Pioneer Rocketry

University of Wisconsin-Platteville

Preliminary Design Report

Minnesota Space Grant Consortium

Midwest High-Power Rocket Competition 2016-2017

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Table of Contents

Executive Summary

Moving into our 5th year as an organization, Pioneer Rocketry has hit the ground running. We began the year with our annual TREX (Team rocketry educational extravaganza) in which all club members learned the basics of high power rocketry. Many members have decided to build on this experience and pursue high power certification, including several members of this team. Currently, four of our team members are high power certified, and those that are not currently certified are in the process of constructing their certification rockets.

Figure 1:Some of our team members' complete and in-progress certification rockets.

Pioneer Rocketry has also hit the ground running with our competition rockets. This began with the construction and flight of the Shredder, a prototype rocket constructed to test the feasibility of our design, along with testing of various construction techniques. The Shredder had two flights, both of which we learned a great deal from.

Moving on from the lessons learned from the Shredder, work began on our final competition rocket. Because of the nature of this competition, the rocket is a relatively simplistic high power rocket, with a minimum-diameter design. The majority of the design decisions were centered around saving weight while still being able to withstand the expected forces from both 100 G+ acceleration and speeds well over the speed of sound. This report will cover the design and construction of this rocket and its electronics, as well as the design and implementation of our electronics systems.

Pioneer Rocketry has been hard at work this year, and we are looking forward to bringing a rocket we are proud of to this competition.

Adrian Guither, Pioneer Rocketry President

Overview of Model Rocket Flight

Shredder was designed to fly on the I-J combination of motors. The fin design was constructed so there would be as much drag as possible.The body tube was made of fiberglassed 54mm cardboard tube. The first flight was at Midwest Power in Princeton, Illinois. The rocket flew on a CTI H565 Vmax motor. This motor was chosen to simulate the high G forces that were expected in the launches to come. A lot of useful information was learned at this launch, but not without cost. After burnout “Shredder” drag separated due to the large drag force the fins created, along with a shear pin that was forgotten to be installed in the rocket. This caused Shredder to deploy the parachute directly after boost and snap the shock cord. Upon crash landing, the rocket was found in three parts: the parachute, the nose cone and electronics, and the fin can section. The electronics and nosecone survived with minor damage and the parachute only had a quick link attached which had drifted for about a half mile. The fin can section suffered the worst fate. However, the only damage occurred from the body tube zippering about one inch. For the next flight the damaged section of the body tube was cut off and a shear pin was added. The second flight was on an H143 and flew successfully as can be seen in the picture below.

Figure 2

Rocket Design

Design Philosophy

With a competition this broad, there are many choices to how to approach it. Multiple altitude adjustment designs were considered, including electric-ducted fans, retrograde thrust with a cold gas thruster, or air brakes, among many others. All of these possible designs were optimized and weighted against each other for the highest figure of merit. Airbrakes appeared to give the highest FM, giving an FM of approximately 100,000. However, in optimizing these designs, the designs with the least mass, and thus the highest altitude, scored the highest, even if the altitude adjustment system did not perform very well. Capitalizing on this, it was decided to discard the extra mass caused by an altitude adjustment system, and utilize a fully passive design. In optimizing this design, it was found that by making the fins and nosecone as non-aerodynamic as possible, the rocket was able to achieve very similar altitudes on both the higher power and the lower power motor. This passive design was able to achieve a FM of over twice the FM possible with an active altitude adjustment system.

Rocket Dimensions

The design of Time Warp is one large optimization problem. The length of the rocket was first decided with a couple factors in mind: space for electronics and space for recovery. With the abundance of electronics going into this rocket the 18" upper section is strictly used for electronics. The diameter of the rocket was one of the main goals is to achieve the highest altitude. The fins' height and root cord were adjusted from Shredder to give a higher altitude on both the low and high powered flights. This is also the reason why it was decided to make Time Warp a 54 mm minimum diameter design. This gives us a better FM score as well as achieving the bonus points for going over 5000 ft.

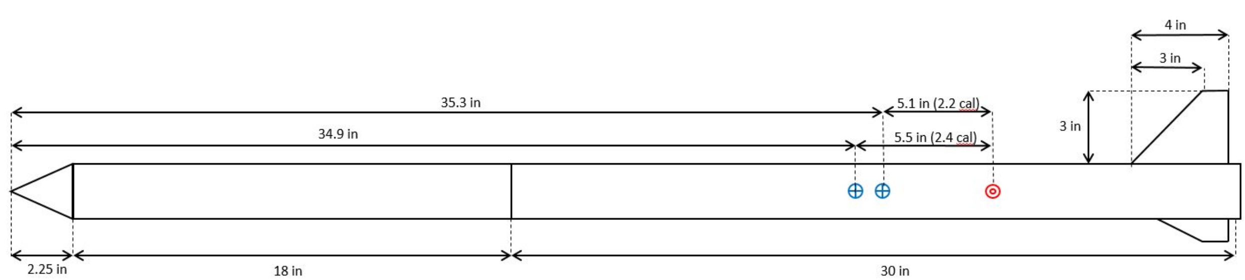

Figure 3: Dimensioned drawing of the rocket, showing CP and CG on both motors

Motor selection

For the motor choice, the J90 and K2045 have been selected. This motor combination give a FM numerator of 45.2. Originally, the rocket was designed around flying on the I55 and the J1520, because this motor combination gives a FM numerator of 76.5, the highest available within the available motors. However, it was found to be difficult to achieve the required rail exit velocity of 45 ft/s on the I55. With the option to fly on motors other than Cesaroni motors, the J90 was found to be the optimal choice for a lower power J. There are a few choices for the optimal higher power K motor. The majority of these motors were found to be plugged. Of the ones available to us for this competition, the choices include the K2045 and the K1440. The K1440 is the optimal choice for the highest FM numerator, giving a FM numerator of 53.6. However, the much higher impulse of the K1440 did not allow for it to be utilized in our fully passive design. The K2045 achieves similar simulated altitudes to the J90 fully passively. Another reason behind the switch from I-J to J-K is that higher altitudes are achievable with the higher impulse motors. With the I-J configuration, it was exceedingly difficult to get to 5000 ft, which would ensure the bonus points for an altitude above 3000 ft. With the J-K configuration, altitudes above 5000 ft are easily achievable.

Note: the term “FM numerator” refers the the multiplication of the ratios of the thrust of the two motors by the ratio of the two impulses.

Propulsion system specifications

For the lower power motor, the Aerotech J90 White Lightning was selected. This motor has both a very low thrust, and a very low impulse for a J motor, ideal for this competition. It has a total impulse of 707 Ns, making it a 11% J, and a initial thrust of 125 N, giving our rocket a thrust to weight ratio of 7.722. Due to the uneven nature of the thrust of the J90, the initial thrust was used instead of the average thrust as it better describes the performance off the launch rail. Even with the low thrust provided by this motor, our rocket is still able to leave the rail at 61.4 ft/s

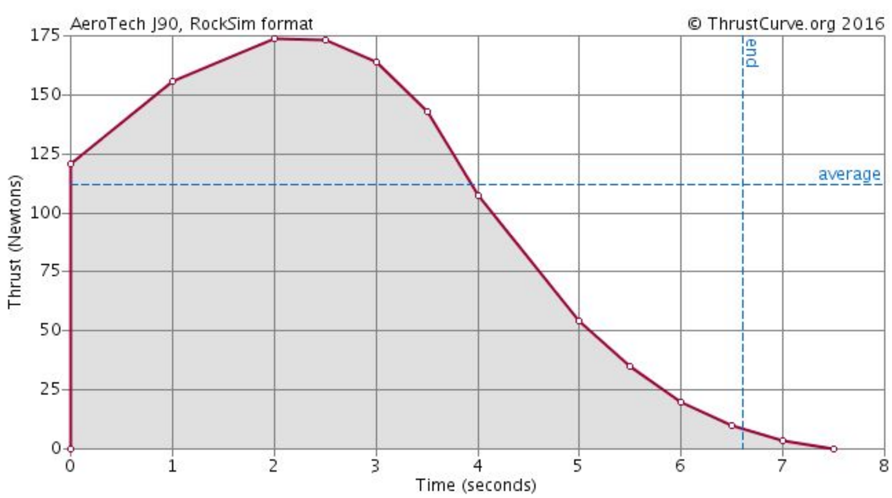

Figure 4: Thrust curve of the Aerotech J90 White Lightning

For the higher power motor, the Cesaroni K2045 VMAX has been chosen. This motor does not have as high of an impulse as other possible motors, but makes up for it with the amount of thrust it provides. It has a total impulse of 1417 N s, resulting in it being a 11%K. The K2045 provides a staggering 2045 N of thrust, giving our rocket a thrust to weight ratio of 99.4 and easily pushing our rocket past the speed of sound.

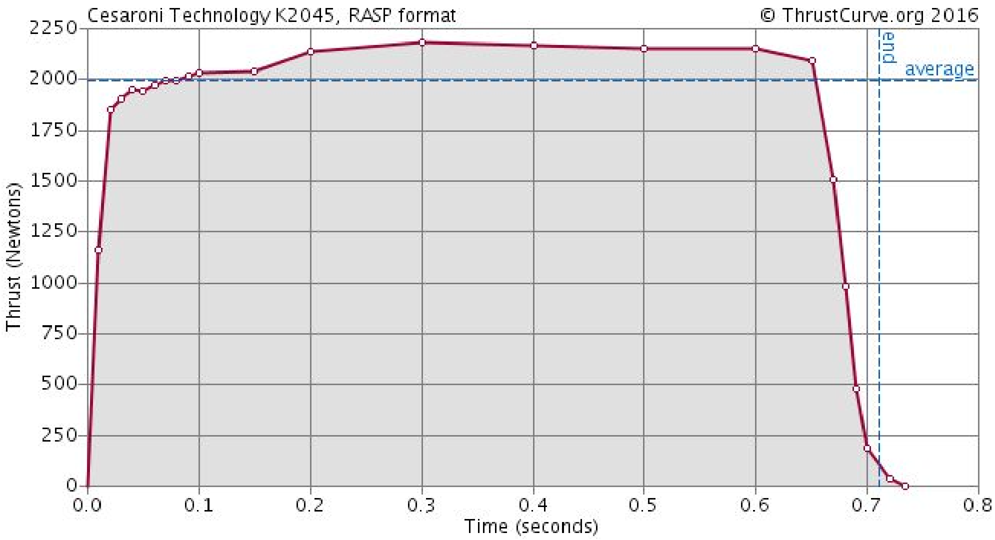

Figure 5: Thrust curve of the Cesaroni K2045 VMAX

Design and construction of rocket features

Nosecone

The nosecone of our rocket was 3D printed out of PLA plastic and reinforced with epoxy. The nose cone is designed to withstand supersonic flight. Similar construction techniques have been used on supersonic rockets in the past. The nosecone is a hack series cone with a height of 2.25 in, giving it a 1:1 aspect ratio. This results in a nose cone that is significantly shorter than a nosecone traditionally found on supersonic rockets. This design allows the rocket to experience significantly higher drag forces in supersonic flight on the K2045, and has a far lesser effect on the drag force of the rocket during the subsonic flight on the J90.

Airframe

The airframe of our rocket was constructed out of 54 mm LOC Precision cardboard tubing, reinforced with a single wrap of 6 oz. fiberglass. In compressive testing, unmodified LOC tubing was found to withstand a compressive load of approximately 200 lbs. With the maximum thrust of the K2045 being 501.6 lbs, this was found to be insufficient. The use of stronger materials such as filament wound fiberglass tubing or carbon fiber tubing was considered, however these materials were found to be too heavy. LOC cardboard tube with a layer of fiberglass reinforcement was found to be able to withstand a compressive load of approximately 1400 lbs. This material was selected, resulting in a factor of safety of 2.8.

Figure 6: Unmodified (left) and reinforced (right) specimens after compressive testing

Fins

The fins of our rocket were constructed out of a ⅜ in thick balsa sandwich, and were surface mounted to the airframe. They were then reinforced with a fin-tip to fin-tip fiberglass reinforcement. Leading edges of the fins were also reinforced with fiberglass. Fiberglass reinforced balsa was chosen for multiple reasons. First, It has an excellent strength to weight ratio. Second, it allows much thicker fins to be very light, compared to a material such as Garolite G10 fiberglass sheet. The thickness of the fins is designed to cause significantly larger drag at supersonic velocities during our higher power flight, and have a far lesser effect on the drag at subsonic velocities on our lower power flight, similar to the nose cone.

Recovery System

The main feature of the recovery system is two parachutes, a 12 inch drogue and a 24 inch main. We found in our simulations that these sizes were sufficient to have the rocket descend at a safe rate of under 24 ft/s. If these sizes are found to be inadequate due to future changes in the rocket, the sizes will be changed accordingly. Both of these parachutes will be manufactured in house, out of ripstop nylon. To test construction techniques, multiple prototype parachutes have been made and successfully flown in a variety of configurations. Possibly the most extreme scenario where these prototype parachutes were tested is during the first test flight of the Shredder. During this flight, the rocket drag separated shortly after burnout, deploying the parachute at approximately 250 m/s. The parachute survived with minimal damage, and has flown successfully on multiple rockets since.

Figure 7: Some prototype parachutes (left) and a rocket being recovered by one (right)

Both the main and the drogue parachute will be ejected at apogee, however only the drogue will be allowed to inflate. The main parachute will be unfurled during descent at an altitude of 700 ft by a Jolly Logic Chute Release. This was done to minimize breaks in the rocket, while minimizing drift and satisfying the requirement that the rocket be dual deployment.

Fly-away rail guides

To minimize uneven drag on the rocket, the decision was made to utilize fly-away style rail guides. The fly-away rail guides are of fairly conventional design, utilizing two rubber bands to propel the rail guides off the rocket after the rocket clears the launch rail. Before the rocket leaves the rail, the rail guides are held in place by the rail. Another reason that fly-away rail guides were used is that because of the minimum diameter nature of the rocket, attaching the rail guides via holes in the body tube was not possible. The possibility of attaching the rail guides directly to the outside of the body tube was attempted with the Shredder, however it was found to be an inelegant solution.

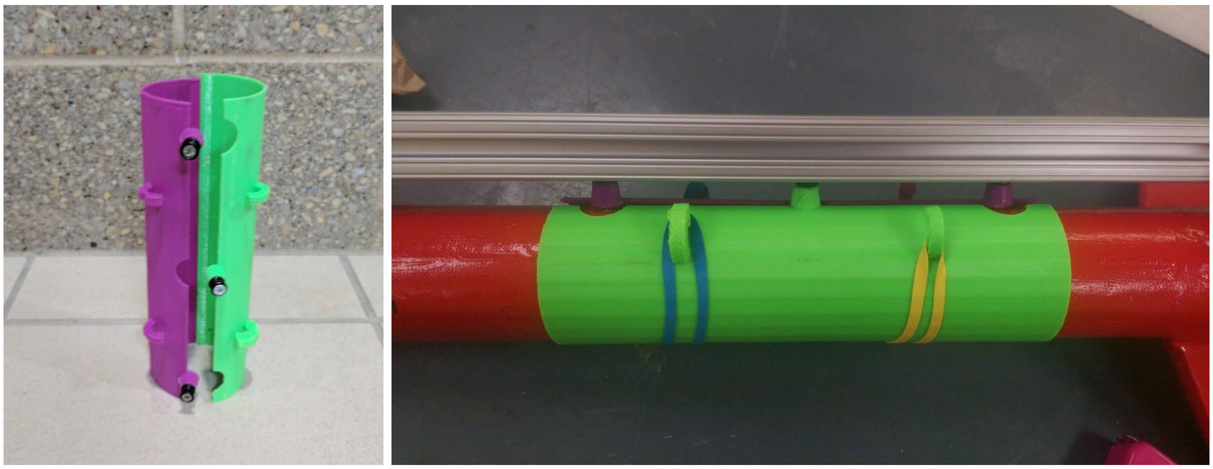

Figure 8: The fly-away rail guides(left) and them holding a rocket on a rail (right)

On the successful test flight of the Shredder it was observed that the fly-away rail guides made contact with the fins after being released from the rocket and thus the rail. As seen in the pictures below it adds a considerable initial flight irregularity to the rocket as it takes flight, but is corrected naturally. In each picture starting from the left it can be seen that when the rail guides make contact with the fins, the rocket veers of to the right as a result. In the next picture the fins correct the instability and the rocket continues upwards. To counteract this, several changes have been or will be made. The first change was the size of the fins on Time Warp are considerably smaller and have a larger sweep angle to prevent the rail guides from making as big of an impact. The second change that will be made is to the design of the rail guides themselves. They will be made with half the material, making them into a semicircle instead. This will allow for less surface area to possibly make contact with the fins after the rocket has left the launch rail.

Figure 9: The fly-away rail guides hitting the fins during ascent

Design features of Electronics

Electronics

The electronics challenges for this rocket are different than in past years. The simulated rocket has a G-force of 100 G's. This means that something that has a mass of 5 g will have the force of 500 grams force at 100 G's. Careful consideration is being made with how the electronics are attached to the avionics sled.

Physical Components of the Avionics Bay

Physical components

- Jst connectors
- (2) arduino micro
- (2) pull pin switches
- Pitot tube
- GPS module with XBee
- (2) cameras
- Jolly Logic Chute Release
- Jolly Logic Altimeter 2

- (3) Lipo batteries

Since the rocket has a minimum diameter design, the electronics needed to fill out more of the length of the rocket in order to accommodate competition requirements as well as our own requirements. The avionics sled was specifically designed to provide support for all of the electronics components along the axis of acceleration.

Pitot Tube

Pitot tube systems work by taking a differential pressure reading between the outside craft and the inside of the craft. These pressure readings are also known as *stagnation pressure* and *static pressure*, respectively. The differential pressure takes both of these pressure readings and returns *dynamic pressure.* Using the dynamic pressure, it is possible to find the fluid flow velocity. The equation for the fluid flow velocity looks like $u=\sqrt{(2*P/\rho)}$.

This equation works fantastically at low speeds. However, our rocket was designed to go well past Mach 1. At these speeds, a bow shock forms at the tip of the pitot tube. This lowers the stagnant pressure and the low-speed approximation no longer applies. To take this into account we use a lookup table that was computed from the Rayleigh Pitot tube formula that takes the bow shock into account. We use a lookup table because the Arduino Micro that is calculating and logging this velocity has limited processing power.

The electronics component of the pitot tube is comparatively simple. We have a differential pressure sensor that outputs a voltage from 0 V to 5 V depending on the difference in pressure between the two ports. One port is connected to the pitot tube and the other is left disconnected in order to measure the static pressure within the nose cone. The pressure sensor is then connected to analog input pins on the arduino data logger. The arduino reads the voltage as a value from 0 - 1023 using its 10-bit Analog to Digital Converter (ADC). This value is converted to a pressure and referenced to the lookup table to determine the speed of the rocket. A possible concern for this approach is accuracy. With only a 0 - 1023 resolution split accross 0 m/s to 680 m/s *and* the fact that the equation grows rapidly at small pressures means low speeds are not accurately logged. An active control scheme would have to take this into account by taking more sensitive pressure readings for increased control accuracy at lower velocities. However, we do not have to take this into account because we are using a passive control scheme.

GPS

An optional add-on to our electronics payload is a GPS/XBee telemetry system. This is in an internal project for Pioneer Rocketry to ensure that we lose far fewer rockets. The idea is to take a GPS module and send the received coordinates over the XBee radios. The user on the receiving end can then open the coordinates on their favorite maps service, such as Bing Maps, OpenStreetMaps, or even MapQuest.

The GPS module used in this project is the Adafruit Ultimate GPS Breakout. This module also includes a pre-written library that lets you simply connect the wires and go. However, that convenience comes with the cost of a very bloated library. We have gutted almost the entire library in an effort to save every byte of memory.

XBee

XBee modules are small modules that provide easy-to-use and reliable radio communication for hobbyist projects. We use these modules for telemetry. The above section stated that we are using these modules to transmit the rocket’s current latitude and longitude. We are also using them to print out any other telemetry that we may want a real time readout for. Data printed out over the telemetry system includes pitot tube velocity, latitude and longitude, and the separation state of the rocket.

The exact XBee modules we use are called the “XBee Pro S1”. These modules transmit a 2.4 GHz radio transmission at about 100 mW. This power give us a range of roughly one mile. This range has proven troublesome in the past with rockets that flew higher than ~3500 ft. Due to this, we usually experience a drop in communication at apogee. Research into new telemetry systems and other XBee modules is ongoing.

Separation Detection System

The separation detection system was designed to be as simple as possible. A pull pin switch design was the simplest to implement and is the same system that is also used to arm the stratologger. The separation detection will work by having a pin connected to the shock cord in the rocket which will be inserted into a tube that forces the limit switch closed. A normally open contact limit switch will be used so that when separation happens, the signal from the arduino will continue through the switch and back to the arduino. The arduino will sense the change in signal from low to high and the code will tell the arduino to print to an SD card when separation has occurred.

The pull pin switch used to arm the stratologger can be seen in figure 10 below. The switch is mounted such that the G forces of the rocket taking off will not have any chance of turning off the electronics. We also have a “remove before flight” tag attached to the pull pin to assure that the electronics are armed before flight

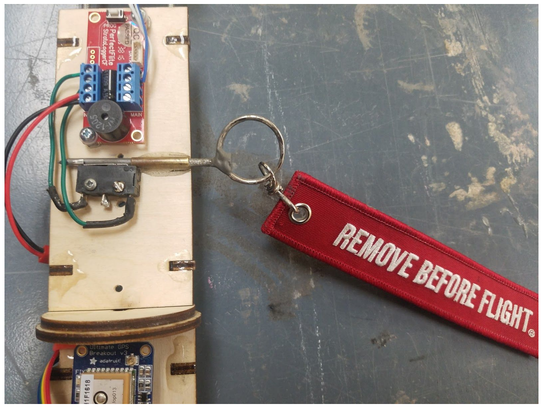

Figure 10: This shows how the pull pin switch is used to arm the electronics

Video capture

The camera design for this rocket is particularly challenging as the design of the rocket depends on a predictable aerodynamic flight profile. This forces the design to have the cameras mounted internally This competition requires a video looking both up and down the rocket. Two separate cameras mounted inside the rocket which are positioned at an angle to the inside of the rocket will satisfy this requirement. With this design a portion of the body tube will need to be cut to allow the cameras to see up and down.

Electronics Testing

A ground test was first conducted on the GPS after assembly to make sure that data was being saved to the SD card. Next the experiment test bed “Iguanodon” was used to test the GPS during flight. The results were exactly what was expected. The GPS printed exact latitude and longitude data as well as horizontal and vertical speed. The next test that was conducted was with the XBee radio modules included. There were some troubles incorporating the XBee code into the code for the GPS, but after some fine tuning, the GPS and radios were working when a ground test was conducted. The current design of Time Warp was ready to fly out in the field but the XBee radios did not seem to work. The data logging and GPS were working so we decided to fly and test the rocket and electronics. Once again it was a successful flight and the data we retrieved was very useful. The GPS was able to give an accuracy of .79 meters which was verified by seeing the actual location the rocket was and where the GPS coordinates were. The next flight will be on a larger motor to test the strain of the electronics in high G situations and will also simulate the rocket as if it were ready to fly in the competition.

Test Flight Performance

The test flight of Time Warp was on a CTI H180 skidmark motor. This motor was specifically chosen because of motors available and the altitude limitation that was at the launch site. A 54 mm to 29 mm motor adapter was used to allow the motor to be used in our 54 mm motor mount tube. The flight performance of Time Warp was fairly close to what was expected, however there were some differences. The biggest difference between simulation and flight was the altitude. This was believed to be caused by the rather high wind speed. Although the 15-20 MPH wind speed was accounted for in the simulation the altitude difference was still 250 ft compared to the actual flight. This is believed to be caused by high altitude wind gusts up to 30 MPH which our simulations do not account for. The relatively high wind speeds also caused Time Warp to drift approximately ¾ of a mile but nevertheless the flight was a complete success.

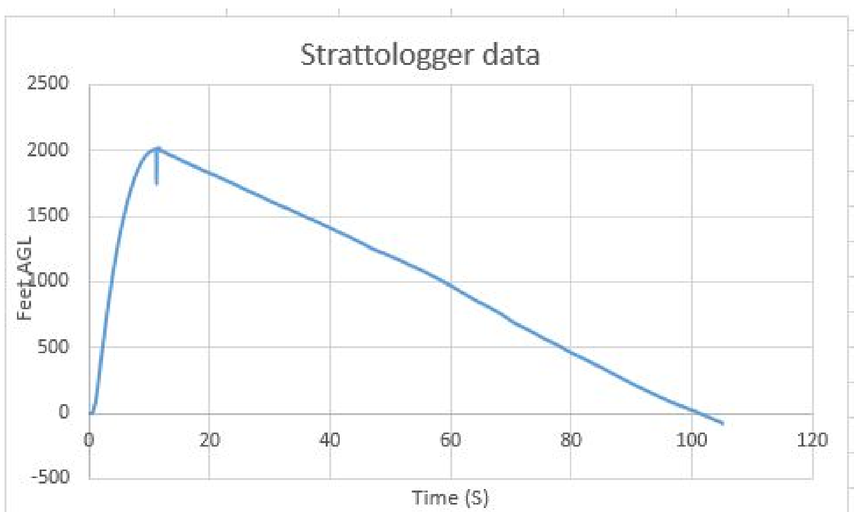

Figure 11: The altimeter data points plotted on excel. Note the spike in the data is due to the ejection forces causing a pressure change.

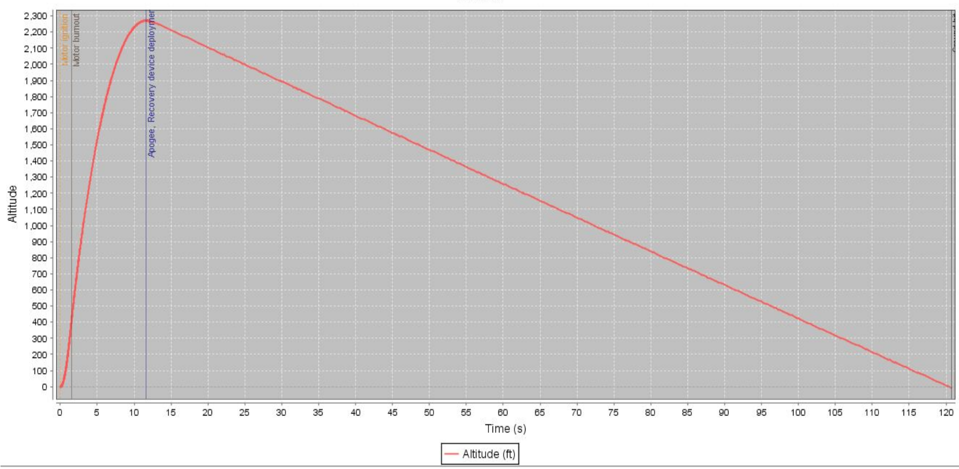

Figure 12: The simulation data is provided by OpenRocket software with accurate launch day conditions.

Analysis of Anticipated Performance

Flight Analysis

Time Warp has very different flight profiles on the J90 and the K2045. The J90 flight remains subsonic, with a maximum velocity of 266 m/s, and accelerates at a rate of 9.1 G, similar to a typical high power rocket. The K2045 flight profile is, altogether, much more aggressive. An acceleration of 114 G propels this rocket to 665 m/s or Mach 1.94 blowing past the speed of sound. Even with these two drastically different maximum accelerations and velocities, the rocket manages to attain relatively similar altitudes on the two motors: 7111 ft on the J90 and 7100 ft on the K2045. Figures 13 through 18 below acceleration, velocity, and altitude profiles on the two flights. These plots were generated using OpenRocket, assuming a wind speed velocity of 5 mph and a launch rail length of 8ft.

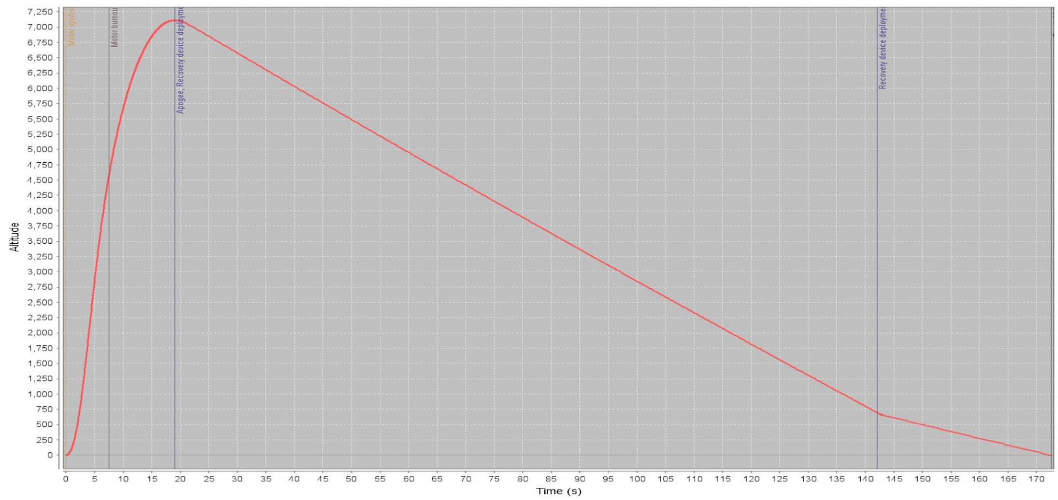

Figure 13: Altitude vs time on the J90

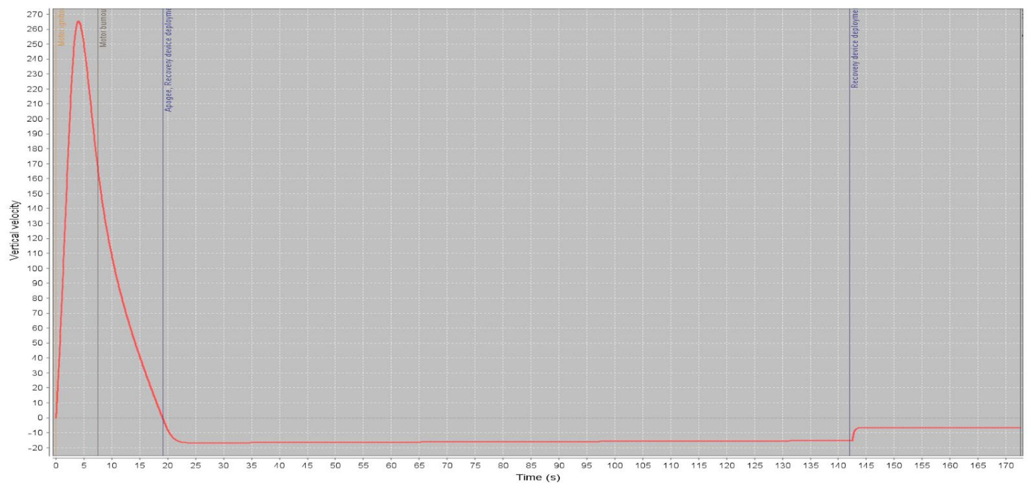

Figure 14: Velocity vs time on the J90

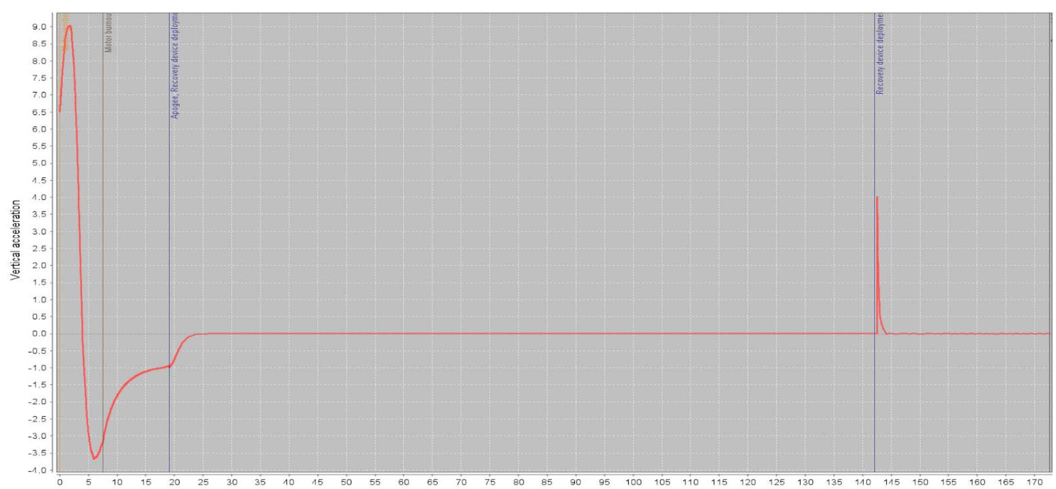

Figure 15: Acceleration vs time on the J90

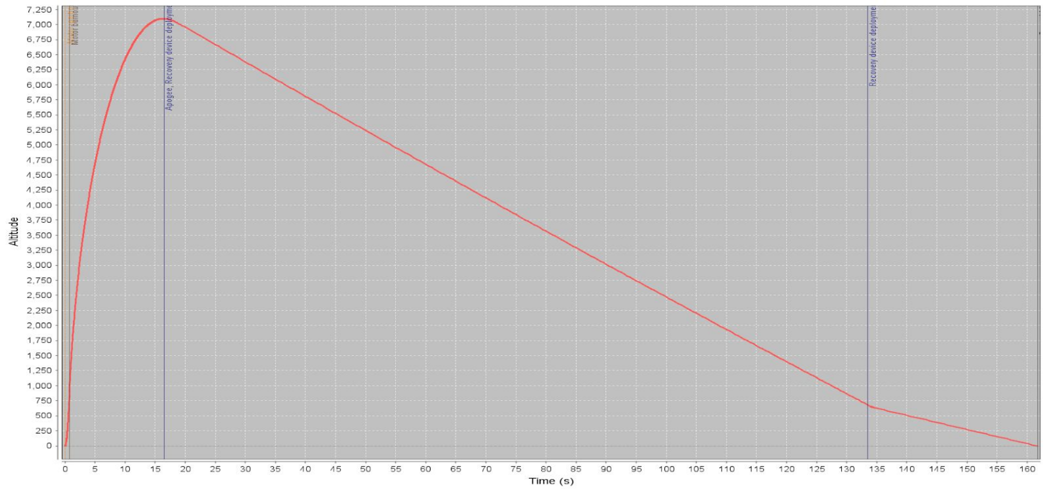

Figure 16: Altitude vs time on the K2045

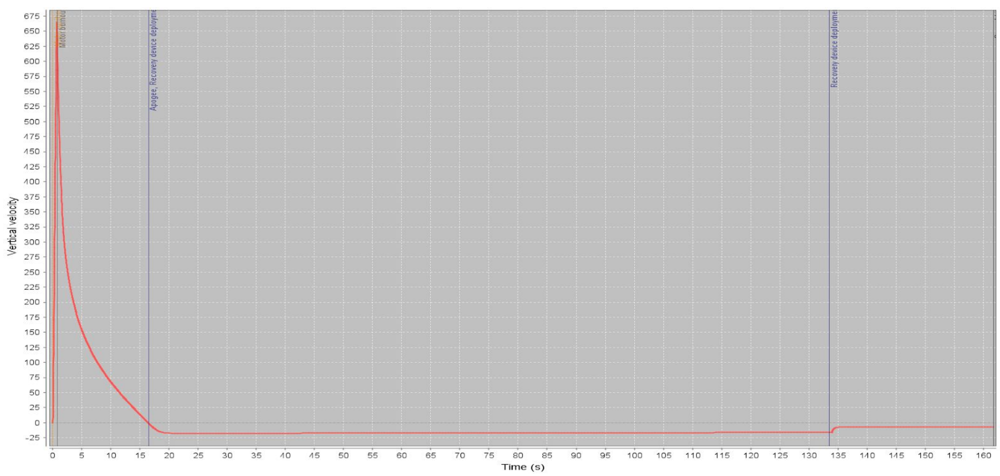

Figure 17: Velocity vs time on the K2045

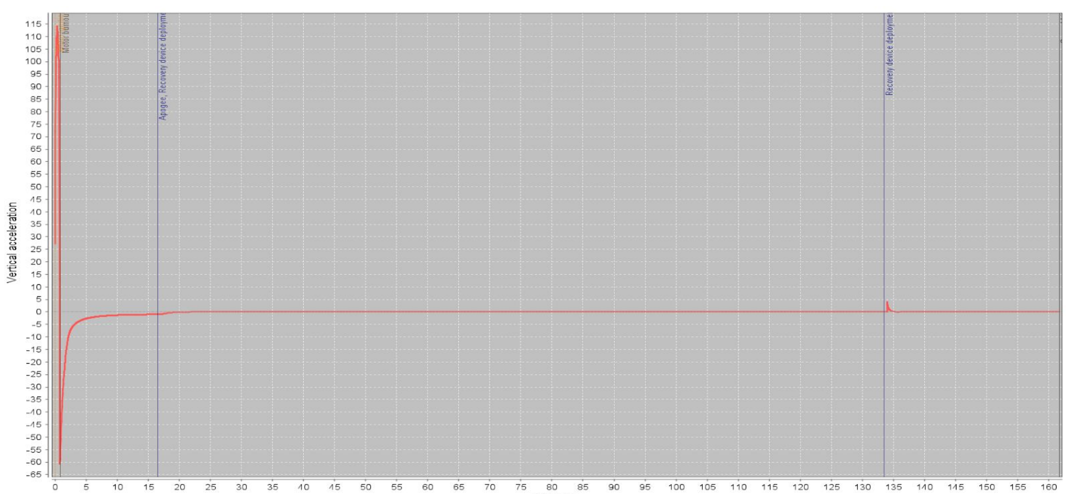

Figure 18: Acceleration vs time on the K2045

Environmental Conditions analysis

Assent

The main environmental factor that affects the flight of the rocket is wind speed. In higher wind speeds, the rocket will weathercock once it leaves the rail. This results in more of a difference on the J90 flight than it does on the K2045 flight because of the differing launch rail exit velocities. Due to the nature of this competition, we expect this issue to be present on all rockets flown for this competition. On both flights, the percent change in altitude is far less than one percent.

	AT J90	CTI K2045
0 mph	7138 ft	7098 ft
5 mph	7111 ft	7100 ft
10 mph	7071 ft	7096 ft
15 mph	7063 ft	7095 ft
20 mph	7014 ft	7085 ft

Table 1: Maximum altitude vs wind speed for both configurations

Descent

The parachutes were chosen in order to minimize drift, while still providing enough drag to have the rocket touch down slower than the maximum of 24 ft/s. The sizing still has the possibility of being changed.

	At J90	CTI K2045
Drogue descent rate	66.8 ft/s	52.8 ft/s
Main descent rate	22.4 ft/s	23.4 ft/s

Table 2: Descent rate on both main and drogue for both configurations

	AT J90	CTI K2056
0 mph	0 ft	0 ft
5 mph	560 ft	996 ft
10 mph	1347 ft	2031 ft
15 mph	2708 ft	3118 ft
20 mph	4042 ft	4083 ft

Table 3: Drift vs wind speed for both configurations

These numbers were all calculated by OpenRocket, using an approximation of the size and drag coefficients of the in house manufactured parachutes. Descent rate experiments will be conducted once the final parachutes have been manufactured. These numbers are expected to possibly change drastically before the flight readiness report.

Stability Analysis

Stability was easily achievable when designing the rocket.This is contributed to by several factors. First, the design of this rocket has the electronics in the upper section of the rocket, moving the center of gravity upward. The rocket is also significantly taller that was originally planned, making the fins and electronics farther apart, increasing stability. What makes the most significant contribution to stability, as with any conventional rocket is the fins. To increase drag, while minimizing weight, the fins are both larger in area and thicker than they would be on a conventional rocket.

All of these factors combined give us a sufficient stability of over two on both configurations. When loaded with the J90, it has a stability of 2.4 cal, while loaded with the K2045 it has a stability of 2.2 cal. During both flights, the stability will increase as the motor burns, moving the center of mass forward.

On the higher power K2045 test flight, it is not expected that weathercocking will be an issue. This is due to the launch rail exit velocity of 225 ft/s off of an 8ft rail, and the high velocities throughout the flight. The flight that will be most affected by weathercocking is the lower power J90 flight. The rocket still leaves the rail at a more than sufficient 61.4 ft/s, so weathercocking is not a safety concern. However, weathercocking does affect our maximum altitude by a significant amount, as can be seen in the environmental conditions analysis section above.

Photographs of Completed Rocket

Figure 19: Our team with the rocket before its first test flight

Figure 20: Time Warp clearing the pad on its first test flight

Safety

Pioneer Rocketry competes in the annual WSGC competition, and conducts its own launch events at the University of Wisconsin-Platteville. It is because of the launches conducted on University property, that the team has a good understanding of the equipment and procedures necessary to reduce the chance of accidents involving property damage or bodily harm.

All flights at the University of Wisconsin-Platteville occur at Pioneer Farms, the university's agriculture-research and animal science center. Due to the location of the Platteville Municipal Airport near the farm and the size and altitude of the rockets being used, special waivers have been obtained from the FAA that allow these launch events to occur.

The team's launch controller was designed with both a key-operated arming switch along with two momentary switches wired in series to minimize the likelihood of accidental launch events. The team's launchpad was built from steel coated in heat-resistant paint, and was designed as an angle-adjustable tripod (+/- 20 degrees) with a blast deflection plate and a six foot launch rail.

Pioneer Rocketry always has a procedural checklist existing for both preflight and postflight operations. They are used for rocket assembly, launch, and recovery. Procedures involving volatile materials such as black powder, motors, and lithium-polymer batteries extend into safe storage through the use of fire-hazard storage lockers and PVC battery-bags. Several members of Pioneer Rocketry are certified in high-powered rocketry by the NAR and TRA.

The team this year contains three members that hold a Level 2 certification, two of which are currently building Level 3 certification rockets. During the construction of the rocket, the team made sure to use all the required safety equipment including but not limited to: air filtration masks, gloves and safety glasses as well as occupying the appropriate vented rooms when it came time to paint.

Pioneer Rocketry takes safety very seriously. Any and all new members go through the club's version of safety training for constructing and launching rockets. The club has many certified members and ten members building certification rockets currently. Pioneer Rocketry holds each member up to current safety procedures, rules, and regulations.

Conclusion

We have designed Time Warp to be light, fast and above all safe. Our simulations predict that our rocket will be able to match the altitudes for both the high impulse motor and the low impulse motor. The test flight showed that the simulations accurately predict the behavior of the motors we will be using. Future test flights will be done to reinforce this conclusion. Before the competition many changes will be taking place including: making parachutes and testing them, new avionics sled, sanding to achieve a better surface finish and implementing the pitot tube system into a new nosecone.

One of the interesting aspects our rocket is its fully passive design. Although this makes the electronics and construction aspect of the rocket easier to build it also made the design the most important. Time Warp will be pushing the capabilities of some components but everything that can be done is being done to keep the rocket as safe as possible. The rocket will have two successful flights and recovery due to both the design and construction of the rocket.

Ad Astra

Special thanks to:

Katie Rabidoux, Advisor
Jake Ellenberger, High Power Mentor
Wisconsin Space Grant Consortium
Minnesota Space Grant Consortium
University of Wisconsin – Platteville
UW-Platteville Pioneer Farms
Packaging Corporation of America
Tim Lehr, Wildman Rocketry

Budget

Name of Item Purchased	Quantity	Unit Price	Total Price
Adafruit GPS	1	39.95	39.95
Antenna	1	12.95	12.95
Antenna adapter	1	3.01	3.01
Perfboard	1	6.72	6.72
Stratologger	6	49.64	297.84
54mm Cardboard tube 34"	4	7.23	28.92
54mm Cardboard Coupler	4	1.85	7.4
AT J90	2	65.69	131.38
AT 54mm 852Ns full casing	1	130.5	130.5
.98 Galon East system Epoxy Resin	1	72.71	72.71
.86 Quart East system Epoxy Hardener	1	27.38	27.38
54mm retainer-retainer body	1	16	16
1/4 inch kevlar shock cord (yards)	15	1.13	16.95
4 pack 1010 rail guides	2	4.75	9.5
Jolly Logic Chute Release	1	129.95	129.95
CTI K2045	2	102.56	205.12
CTI K2045	1	179.61	179.61
AT J1299	2	80.99	161.98
Travel	1	600	600
Total			2077.87

A total of $2077 is expected to be spent on this project, including $600 for travel.