Pioneer Rocketry

University of Wisconsin-Platteville

Flight Readiness Report

Minnesota Space Grant Consortium

Midwest High-Power Rocket Competition 2016-2017

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Summary of design

Design Philosophy

To design a successful rocket for year's adaptable rocket challenge, many different design choices needed to be simultaneously evaluated. Multiple altitude adjustment designs were considered, including electric-ducted fans, retrograde thrust with a cold gas thruster, or airbrakes . All of these possible designs were optimized and weighted against each other for the highest figure of merit (FM). Airbrakes appeared to give the highest 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 certain components, such as the fins and nosecone, could be tweaked in order to achieve very similar altitudes on both the higher impulse and the lower impulse motor. This passive design was theoretically able to achieve over three times the FM possible with an active altitude adjustment system.The disadvantage to a fully passive system is the lack of control. A passive system is not able to react to the conditions on launch day, while a fully passive one may be able to. It was decided that even if the conditions varied significantly, the passive design would still outperform active designs.

Rocket Dimensions

The design of Time Warp was 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 inch upper section is strictly used for electronics. The 30 inch lower section houses the motor, as well as all of the recovery hardware. A minimum diameter design was utilized to achieve the highest altitude. The fins' height and root cord were adjusted from our prototype rocket, “The Shredder”, to give a higher altitude on both the low and high powered flights. This gives us a excellent FM score as well as achieving the bonus points for going over 5000 ft.

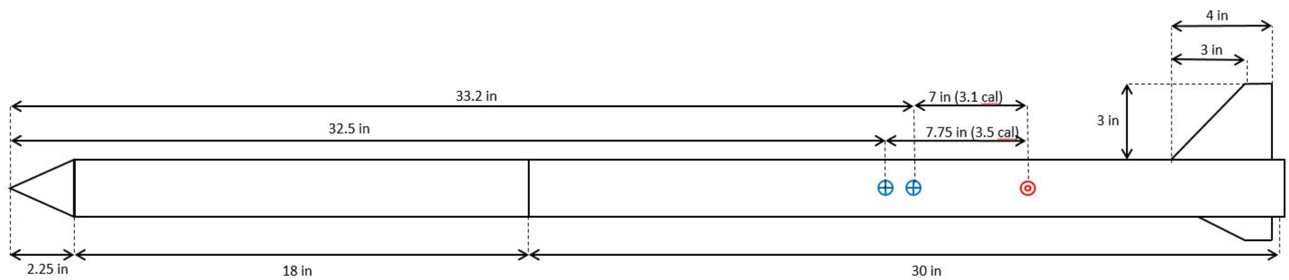

Figure 1: Dimensioned drawing, showing CP(red) and CG(blue) on both motors

Stability Analysis

Stability was easily achievable when designing the rocket due to several factors. First, the design of this rocket has the electronics in the upper section of the rocket, which moves the center of gravity forward. Second, the rocket is significantly taller than was originally planned, making the fins and electronics farther apart, which increases stability. Third, to increase drag, while minimizing weight, the fins are both larger in area and thickness than they would be on a conventional rocket. This design choice has the greatest effect on the rocket's stability.

All of these factors combined give us a sufficient stability of greater than 2 cal on both configurations. When loaded with the J90, it has a stability of 3.5 cal, while loaded with the K2045 it has a stability of 3.1 cal. During both flights, the stability will increase as the motor burns, which will move the center of mass forward.

Motor Selection

The J90 and K2045 are the motors our team chose. 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 possible FM numerator 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

The Aerotech J90 White Lightning was selected as the lower power motor. This motor has both a very low thrust, and a very low impulse for a J motor, which we found to be ideal for this competition. It has a total impulse of 707 N s, making it a 11% J, and a initial thrust of 125 N, giving our rocket a thrust to weight ratio of 7.7. Due to the uneven nature of the thrust of the J90, the initial thrust was used to calculate this ratio instead of the average thrust as the initial thrust 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 55.1 ft/s

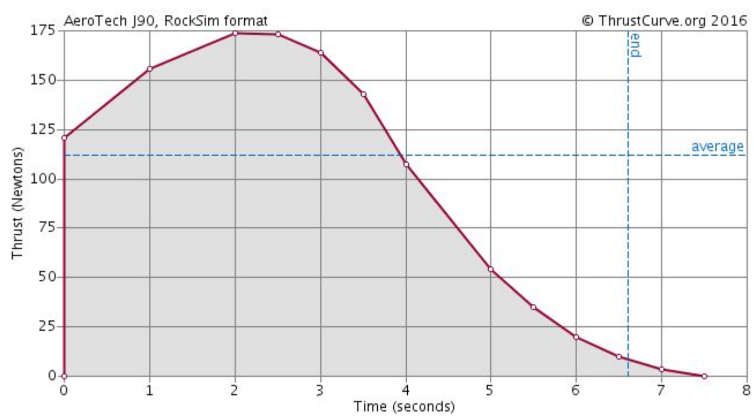

Figure _: Thrust curve of the Aerotech J90 White Lightning

The Cesaroni K2045 VMAX was chosen as the higher power motor. This motor does not have as high of an impulse as other possible motors, but provides a greater thrust. It has a total impulse of 1417 N s, resulting in it being a 11% K. The K2045 provides 2045 N of thrust, giving our rocket a thrust to weight ratio of 84.4, easily pushing our rocket past the speed of sound.

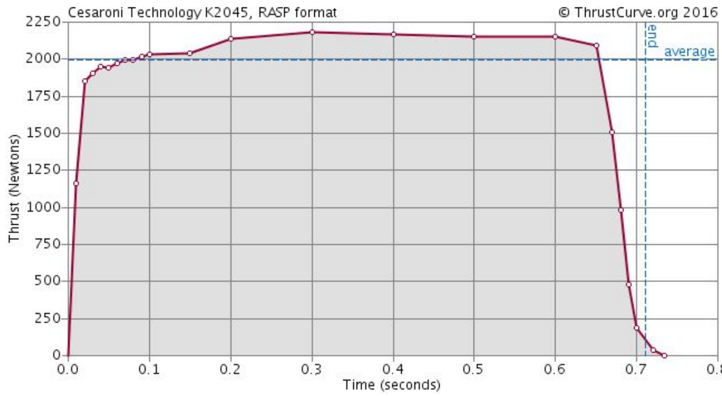

Figure _: Thrust curve of the Cesaroni K2045 VMAX

Design and construction of rocket components

Nosecone

The nosecone of our rocket was 3D printed out of PLA plastic and reinforced with epoxy. The nosecone is designed to withstand supersonic flight. This construction technique resulted in a solid nosecone through two test flights. The nosecone is a Haack series cone with a height of 2.25 inches, giving it a 1:1 aspect ratio. This results in a nosecone 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 smaller 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 too heavy. LOC cardboard tube with a layer of fiberglass reinforcement can withstand a compressive load of approximately 1400 lbs. This material was selected, resulting in a factor of safety of 2.8. This material did not sustain damage on either test flight..

Figure 2: Unmodified (left) and reinforced (right) specimens after compressive testing

Fins

The fins of our rocket were constructed out of a ⅜ inch 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 are designed to cause significantly larger drag at supersonic velocities during our higher power flight, and have a far smaller effect on the drag at subsonic velocities on our lower power flight, similar to the nosecone's design. These fins did not sustain any damage on either test flight..

Electronics

Parachute Deployment Monitoring System

A simple approach was taken to detect the parachute deployment. A pull pin style switch (the same that is used to arm the altimeter) is used to record when the separation occurs. An arduino micro with an SD card read-write module is used to record the data. The pull pin switch is connected to the arduino via an analog out pin and an analog in pin. The pull pin switch is set up in the normally closed position and when the pin is installed it will open the switch indicating that the rocket is together in one piece. The analog out pin will always be sending a high signal and the analog in will always be deciding if there is a high signal. When the separation occurs the switch will closed and the arduino will see the high signal. This will print “Separation” to the SD card with a timestamp of when it occurred. We will also be writing the velocity data to the same SD card so it can be determined when launch, boost, coast, apogee and separation occur. The forward and aft looking cameras see the parachutes and can also be used to verify separation.

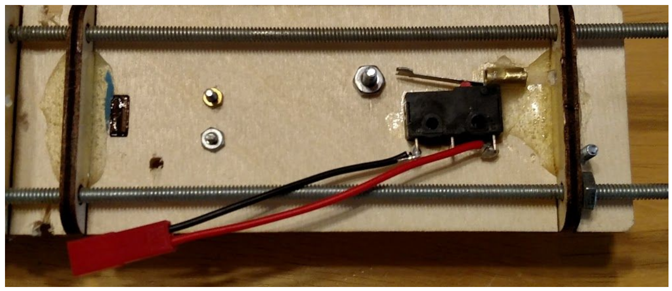

Figure 3: the pull pin switch used to detect separation

Pitot Tube

Pitot tube systems work by taking a differential pressure reading between the outside of the 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 using the equation $u = \sqrt{\frac{2P}{\rho}}$.

This equation only works for subsonic speeds. At speeds that are transonic or supersonic, this equation is no longer accurate. 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 are using the Rayleigh Pitot tube formula that takes the bow shock into account. Unfortunately, there is not an all-encompassing equation for airspeed that works at subsonic, transonic, and supersonic speeds. Due to this, we are only measuring the pressure of the pitot tube and analyzing the data collected later.

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 nosecone. 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 logged to a Comma Separated Variable (CSV) file on board the rocket for later analysis. 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 these variables into account because we are using a passive control scheme.

GPS

Also included in our electronics payload is a GPS 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 3DR telemetry 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 library that was pre-written by Adafruit. This library lets you simply connect the wires and interact with the GPS module. 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.

The 3DR radio system is designed for use in quadcopters but can easily be used for our purposes. We adopted the 3DR radio system for our last test flight after having difficulty with XBee radio systems. The 3DR radios also provide many advantages over XBee radios. The most apparent advantages are cost and ease of use. With the 3DR radio system there can be many different receivers on the ground that can pick up the signal from the transmitter on the rocket, much like XBee radios. However, the 3DR radio receivers can be plugged into most smartphones and the GPS data can be observed using any serial monitor. This offers a huge increase in ease of use over the XBee radio system, which required a special program and API to interface with.

Pioneer Rocketry uses Slack for intra-team communication. Taking advantage of the ease of use of the 3DR radio system, we wrote a Python script that can receive and parse the GPS telemetry data from the rockets. From this data, we can notify the entire team of the rocket’s location through Slack. The Python script notifies the team of the rocket’s location if the location of the rocket was not received for one minute, or the standard deviation of the last 20 recieved locations is less than 10 meters. This enables the recovery of our rocket to be as fast and seamless as possible.

Safety

Throughout the design and construction process, safety was the primary design consideration. While sacrificing safety would have resulted in a significantly higher figure of merit, design decisions were made to produce a safe rocket with a significantly lower score. Our team did not find it acceptable to sacrifice safety simply for a higher figure of merit. The rocket has been test flown three times with no safety issues.

Throughout the construction and testing process, rigorous safety protocols were followed when dealing with potentially harmful supplies. When dealing with any potentially dangerous materials, such as epoxy, fiberglass, or paint, appropriate personal protective equipment was utilised. When dealing with energetics associated with high power rockets, such as ammonium perchlorate composite propellant, or black powder, all such materials were handled by members with high power certification. We are pleased to report that there were no incidents during the fabrication or testing of our rocket.

Changes Since Preliminary Design Report

There have been many minor changes since the Preliminary Design Report, but no major ones. The airframe of the rocket remains the same and has now successfully been tested three times, in multiple configurations. The most notable changes are the changes in parachutes, and the abandonment of the fly away rail guides.

Both of these changes were improvements made after the team evaluated the rocket's performance during its test flights. The parachute sizing has been updated to minimize drift and landing velocity. This was done by drastically reducing the size of our drogue parachute to 4 inches, and increasing the size of our main parachute to 32 inches. More information about these parachutes and how they performed during our test flight can be found in the "Recovery Analysis" section.

As discussed in the preliminary design report, the fly away rail guides were hitting the fins before they fully left the rocket, resulting in all rockets flown with them fishtailing significantly off the pad. This problem has been fixed by utilizing a much more traditional style of rail buttons, mounted directly to the airframe.

Other changes since the preliminary design report are mostly focused around the electronics section. Heavier 9V batteries have been swapped out for lighter Lithium-Polymer batteries, The pitot tube sensor has been upgraded so that the system should be able to measure velocities up to Mach 2. The final change to our electronics is a change of radios utilized in the GPS Module. The Xbees were discarded in favor of the 3DR radio system. This system was found to be much easier to use, and more reliable.

Photographs of Construction

Figure 4: Chandler machining the pitot tube attachment point

Figure 5: The tube being vacuum bagged during the fiberglassing process

Figure 6: Adrian applying the fin tip to fin-tip fiberglass reinforcement

Photographs of completed rocket

Figure 7: the team with the rocket before the second test flight, on the K2045

Figure 8: Timewarp leaving the pad on an AT J90

Figure 9: Successful recovery aided by the GPS module after the third test flight

Figure 10: Timewarp with its final paint scheme

Flight Performance

Summary of K2045 flight

The flight characteristics of the K2045 flight were nominal throughout boost, coast deployment and recovery. During boost immediately after Timewarp left the pad, the rocket weathercocked at an approximate 15 degree angle into the 10-15 mph wind. With its large fins and stability the rocket corrected itself and ascended vertically past the speed of sound until the end of boost. The coast phase of the K2045 is where the fin and nosecone designs come into play to slow down the rocket. From there the altimeter deployed the drogue and main parachute, with the main being restricted by the the chute release. At the specified main parachute deployment altitude the Jolly Logic Chute Release deployed the main parachute, and the rocket proceeded to land safely.

Summary of J90 flight

The flight characteristics of the J90 flight were very similar to the K2045 flight with some key differences. With the wind being at approximately 10 mph, Time Warp weathercocked less significantlythan the K2045 test flight. The fins again corrected the weathercocking. The J90 motor's long burn pushes the rocket upward at a much slower rate. The coast phase of the J90 is shorter than the K2045 because of the burn duration of the J90. From there the altimeter deployed the drogue and main parachute with the main being restricted by the the chute release. At the specified main parachute deployment altitude the Jolly Logic Chute Release deployed the main parachute, and the rocket touched down safely shortly after.

Numerical methodology

Because of the barometric nature of the altimeter chosen, the data required some rigorous numerical analysis to account for transonic and supersonic effects. On both test flights, we only directly measured position data with the PerfectFlite Stratologger CF, which was stored as a .csv file that could be analyzed in Microsoft Excel. The position data was taken every 0.05 s. For the first test flight on the K2045, the data was relatively smooth, except for where the rocket went transonic or supersonic. To counteract this, the position data was boxcar averaged, which is a technique that smooths data by averaging every point with its surrounding four data points to reduce the prominence of 'jumps' in the data. A sixth-order polynomial equation curve was fit to the position data with an R^2 value of 0.99. This equation was then input into Wolfram Mathematica 11. The first and second derivatives of the resulting position equation were taken to produce a velocity curve and an acceleration curve. The velocity and acceleration time axis is shifted by just under two seconds due to the boxcar averaging, which results in a two second offset in the timing of the flight data. The magnitudes of the position, velocity, and acceleration curves were not significantly affected, so the apogee, maximum velocity, and maximum acceleration values were not affected by the time offset. The J90 position data was very smooth to begin with, and did not require the full four data points of boxcar smoothing; only two surrounding data points were averaged with any given "center" data point. Thus, the J90 position data was fit to a curve and velocity and acceleration curves were produced using the same process as before. The J90 velocity data also needed to be shifted vertically by about 50 ft/s due to a mismatched y-intercept location (zeroed at the launch site altitude).

Boost Phases

The most significant differences between the test flights with the two motors occurred during the boost phase. The K2045 left the launch rail at 207 ft/s, while the J90 left at 55 ft/s, both above the required 45 ft/s. High wind conditions would cause the J90 flight to weathercock more than the K2045 and rise to a lower altitude due to the J90's lower velocity off the rail. The difference in burn time of the motors is what makes this design a viable option. The J90 burns for for 10 times longer than the K2045 does (7 seconds for the J90 motor, and 0.7 seconds for the K2045 motor). During the test flight using the J90 motor, the rocket began to slow down while the motor was still burning. This very unusual result, caused by drag forces exceeding thrust, was also backed up by the Openrocket simulation.

Coast Phases

Upon analysis of the coasting phase, it appears that the passive design of fins with extremely thick leading edges performed its intended function, quickly slowing down the rocket with the K2045 motor and barely producing appreciable drag until the last 2.4 s of burn on the J90 motor. The time from motor burnout to apogee was just over 11 s for the J90 configuration, and 14.8 s for the K2045 configuration. The total flight times were 153 s and 180 s, respectively. This shows that the lengthy burn time of the J90 is an advantage in our design. Upon coasting, the rocket continued to rotate at a high rate. Some possible reasons for this rotation are the addition of the camera holes or a fin that is not perfectly aligned. Since the rocket design is minimum diameter and the fin contacts are extremely large compared to the diameter of the rocket,, a misalignment of one of the fins could result in a relatively large rotation velocity (?). A loud whistling can be heard in the video throughout the coast phase until apogee.

Recovery System Performance

Our recovery system, while dual deploy, differs from a traditional dual deployment system. The rocket design that was chosen requires that the main parachute and the drogue parachute to be deployed at apogee. To prevent the main parachute from opening, a Jolly Logic Chute Release is used. The drogue parachute is a custom made 4 inch parachute made from ripstop nylon with braided polyester shroud lines. The parachute was made to fulfill the requirement of having a drogue parachute while maintaining a high descent velocity to aid in a faster recovery. The main parachute is a Top Flite Recovery 36” thin mill parachute. This parachute was chosen because of its lightweight construction and small packing size. The descent rate under the drogue parachute was was recorded to be 67 ft/s during the test flight. This is lower than what was expected because the main parachute is out of the body tube but still bundled with the Jolly Logic Chute Release. Once deployed, the rocket had a descent rate of 14.7 ft/s under main, which satisfies the requirement for descending less than 24 ft/s. The Jolly Logic Chute Release was set for 800 ft main deployment for the test launches but can be set lower depending on wind speeds.

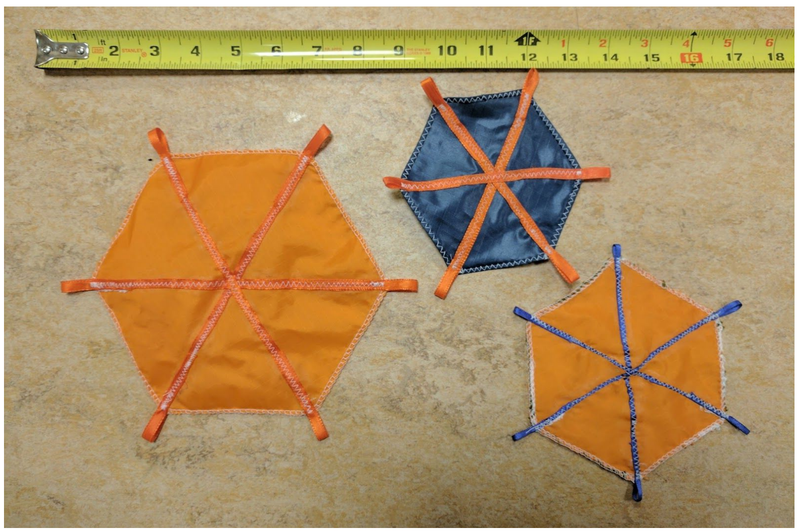

Figure 11: Handmade small drogue parachutes

Wind Speed	Drift on J90	Drift on K2045
0 mph	0 ft	0 ft
5 mph	355 ft	462 ft
10 mph	486 ft	900 ft
15 mph	310 ft	1421 ft
20 mph	68 ft	1976

Table 1: Drift vs Wind Speed in both K2045 and J90 configurations

As you can see in the Table 1, the rocket should stay well within the launch site regardless of wind speed. The J90 simulation weathercocks significantly, causing the rocket to drift a minimal amount away from the launch pad . The K2045 performs as expected, but does not drift far due to the four inch drogue parachute.

Performance of the onboard video and deployment state monitoring system.

In order to minimize drag, it was decided that the cameras would be mounted internally. The cameras were mounted at a 15 degree angle relative to the rocket and holes were cut in the body tube of the rocket to allow the cameras to get a view out of the rocket. The size of the holes were small enough to keep the integrity of the body tube, while still allowing visibility outside the rocket. One side effect of the large rectangle holes cut in the body tube is a loud whistling. This was observed on both of our test flights happening after motor burnout and pitch changing with velocity leading up until separation.

While internally mounted cameras were most likely to maximize the FM, the design was not ideal. Both of our cameras have a fairly limited field of view outside the rocket. However, the camera data still provides great scientific benefit, even if the footage is not as aesthetically pleasing as it could be. The cameras were utilized to see the parachutes during the descent phase. From the video taken during test flights, it was verified that both our main and drogue parachute were ejected at apogee, with the main held by the Jolly Logic chute release. Later in the video, shortly before landing, the main parachute can be seen fully deployed.

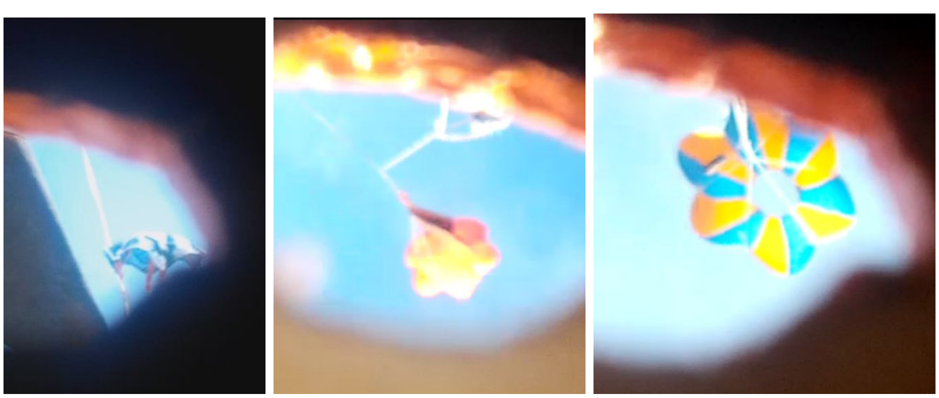

Figure 12: View of the parachutes from inside the rocket, taken during descent on various flights

Peak Altitude Comparison to Expectations:

The rocket, on a K2045 motor, achieved an apogee of 6872 ft, which is a difference of only 85 ft or 1.3% from the simulated value of 6787 ft. On the J90 motor, the rocket achieved an apogee of 6210 ft, which is a difference of 3 ft, or 0.05%, from the simulated value of 6207 ft.

Even though the K2045 simulation closely predicted the achieved apogee, we adjusted the coefficient of drag for the rocket in the simulation (based on the first test flight), which led to the much closer apogee prediction seen in the case of the J90.

Motor	Rocket Loaded Mass (g)	Predicted Apogee (ft)	Actual Apogee (ft)	Predicted Max Velocity (Mach)	Actual Max Velocity (Mach)	Predicted Max Accel (G's)	Actual Max Accel (G's)
J90	1984	6207	6210	0.68	0.65	7.48	8.15
K2045	2440	6872	6787	1.67	1.51	96.8	96.8

Table 2: Predicted and actual results

Peak Velocity and Acceleration Comparison to Expectations:

The rocket, on a K2045 motor, achieved a maximum acceleration of 96.8G, which is nearly identical to the simulated value of 98.6G a minimal difference. On the J90 motor, the rocket achieved a maximum acceleration of Mach 8.15G , which is close to the simulated value of 7.48G, a difference of 8.6%.

In the K2045 configuration, the rocket achieved a maximum velocity of Mach 1.51, which is an error of 10% with respect to the simulated value of Mach 1.67. On the J90 motor, the rocket achieved a maximum of Mach 0.65, which is an error of 4.5% with respect to the simulated value of Mach 0.68.

Velocity vs. Time Comparison to Expectations:

As expected, the maximum velocity of the rocket in the K2045 configuration was reached at burnout, 0.7 seconds into the flight, and the maximum velocity of the rocket in the J90 configuration occurred around 4.5 seconds into the flight. With the thrust curve of the J90 diving sharply at 4.5 seconds and the drag caused by the large fins and blunt nosecone, the rocket was decelerating in the last 2.4 seconds of the motor burn.

OpenRocket Expectation Graphs:-

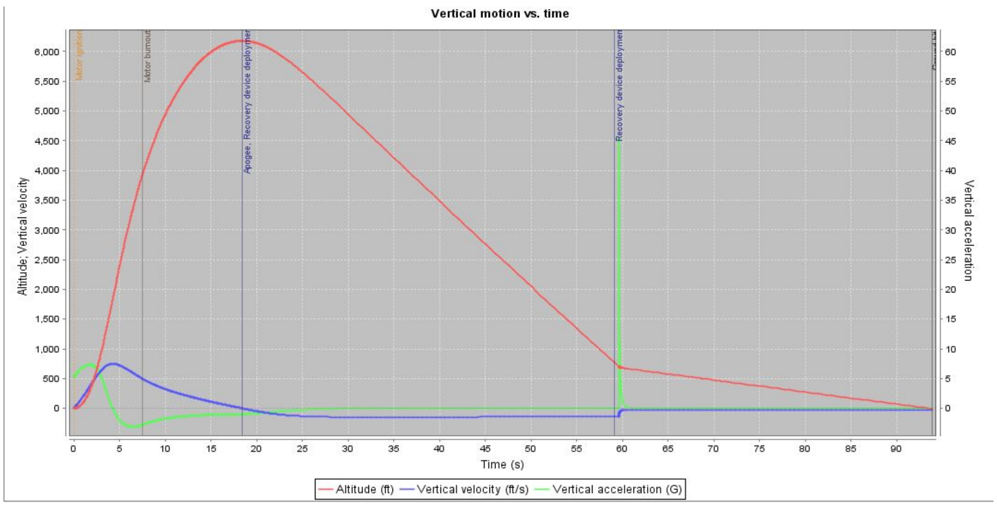

Figure 13: Predicted flight performance on the AT J90

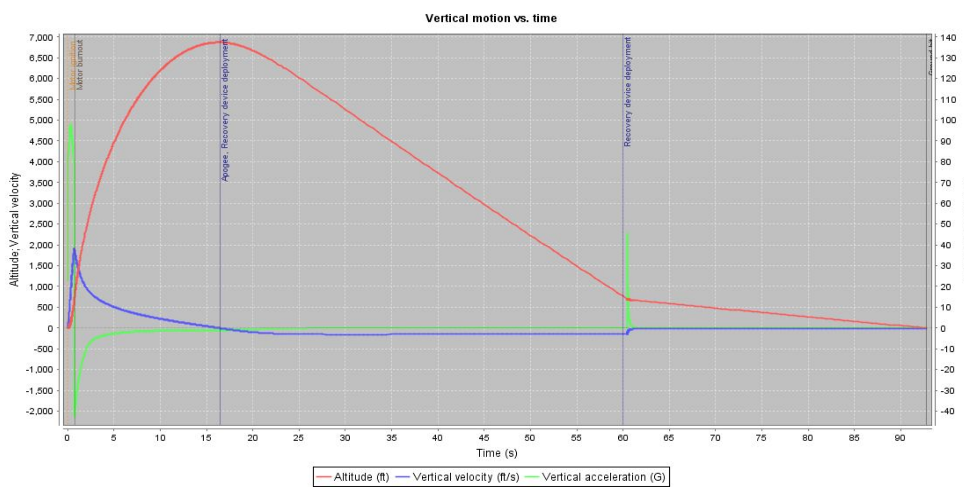

Figure 14: Predicted flight performance on the CTI K2045

Actual Data Graphs for Boost and Coast Phases:

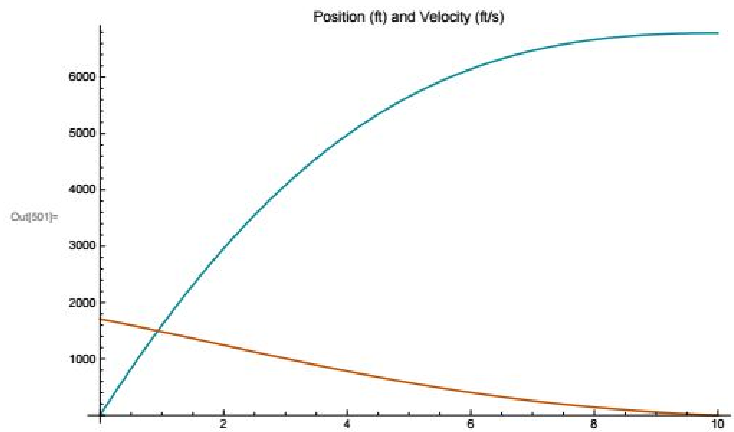

Figure 15: Smoothed Altitude (blue) and Velocity (orange) vs time on the K2045

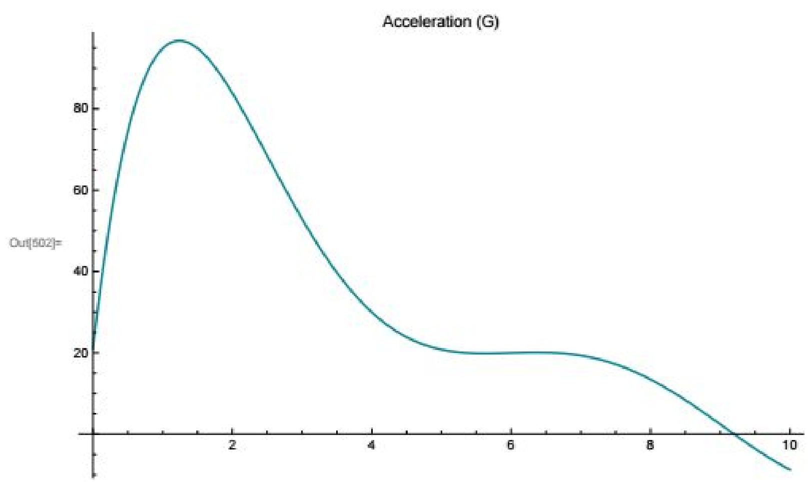

Figure 16: Smoothed Acceleration vs time on the K2045

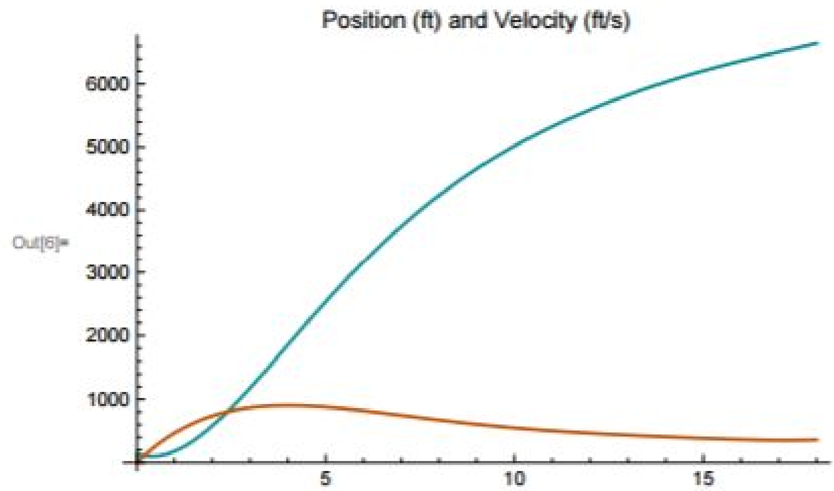

Figure_: Smoothed Altitude (blue) and Velocity (orange) vs time on the K2045

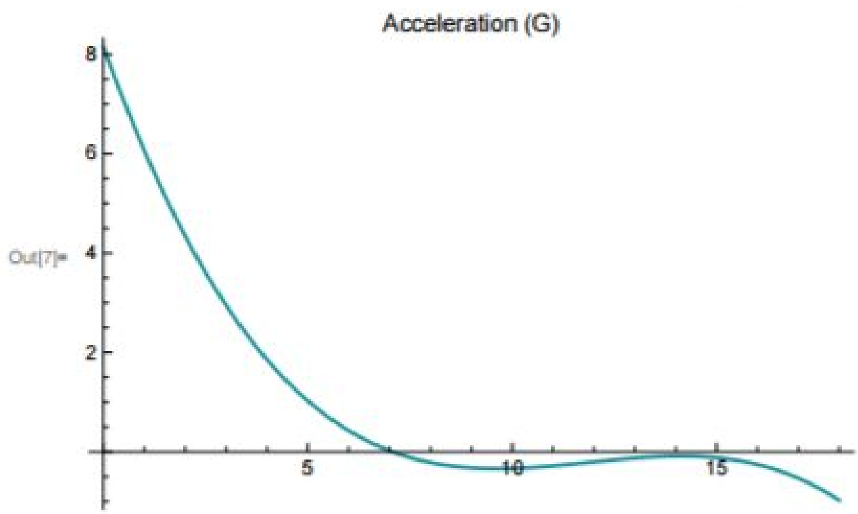

Figure_: Smoothed acceleration vs time on the J90

Potential Design Improvements

There are several possibilities for future optimization of our rocket. These arise mostly from the rocket being heavier than was initially expected. Both the electronics and the fin can ended up overweight.

Steps could be taken to use lighter components in the electronics section. Heavy 9V batteries have already been substituted for lighter lithium polymer batteries, but there are several other components that could be better optimized to save weight, such as the pitot tube system and the GPS module.

During construction of the fin section, an excess of epoxy was used to reinforce the fins. While this resulted in a stronger rocket, it was likely not necessary for this rocket. Potentially a filler material could have been used to lighten the epoxy while still providing the needed strength

Key Findings

Pioneer Rocketry has never before flown a rocket this high, achieved velocities this fast, or accelerated as much as during this project.

One key finding is that some features, most notably the blunt nosecone, cause significantly more drag at higher velocities than they do at lower velocities. This discovery is at the heart of our fully passive design. Another critical finding is the effects of high accelerations on internal components. The team was very pleased to discover that no components of the rocket sustained any damage after a high G flight.

Conclusion

We have designed Time Warp to be light, fast, and above all, safe. Our simulations predict that our rocket will be able to perform excellently on both the high impulse motor and the low impulse motor. These simulations have been verified by test flights on both motors that we will be flying on at the competition.

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 the rocket is designed to fly as safely as possible. The rocket has survived test flights under strenuous conditions, and we believe that it will not disappoint us during the competition.

Ad Astra

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Tim Lehr, Wildman Rocketry

RL Pioneer Rocketry Budg

If there are any questions regarding MRL budget please contact Morgan Fenger at fengerm@uwplatt.edu

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Component	Company	Unit Price	Quantity	Shipping	Total Price
Adafruit GPS	Digikey	39.95	1		$ 39.95
Antenna	Digikey	12.95	1		$ 12.95
Antenna adapter	Digikey	3.01	1		$ 3.01
Perfboard	Digikey	6.72	1	$7.99	$ 6.72
Stratologger	PerfetFlite	49.64	6	$12.35	$ 310.19
54mm Cardboard tube 34"	Wildman	7.23	4		$ 28.92
54mm Cardboard Coupler	Wildman	1.85	4		$ 7.40
AT J90	Wildman	65.69	1		$ 65.69
AT 54mm 852Ns full casing	Wildman	130.5	1		$ 130.50
54mm retainer-retainer body	Wildman	16	1		$ 16.00
1/4 inch kevlar shock cord (yards)	Wildman	1.13	15		$ 16.95
4 pack 1010 rail guides	Wildman	4.75	2		$ 9.50
Jolly Logic Chute Release	Wildman	129.95	1	$12.35	$ 129.95
.98 Galon East system Epoxy Resin	Noah's Marine	72.71	1		$ 72.71
.86 Quart East system Epoxy Hardener	Noah's Marine	27.38	1	$15.32	$ 27.38
CTI K2045	Chris's Rocket Supplies LLC	179.61	1	$55.17	$ 234.78
Sd card reader	Digikey	7.5	2		$ 15.00
Arduino Micro	Digikey	20.48	1		$ 20.48
Pressure Senser	Digikey	17.42	1		$ 17.42
Perfboard	Digikey	3.15	3	$7.99	$ 17.44
Extended forward closure	Wildman	40.5	1		$ 40.50
CTIK2045	Wildman	102.56	1	NA	$ 102.56
Travel Expenses		846.44	1	NA	$ 846.44
					$2,172.44