how fiberglassing components affected their compressive load, raw materials were obtained, cut out two pieces of equal size, epoxied fiberglass to one of the pieces, and tested their strength in a Universal Testing Machine. Results found that by applying fiberglass cloth to our rocket’s components, their compressive strength increased by a factor of 7.

Testing

Smaller Scale Model. The Orbital ATK Pegasus XL is different from a conventional rocket in that it has a wing. It was not known if such a design could be simulated accurately, or if it would fly stable at all. With so much unknown about the rocket, it was decided to make a lower impulse scale model to assess these concerns. The purpose of the smaller scale model was to assess whether conventional model rocket simulation software would work with this unique design.

The smaller scale model test flight was a great success. The rocket flew stable, and reached an altitude that was very close to the simulated altitude (error of 0.1%). The measured peak altitude was 784 feet while simulation data gave us 785 feet. This design did use a significant amount of nose weight in order to make it stable, and this has been accounted for in our final competition design.

Fig. 6: Christina, Adrian, Tyler, and Bryan with smaller scale model

Test Flights

Prior to the competition, three test flights were conducted with the completed rocket. Two flights out of Richard Bong State Recreation Area, and one out of our very own launch site, Pioneer

Farms. With the rocket successfully flight tested, we moved on to the competition.

Fig. 7: Liftoff on the first test flight of our competition rocket

Flight Summary

During the competition, we were able to conduct three successful flights.The rocket sustained no damage during any of the flights and our team was able to recover the rocket quickly. This allowed us to select the flight with the highest possible score to submit as our scoring flight.

Due to our experience gained from our three test launches of the pegasus rocket, we were able to execute our pre and post launch procedure flawlessly. We utilized checklists that we had established and refined at previous launches to ensure all steps were as fast as possible. It is due to our practice launching our rocket that we were able to be the first CRL team to launch on launch day, as well as the only team to launch three separate times.

Fig. 8: The Pegasus at liftoff for competition launch 1, 2, 3 Respectively

Anticipated Performace vs. Actual Performance

Altitude Comparison:

The differences in predicted and actual apogee for each flight were 107 ft, 237 ft, and 157 ft. We undershot our predicted apogee value each time which we believe is due to the wind conditions. Our estimates were based on test flight data from nearly zero wind conditions. We now believe that the wing has a much greater effect on the altitude at higher wind speeds.

Acceleration Comparison

Our predicted and actual thrust curves appear very close with the exception of noisy data provided by the raven. However, the peak values are not identical. We predicted a maximum acceleration of 15.6G, and the accelerometer reported a maximum acceleration of 21G. We believe the accelerometer to be faulty, because the rocket weighed roughly 40 N, and our motor, the CTI I540 provides a maximum thrust of 620 N, Giving our rocket a thrust to weight ratio of 15.5. We believe that this is the acceleration that our rocket experienced, and that the raven's accelerometer was not calibrated properly.

Velocity Comparison

Similarly to our acceleration data, our velocity data is based off of a numerical first derivative approximation. Our data showed a maximum velocity of around 480 ft/s on our scoring flight. The Raven 3 provided by WSGC measured a maximum velocity of 499 ft/s on our scoring flight. This is the barometrically derived velocity, as the accelerometer of the raven was not providing accurate acceleration data. This was very close to our predicted maximum velocity of 494 ft/s, and we are very satisfied in the accuracy of our predictions.

Conclusion

Pioneer Rocketry is doing very well, and we are very happy with the results from this year's competition. The Pegasus rocket posed a unique challenge, and we did our best to construct a great rocket that we are pleased to have flown at this year's competition. The percent error from our predicted and actual altitude was 6%, putting us first in the flight score category, as well as the competition overall. We are also very grateful that we were able to fly three times at the competition, and very satisfied with the consistent apogees. We are, as always, thrilled to have this opportunity and to share our enthusiasm for aerospace with the world.

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References

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Tripoli Rocketry Association. Code for High Power Rocketry. May 2016. PDF.