Project 2.1.4

Aerodynamic Design

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Design Brief

Designers: Tanish Baranwal, Grace Liu, Advait Shewade, Ridhi Tamirasa

Client: Nitro Planes

Problem Statement: Nitro planes is looking to manufacture a series of toy projectiles that are engaging.

Design Statement: Design and build a paper rocket to understand which designs fly the furthest using given materials, and following constraints.

Constraints:
- Material paper products and tape
- Additional material must be approved
- Body diameter must fit over ¾” PVC pipe
- Body length between 10”-15”
- Wingspan less than 24”
- Launched at specified psi with provided rocket launcher
- Angle of launch determined by team

Deliverables:
- One Prototype per team member for testing each launch day
- Team spreadsheet with requirements met
- A final document in electronic form detailing your design process
- Final design recommendations

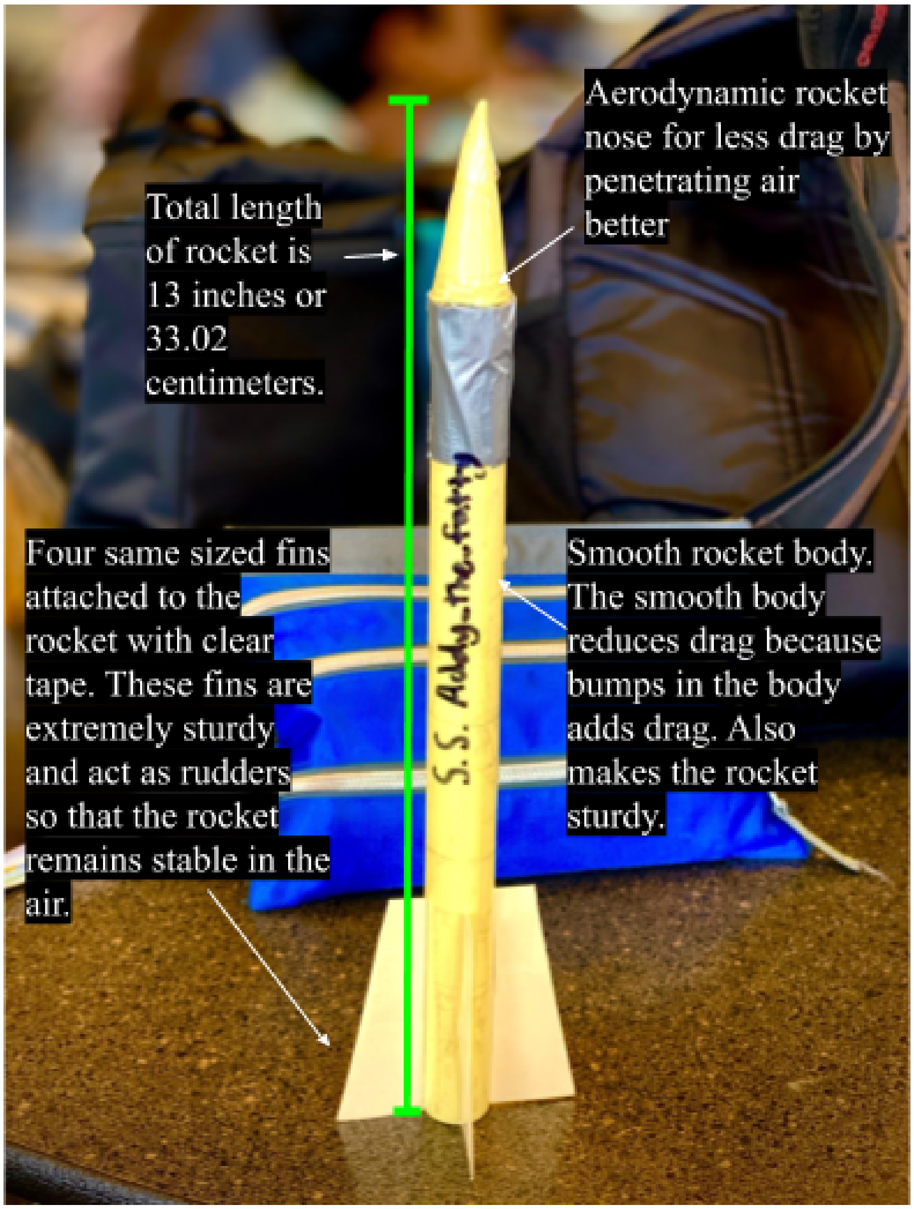
Team Norms & Consequences:

1. No off-topic conversations permitted
2. Everyone will contribute equally on documentation
3. No foul language
4. Respect the opinions of all team members

If any of these team norms are broken, offending members are responsible for buying boba

Design Evaluation - Advait

<u>Picture</u>

Rocket #1


Description

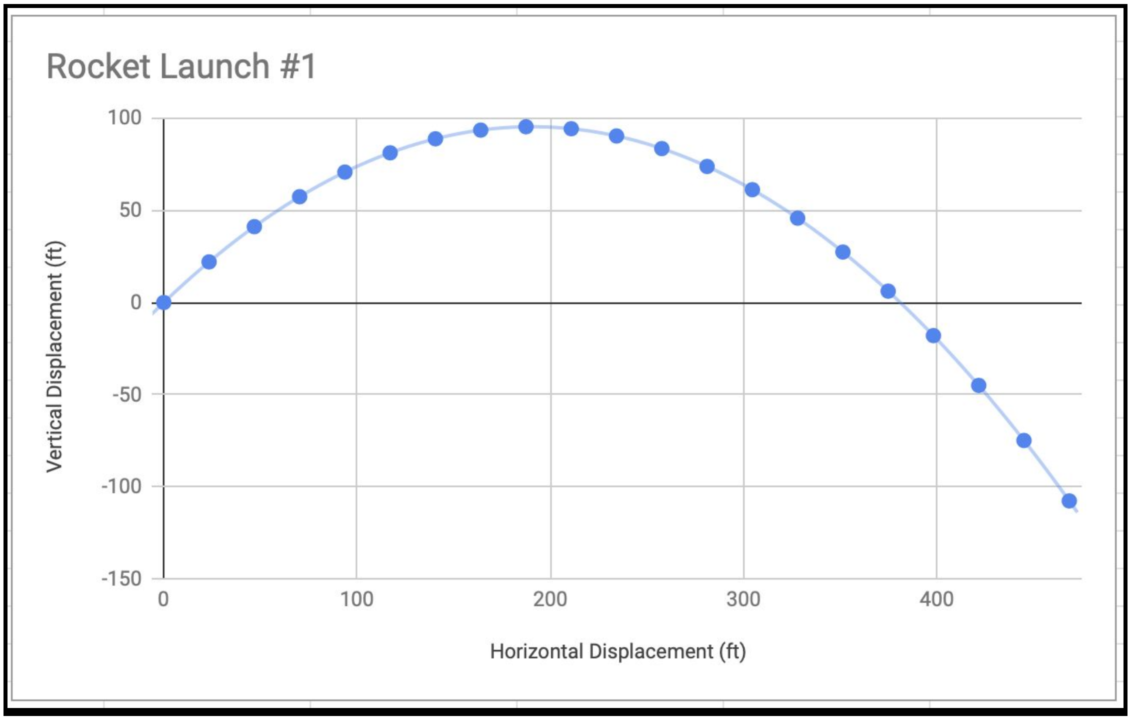
The first iteration of my rocket was the *S.S Addy_the_fatty*. This rocket was made to excel in every which way on Launch Day One. The main aspects of the rocket that made it very aerodynamic were the fins, the body, and the nose. The fins were constructed out of a cut up manilla folder. These fins were all the same size, and were precisely cut to be that way. These fins, originally very big, were cut down to be moderately sized. The reason I made this change was to reduce drag. The fins are positioned ninety degrees apart on the body of the rocket. This design of fins greatly improved the rocket's ability to be stable while in flight. Next, the body. The body was measured to be eleven inches long. It was first rolled up and then taped over. To reduce the drag created by the bumps in the tape, I added another layer of clear tape over the body. This body was also not too tight but still allowed a seal over the launcher so that the air pressure would build up when the rocket was ready to launch. One end of the rocket was sealed off with duct tape to create a secure pressure cap. Lastly, the nose. The nose of my rocket is also made out of cardstock. This nose was made using a circular piece, cut along its radius and then rolled up to create a perfect cone. The cone's base's diameter was measured to fit perfectly along the seventh-eighths inch diameter. The nose was attached to my rocket using duct tape. Again, to maintain a low drag coefficient, clear tape was added over the point where the cone meets the body. Even by doing this however, that part remained bumpy.

This rocket's experimental data and its theoretical data were very different. On the launch day, the rocket flew for six seconds, it was launched at forty five degrees. The rocket went one hundred and twenty seven yards or three hundred and eighty one feet. Through various velocity formulas, theoretically, my rocket would have gone further. As seen in the graph below, the rocket continues under the Y Axis for a considerable distance. The reason for these discrepancies could be due to the wind, the air molecules hitting the rocket in its flight, and also rounding errors.

Recommendation

This rocket would definitely be recommended to Nitro Planes because of the rocket's low drag coefficient and its well constructed and sturdy body. Even under high wind, this rocket performed very well and it remained stable in the air. This rocket is also relatively heavy, adding to the stability of the rocket. This allows the rocket to fly better in harsh weather conditions. Through a commercial standpoint, for Nitro Planes, this rocket would be really good because it is sturdy, so it can stand up to many uses. The rocket, also made from just paper and tape, is very cheap to make. That is why this rocket is recommended.

Data Table

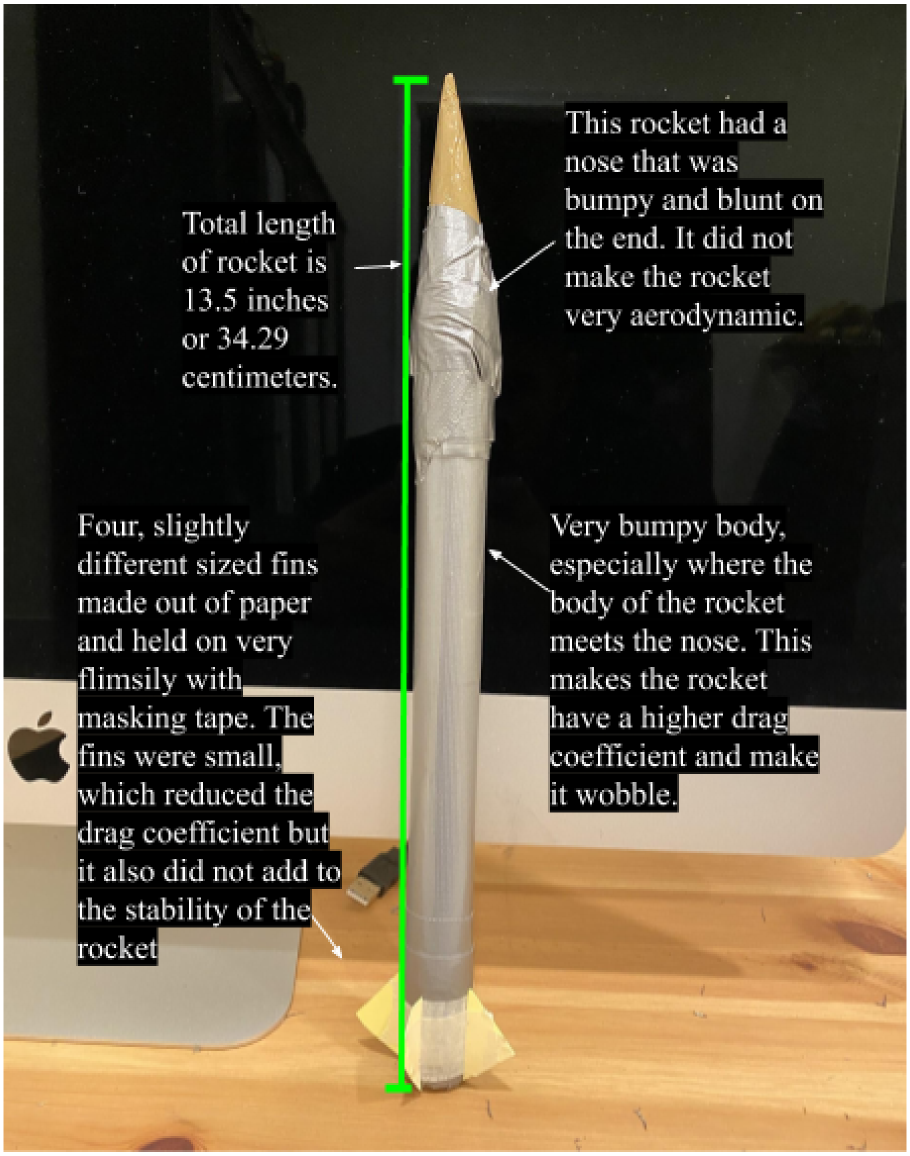


XY - Scatter Plot and Horizontal Versus Vertical Displacement

Initial velocity	110.42	Time	X	Y
Angle	45	0	0	0
		0.3	23.42361923	21.98361923
		0.6	46.84723847	41.08723847
		0.9	70.2708577	57.3108577
		1.2	93.69447693	70.65447693
		1.5	117.1180962	81.11809617
		1.8	140.5417154	88.7017154
		2.1	163.9653346	93.40533464
		2.4	187.3889539	95.22895387
		2.7	210.8125731	94.1725731
		3	234.2361923	90.23619234
		3.3	257.6598116	83.41981157
		3.6	281.0834308	73.7234308
		3.9	304.50705	61.14705004
		4.2	327.9306693	45.69066927
		4.5	351.3542885	27.3542885
		4.8	374.7779077	6.137907737
		5.1	398.201527	-17.95847303
		5.4	421.6251462	-44.9348538
		5.7	445.0487654	-74.79123456
		6	468.4723847	-107.5276153

Picture

Rocket #2



Description

The second iteration of my rocket was the *S.S Addy_the_fatty* 2.0. This rocket was meant to be a rocket that I would not recommend. I made it as an experiment to see which features worked and did not. The main aspects of the rocket that made it, opposed to my first rocket, not *as* great were the small and flimsy fins, the bumpy and heavy body, and the very crude and bumpy nose. Starting from the top, the nose was constructed out of cardstock. Resources were limited, so instead of clear tape, I used the less reliable and less sticky counterpart, the brown tape. This tape was not effective at all, as it unstuck very easily and it was very bumpy when I put it on. This nose was attached to the body using several layers of duct tape, which benefitted it only by making the rocket *very* head heavy. However, this crude layer of tape added a lot of bumps to the rocket and it was the opposite of aerodynamic. This nose was also pretty blunt at the end, increasing the drag coefficient of the rocket. Moving on to the body. The body was actually constructed better than my first rocket. It was smooth and it made the rocket heavy, due to the layers of duct tape. Where it looked through, was in the diameter. There was an uneven diameter between one end and the other, making the rocket inconsistent. Lastly, the fins. I would say that the fins were the worst part of my rocket. Partly due to a time limitation and also due to experimenting, I made my fins very small and all of them were different sizes. They were attached using masking tape which also made them very flimsy and they moved a lot. On top of that, they did not add much stability to the rocket. The only plus side to the fins, was their size. Their size being small, made the drag coefficient less.

This rocket's experimental data and its theoretical data were actually very similar. On Launch Day Two, the rocket was launched again at forty five degrees because it was effective the first time. The rocket flew for four and seven tenths of a second and it went one hundred and sixteen yards or three hundred and forty eight feet. The rocket performed *way* better than I expected but it also proved that what I added did not make the rocket a lot worse, as I thought it would have been. Theoretically, my rocket went the name distance and it was very similar to the golden value of zero for the ending height. This is mainly due to there not being wind on the day that I launched this rocket

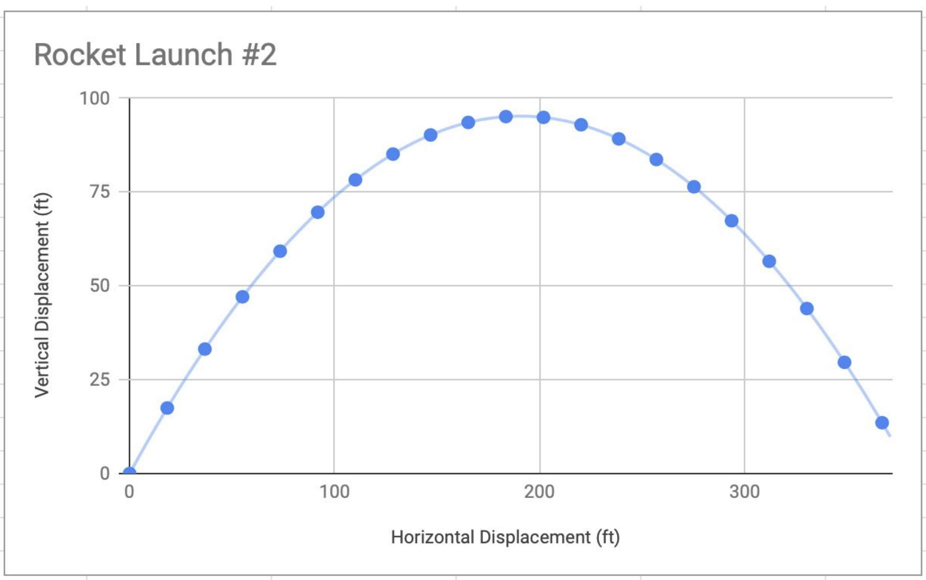
Recommendation

This rocket has some aspects which are recommended and which aren't. I would recommend the small fins because of their reduced drag but I would make them sturdy like the first rocket. Other than that, I would not recommend this rocket. It used more materials then my other one, making it more expensive to build. Also the rocket is very crudely constructed. The nose was flimsy and the fins were very flimsy. This rocket, in only a few launches, would be destroyed. This is why I would not recommend this rocket.

Data Table

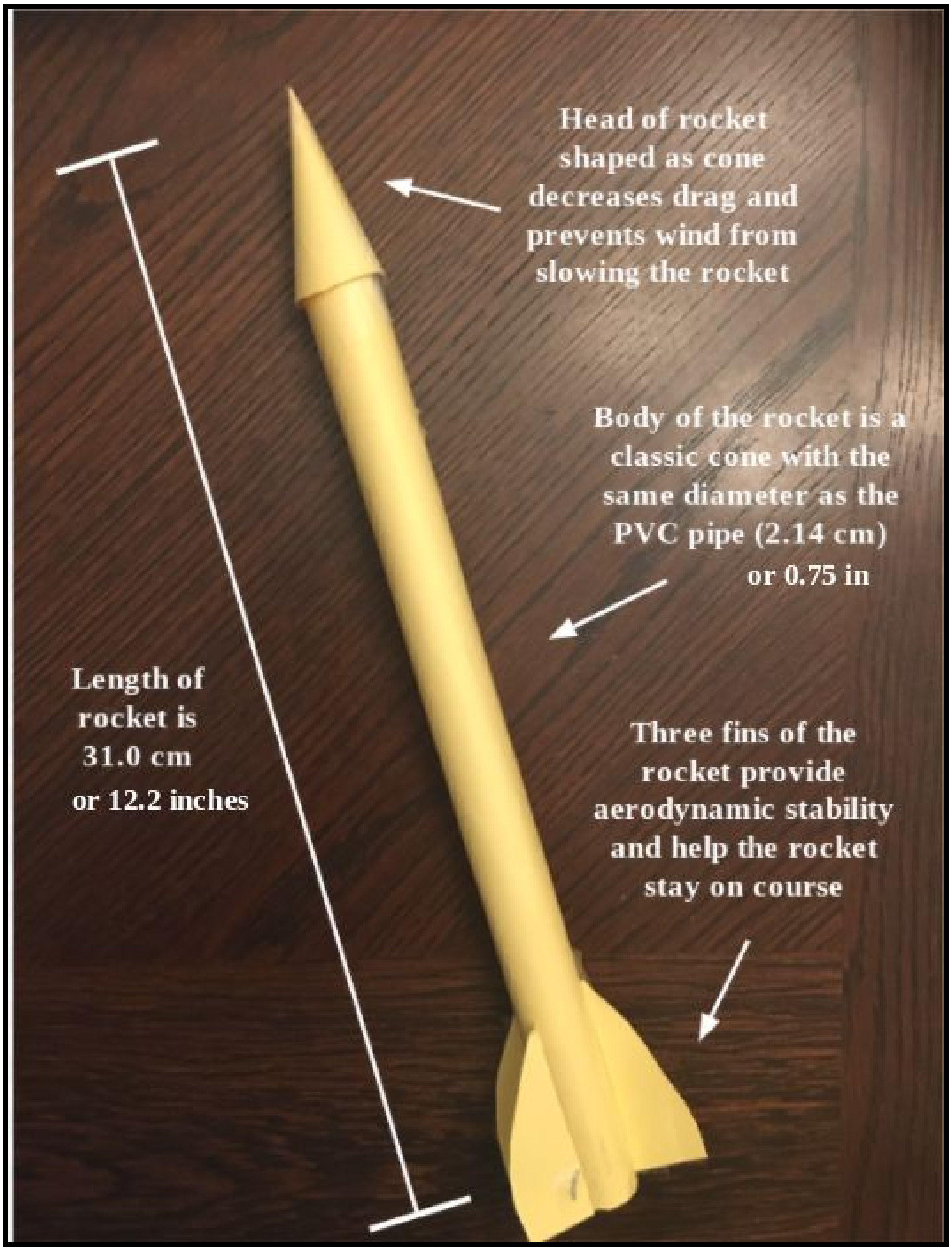
Initial velocity	105.53	Time	X	Y
Angle	45	0	0	0
		0.235	18.34850173	17.46490173
		0.47	36.69700347	33.16260347
		0.705	55.0455052	47.0931052
		0.94	73.39400693	59.25640693
		1.175	91.74250866	69.65250866
		1.41	110.0910104	78.2814104
		1.645	128.4395121	85.14311213
		1.88	146.7880139	90.23761386
		2.115	165.1365156	93.5649156
		2.35	183.4850173	95.12501733
		2.585	201.8335191	94.91791906
		2.82	220.1820208	92.9436208
		3.055	238.5305225	89.20212253
		3.29	256.8790243	83.69342426
		3.525	275.227526	76.41752599
		3.76	293.5760277	67.37442773
		3.995	311.9245295	56.56412946
		4.23	330.2730312	43.98663119
		4.465	348.6215329	29.64193293
		4.7	366.9700347	13.53003466

XY - Scatter Plot and Horizontal Versus Vertical Displacement



Design Evaluation - Grace Liu

<u>Pictures of Prototypes</u>

Rocket #1


Description

The first iteration of the rocket was designed to travel the maximum distance under the weather conditions on Launch Day 1. The rocket consisted of three main sections: the nose cone, the body, and the rocket fins. Its overall length was 12.2 inches, which was between the limit of 10 to 15 inches. The nose of this first iteration was a long and pointed cone. According to the principles of aerodynamics, certain shapes of cones reduce drag and allow the rocket to travel at higher speeds. Compared to a blunt shape, a cone shape reduces more drag. In addition, the nose cone was made from yellow cardstock to increase the strength of the material. Duct tape was attached to the inside of the nose cone to ensure that the pressure cap would not explode. The body of the rocket was also made from thin yellow cardstock. The diameter of the body cylinder was the same as the PVC pipe, about exactly 0.75 inches. Finally, this iteration of the rocket inches three fins spaced evenly around the end of the body. The fins were cut in a curved shape to keep the rocket stabilized in midair. They were also designed to keep the rocket on course with extra weight so that the rocket would not be top-heavy.

The experimental data for this rocket was different from the calculated theoretical values. On Launch Day, the rocket flew a total of 24 feet in 2.2 seconds at a launch angle of 45 degrees. This specific launch angle was chosen because the sin of 45 and the cos of 45 are exactly equal and the largest values possible for both the initial velocity in the x direction and the initial velocity in the y direction. This rocket did not fly in a straight path and curved sharply to the left. The theoretical horizontal displacement at the final time was calculated to be 45.61 feet, which was more than the experimental value. Reasons for this discrepancy could be the loose pressure cap on the nose cone causing air to leak out of the rocket during launch, therefore decreasing the final distance travelled. The theoretical vertical displacement was calculated to be -31.83 feet, an impossible value considering the rocket would have hit the ground at 0 feet. The main reason behind these discrepancies could have been wind because weather conditions were less than ideal on the day of the launch. There were moderate to strong wind currents on the launch location, which could have slowed down the rocket.

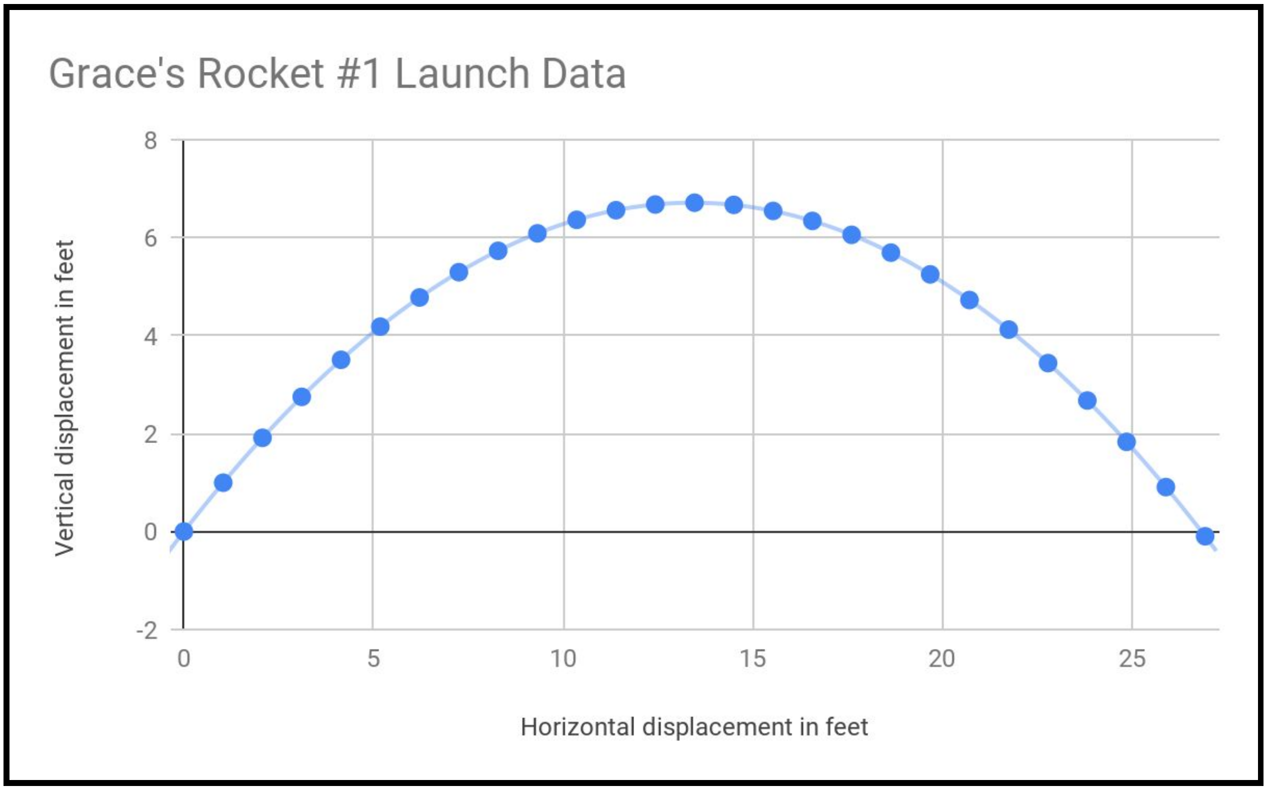
Recommendation

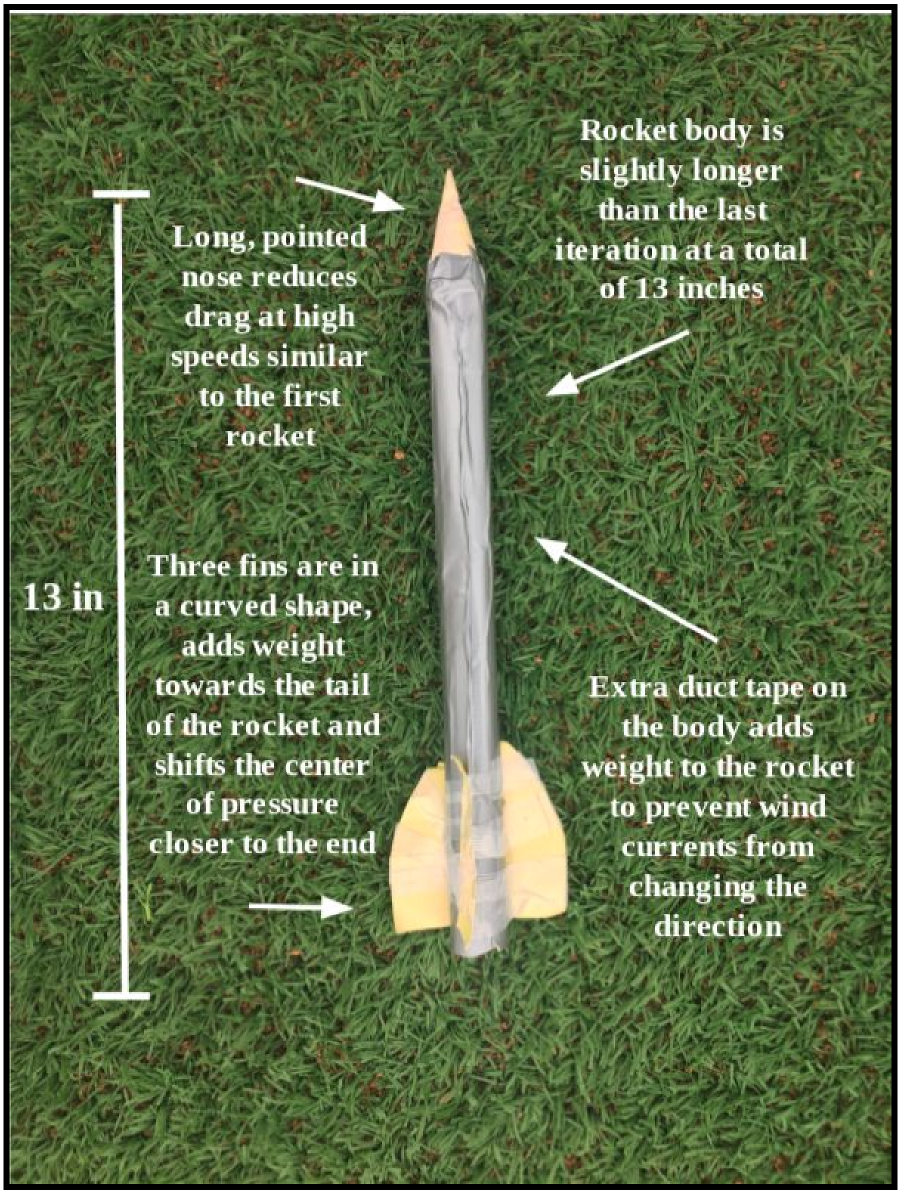
This rocket would not be recommended to Nitro Planes because of its poor performance and low quality pressure cap. If used, this rocket would perform best under weather conditions with favorable wind currents in the direction of launch. Based on the lightweight design of this rocket, strong wind currents would likely propel the rocket to farther distances compared to the theoretical values. However, wind could also affect the direction of the rocket. Several modifications could be made to this rocket to improve its performance. First of all, the overall weight of the rocket should increase in order to ensure the rocket stays on course. Experimental data shows that this iteration of the rocket changes direction when there are strong wind currents. One way to increase the weight of the rocket would be adding extra layers of material on the inside of the rocket. Another change that could be made to this rocket would be tightening the pressure cap and securing the nose cone. In this rocket, the nose cone was attached on the inside with standard Scotch tape, which was flimsy and ineffective. A better alternative would be to secure the nose cone from the outside using a stronger material like duct tape.

Data Table

Iniitial velocity (ft/s)	29.31	Time	X	Y
Angle (degrees)	45	0	0	0
		0.05	1.036257454	0.996257454
		0.1	2.072514908	1.912514908
		0.15	3.108772362	2.748772362
		0.2	4.145029816	3.505029816
		0.25	5.18128727	4.18128727
		0.3	6.217544724	4.777544724
		0.35	7.253802178	5.293802178
		0.4	8.290059632	5.730059632
		0.45	9.326317086	6.086317086
		0.5	10.36257454	6.36257454
		0.55	11.39883199	6.558831994
		0.6	12.43508945	6.675089447
		0.65	13.4713469	6.711346901
		0.7	14.50760436	6.667604355
		0.75	15.54386181	6.543861809
		0.8	16.58011926	6.340119263
		0.85	17.61637672	6.056376717
		0.9	18.65263417	5.692634171
		0.95	19.68889163	5.248891625
		1	20.72514908	4.725149079
		1.05	21.76140653	4.121406533
		1.1	22.79766399	3.437663987
		1.15	23.83392144	2.673921441
		1.2	24.87017889	1.830178895

XY - Scatter Plot and Horizontal Versus Vertical Displacement



Rocket #2


Rocket body is slightly longer than the last iteration at a total of 13 inches
Long, pointed nose reduces drag at high speeds similar to the first rocket
13 in
Three fins are in a curved shape, adds weight towards the tail of the rocket and shifts the center of pressure closer to the end
Extra duct tape on the body adds weight to the rocket to prevent wind currents from changing the direction

Description

The second iteration of the rocket improved on most of the flaws from the first design. Like its original version, this rocket also consisted of a nose cone, a body, and three rocket fins. The first modification made to the previous design was increasing the length of the rocket. The purpose of this change was to improve the stability of the rocket during its flight by shifting the center of pressure to behind the midpoint of the length of the rocket, increasing the distance between the center of mass and the nose cone. Duct tape was also added along the length of the rocket to increase weight and strengthen the weak cardstock. Instead of attaching the nose cone from the inside of the body, duct tape was secured all around the outside to form a more effective pressure cap. This way, no air would escape. Similar to the first design, the pointed nose cone was kept because of material restrictions. Although a parabolic shape was more suited to flight, it was impossible to create a rounded nose cone with paper and ape talone. In addition, the fins of the second rocket were also longer. Since the center of mass needed to be in front of the center of pressure, the larger tail fins helped move the center of pressure towards the end of the rocket.

The experimental data for this rocket was more similar to the calculated theoretical values than the last rocket. This rocket flew 243 feet in 3.5 seconds at a launch angle of 45 degrees. This rocket flew in a straight path and was a large improvement from the first iteration. The calculated theoretical values were more similar to the experimental data because of better weather conditions on the day of the launch. The theoretical horizontal displacement at the final time was calculated to be 230.79 feet, which was very similar to the experimental value. The theoretical vertical displacement was calculated to be 34.79 feet, which was unlikely considering the rocket hit the ground at the recorded time. A possible error could have been recording time inaccurately by a fraction of a second. Based on the theoretical calculations, the rocket should have hit the ground later.

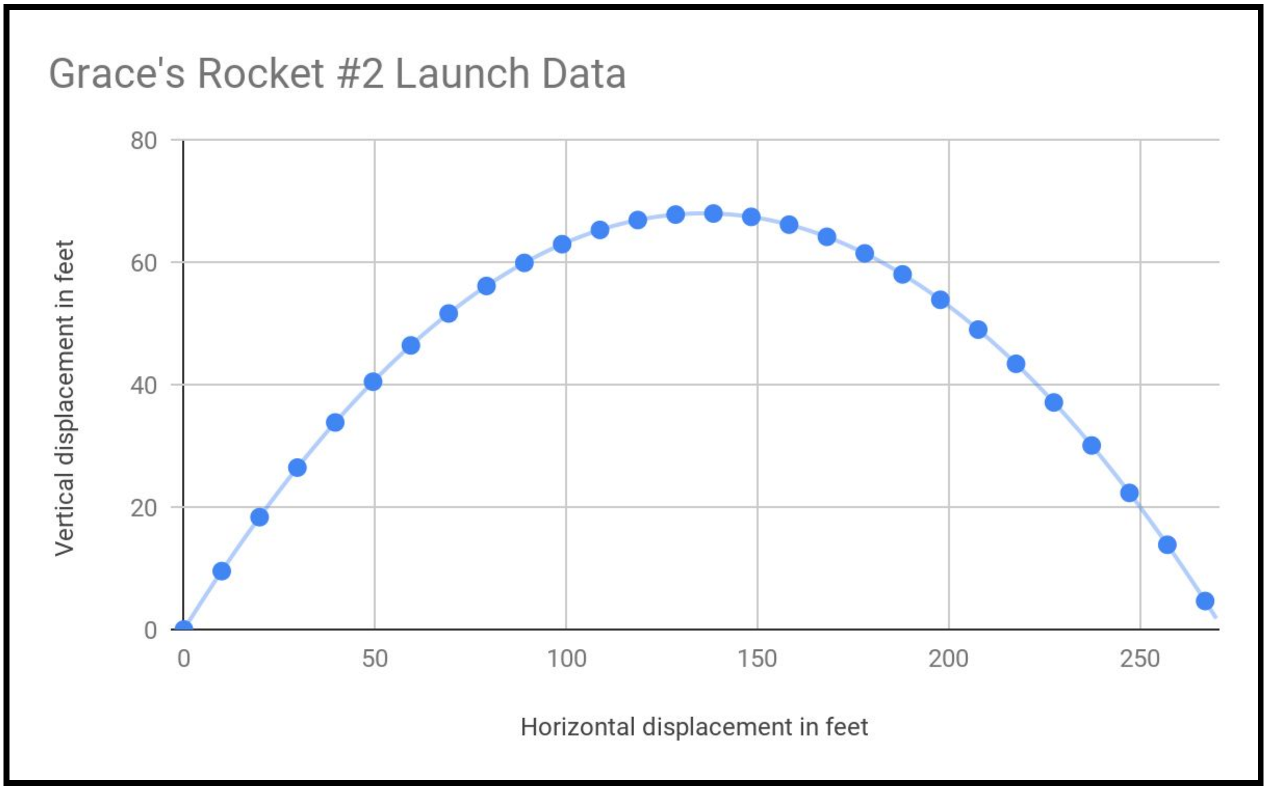
Recommendation

Overall, this rocket would be recommended to Nitro Planes because of its superior performance and higher quality. Compared to the first launch result of 24 feet, this rocket traveled over ten times the distance to reach 243 feet. This rocket should be used under ideal weather conditions where there is little wind. Since this rocket was modified to be heavier than the last rocket, this rocket is less likely to change direction midair. The extra stability of the rocket will result in optimal distance traveled and can be reused due to the sturdier materials. Further modifications recommended would include adding extra weight to the front nose of the rocket to further counterbalance the heavy tail fins, resulting in more drag.

Data Table

Iniitial velocity (ft/s)	93.26317086	Time	X	Y
Angle (degrees)	45	0	0	0
		0.15	9.892053082	9.532053082
		0.3	19.78410616	18.34410616
		0.45	29.67615925	26.43615925
		0.6	39.56821233	33.80821233
		0.75	49.46026541	40.46026541
		0.9	59.35231849	46.39231849
		1.05	69.24437157	51.60437157
		1.2	79.13642466	56.09642466
		1.35	89.02847774	59.86847774
		1.5	98.92053082	62.92053082
		1.65	108.8125839	65.2525839
		1.8	118.704637	66.86463698
		1.95	128.5966901	67.75669007
		2.1	138.4887431	67.92874315
		2.25	148.3807962	67.38079623
		2.4	158.2728493	66.11284931
		2.55	168.1649024	64.1249024
		2.7	178.0569555	61.41695548
		2.85	187.9490086	57.98900856
		3	197.8410616	53.84106164
		3.15	207.7331147	48.97311472
		3.3	217.6251678	43.38516781
		3.45	227.5172209	37.07722089
		3.6	237.409274	30.04927397
		3.75	247.3013271	22.30132705
		3.9	257.1933801	13.83338013
		4.05	267.0854332	4.645433216

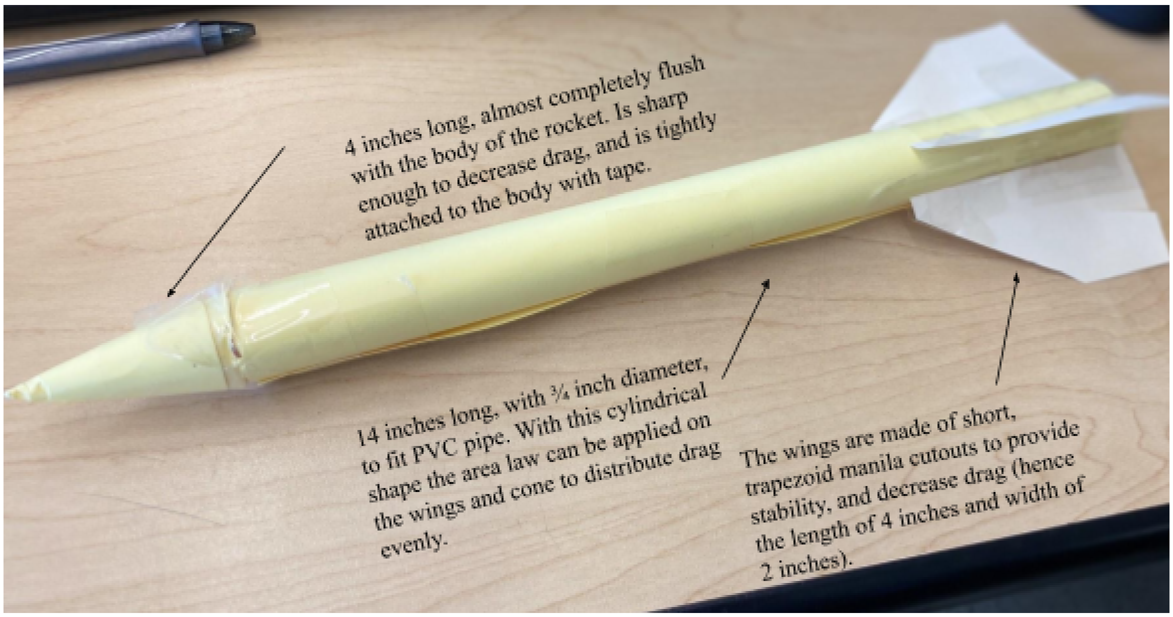
XY - Scatter Plot and Horizontal Versus Vertical Displacement



Design Evaluation - Ridhi Tamirasa

Pictures of Prototypes

Rocket #1



Description:

The first design of the rocket, was built with the idea of decreasing drag in every way possible. As seen with the construction of the rocket with only manila paper, and tape, attempts to make the rocket as aerodynamic as possible are seen. The rocket, when building it, was split into three main subsystems, the body, cone, and wings.

The core of the rocket was built with the idea of drag. Rather than build a rocket with a heavy center, that would cause it to drag once launched, lighter materials would be used. Rolling thirteen inches of manila paper over a PVC pipe provided not only the stability of cardstock paper, but the weightlessness required for a distant flight. The length of the rocket was built at allowed for it to reach the requirements, as well as balance the weight of the cone and wings to have the rocket top heavy.

After building the center of the rocket, perhaps the most essential part of the rocket was built, the head. As this is the first part of the rocket that actually cuts through the wind, the front of the rocket had to not only be sharp, but very sturdy and slightly heavier than the back of the rocket. After deciding on a length that would be reasonable to project the rocket into the air, the four inch cone was constructed and attached onto the rocket. The cone allowed the rocket to pierce through air resistance, and maintain its shape, allowing for successful design.

The final subsystem, wings, were built based off of previous designs of rockets. Rather than allow for a significant amount of lift to take place with large wings, the first iteration wings were built short. The shape of the wings was decided based off of research of aerodynamic shapes. After teardrop shaped wings, triangles, and squares were the most aerodynamic. To experiment, combining both the square and triangle shapes, into trapezoidal shaped wings would be the most aerodynamic after testing times in the classroom.

The final results of the first rocket iteration were seen, with a travel time of 3.6 seconds and a total distance covered of 59 feet. This meant that my initial velocity was 43.45 feet per second. The data table, and graph confirmed this travel with a theoretical total horizontal displacement of approximately 58 feet. Despite the wind and other external conditions the rocket was able to reach the theoretical distance.

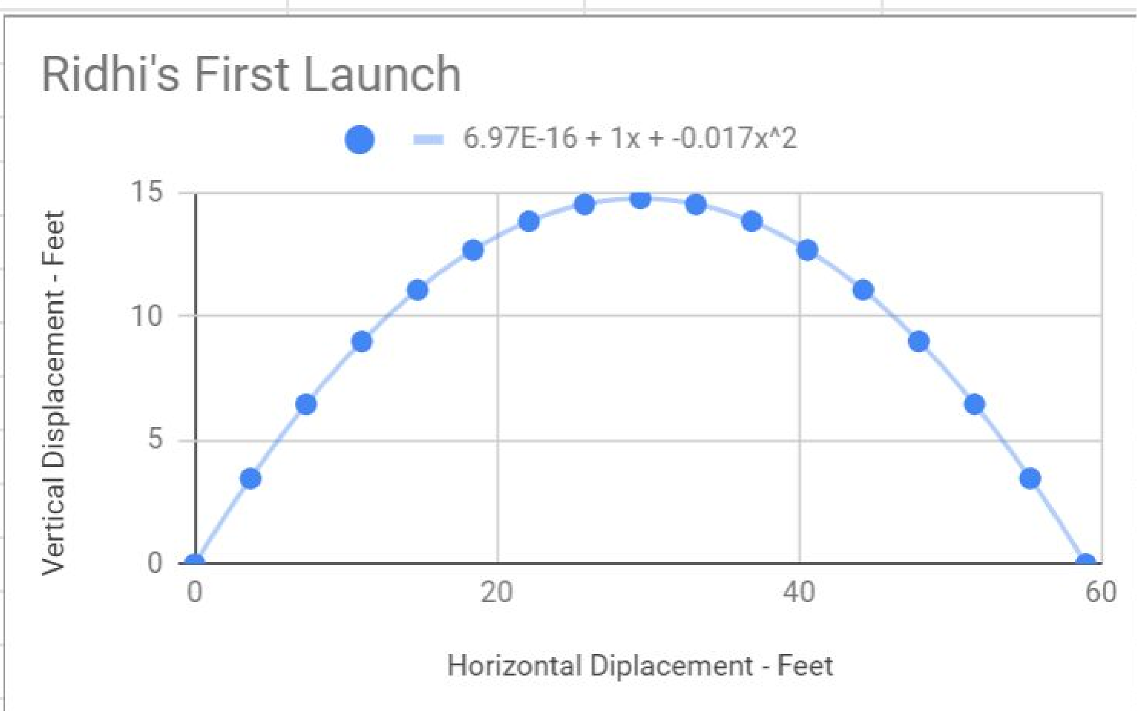
Recommendation:

This rocket should be used in the days of light wind, humidity. Due to its construction of paper, and short wings, wind of any direction would be a hindrance to its flight. Humidity, would also be difficult for the rocket to push through, in order to fly a reasonable distance. Once viewing the plane in flight, there were a series of issues with the design. The rocket was very slow in the air, the cone was slightly crushed after flight, and the wings were not successful in lifting the projectile. To improve these issues, a stronger body would be required, as well as a stronger cone. In addition the attachment of tape on the body of the rocket, such that there would be a smooth surface rather than a rough paper edge was another possible improvement. The largest change would be getting more lift in the rocket such that once launched, the wings would be large enough to propel it. These amongst other changes were applied in the second iteration of the rocket.

Data Table :

Iniitial velocity	43.45	Time	X	Y
Angle	45	0	0	0
		0.12	3.686854757	3.456454757
		0.24	7.373709514	6.452109514
		0.36	11.06056427	8.986964271
		0.48	14.74741903	11.06101903
		0.6	18.43427379	12.67427379
		0.72	22.12112854	13.82672854
		0.84	25.8079833	14.5183833
		0.96	29.49483806	14.74923806
		1.08	33.18169281	14.51929281
		1.2	36.86854757	13.82854757
		1.32	40.55540233	12.67700233
		1.44	44.24225709	11.06465709
		1.56	47.92911184	8.991511842
		1.68	51.6159666	6.457566599
		1.8	55.30282136	3.462821357
		1.92	58.98967611	0.007276113707

XY - Scatter Plot and Horizontal Versus Vertical Displacement



Rocket #2


Description:

The second design of the rocket, improved on many of the faults seen in the first iteration, with the overall size of the rocket deceased to fifteen inches. This rocket decreased air resistance as well as improved on ensuring that the rocket was top heavy upon launch.

The body of the rocket was built with manila paper, and reinforced with duct tape to make it both heavier to be resistant to wind. The duct tape also made the body stronger in supporting the heavier wings in the back. The cone for the rocket was reinforced with duct tape and attached flush to the top of the body. Rather than elongate the cone, the cone was decreased to directly decrease drag. For the wings improving on the previous design of shorter wings, to gain more lift, the wings needed to be larger and in a more aerodynamic shape. The previous square triangle compromise, was changed to larger, triangular shaped manila cutouts that would gain more lift once launched. After building the rocket, to ensure that the faults of the previous rocket were not repeated, testing the projectile for top-heaviness, air resistance being distributed equally, and the nose being strong occured.

The final results of the first rocket iteration were seen, with a travel time of 3.35 seconds and a total distance covered of 37 feet. This meant that my initial velocity was 38.76 feet per second. Despite the final results of 37 feet, the data table reaching a maximum horizontal displacement of 46 feet means that external factors had a great impact on the flight of the rocket.

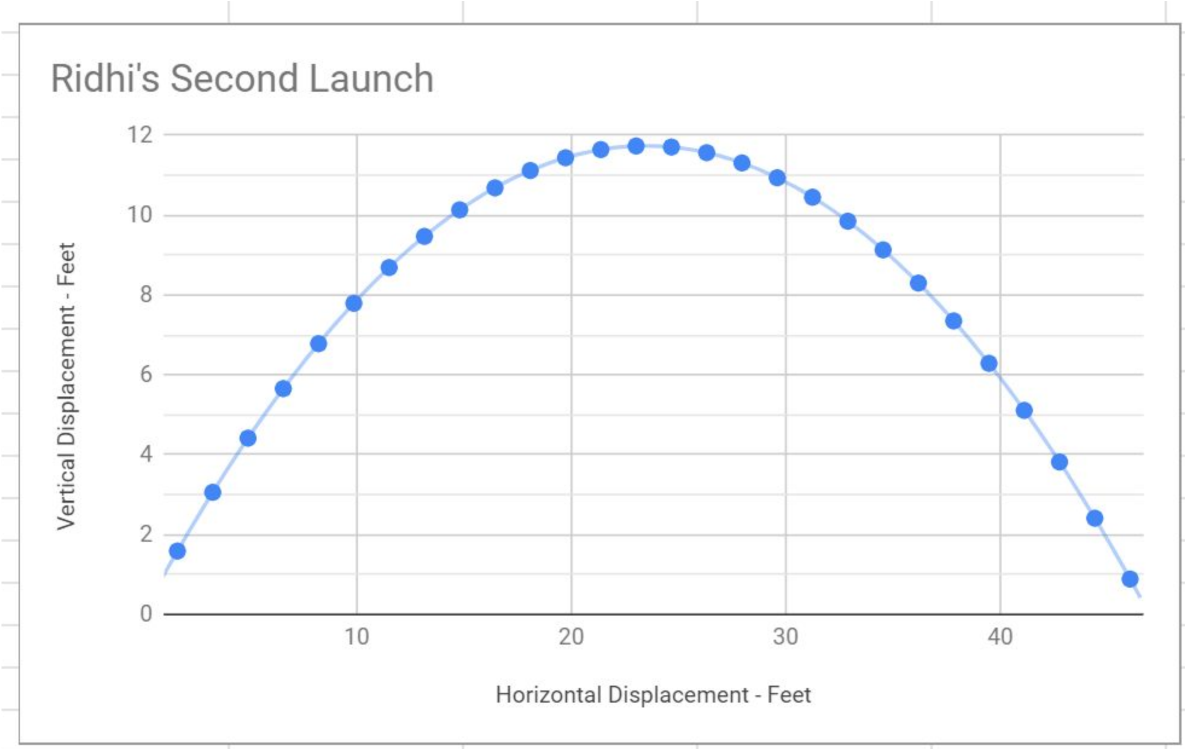
Recommendation

This rocket is recommended for flight in mild wind weather. As its body is still stable, air resistance is not as big of a concern as the previous design.Future designs of the rocket include improving the projectile against air resistance, decreasing drag, and maintaining the area rule. To decrease air resistance a number of changes must be made to the plane. The previous light body, was not resistant to the gusts blowing against the projectile. A more reinforced body, most likely multiple sheets of manila paper are required to support the projectile. In addition, the previous short cone did not decrease the drag of the plane, as its original purpose was. A longer nose, as well as shorter wings would assist in decreasing the drag of the plane. Unfortunately the large wings did not help with lift, and rather made maintaining the area rule, equal air resistance distribution, very difficult. Final changes for the rocket include, a heavier body, shorter triangle shaped wings, and a longer nose to allow the rocket to perform at its full potential.

Data Table :

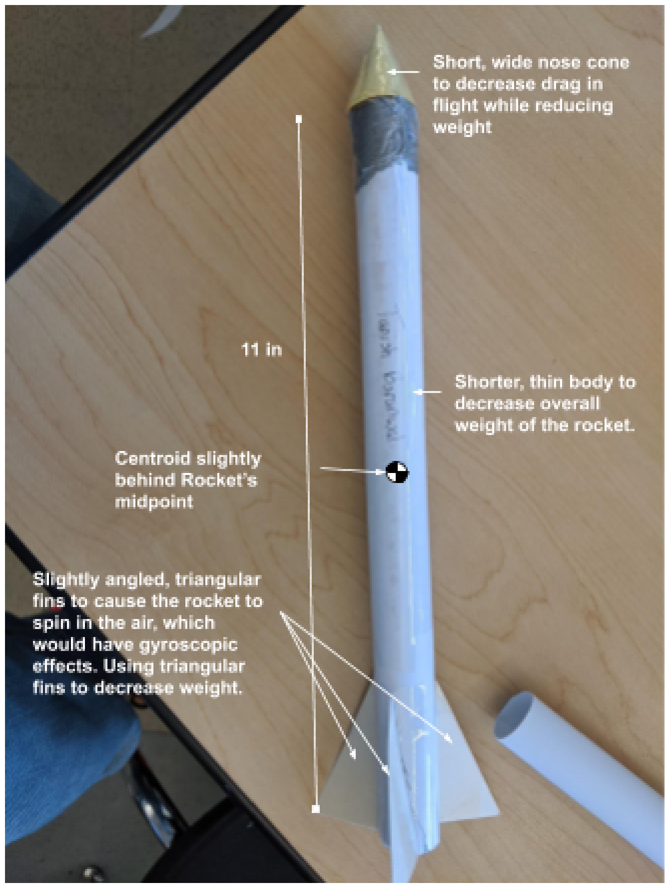
Iniitial velocity	38.76	Time	X	Y
Angle	45	0	0	0
		0.06	1.64444753	1.58684753
		0.12	3.288895061	3.058495061
		0.18	4.933342591	4.414942591
		0.24	6.577790121	5.656190121
		0.3	8.222237652	6.782237652
		0.36	9.866685182	7.793085182
		0.42	11.51113271	8.688732712
		0.48	13.15558024	9.469180243
		0.54	14.80002777	10.13442777
		0.6	16.4444753	10.6844753
		0.66	18.08892283	11.11932283
		0.72	19.73337036	11.43897036
		0.78	21.37781789	11.64341789
		0.84	23.02226542	11.73266542
		0.9	24.66671295	11.70671295
		0.96	26.31116049	11.56556049
		1.02	27.95560802	11.30920802
		1.08	29.60005555	10.93765555
		1.14	31.24450308	10.45090308
		1.2	32.88895061	9.848950607
		1.26	34.53339814	9.131798137
		1.32	36.17784567	8.299445667
		1.38	37.8222932	7.351893198
		1.44	39.46674073	6.289140728
		1.5	41.11118826	5.111188258
		1.56	42.75563579	3.818035789
		1.62	44.40008332	2.409683319
		1.68	46.04453085	0.8861308492

XY - Scatter Plot and Horizontal Versus Vertical Displacement:



Design Evaluation - Tanish Baranwal

Pictures of Prototypes

Rocket #1


Description

The goal of the first rocket iteration was to build a rocket that was as light as possible while still remaining sturdy enough to fly straight in the wind and survive multiple launches. To achieve this, three modifications were made to the standard rocket design: The cone was made to be particularly small and wide, so that it would still complete its job of smoothing out the drag curve while have as low weight as possible. For the same reason, the cone was made out of thinner construction paper and reinforced with only a single layer of the thin packing tape. The body of the rocket was made to be as small as possible while still meeting the requirements of the body being between 10 to 15 inches. The body was also made to be as thin as possible, using only one sheet and one layer of thin printer paper reinforced with the same thin packing tape as used in the cone. Conscious of how easily the wind would be able to alter the rocket's flight due to its low weight, larger fins were added to the rocket and were slightly angled to cause the rocket to spiral in flight. This spiral was to stabilize the rocket by acting as a gyroscope so that the rocket could withstand the wind and fly straight.

The rocket flew 360 feet in horizontal distance and reached a height of 90 feet. The duration of the flight was 4.8 seconds, and the calculated total theoretical distance traveled by the rocket is 413 ft (calculated by the arc length formula).

The actual flight values were very close to the theoretical values, as can be seen in the table and graph below. This difference occurred because the distance recorded for flight assumed that the rocket flew exactly straight, when in reality it did not, which led to the theoretical horizontal displacement was slightly greater than the actual horizontal displacement, albeit by very little. The discrepancy in the vertical displacement can be explained by the fact that there was some wind higher up in the sky on the launch day since flags were waving in the wind in the direction of launch. This meant that the rocket went slightly farther than expected due to the wind.

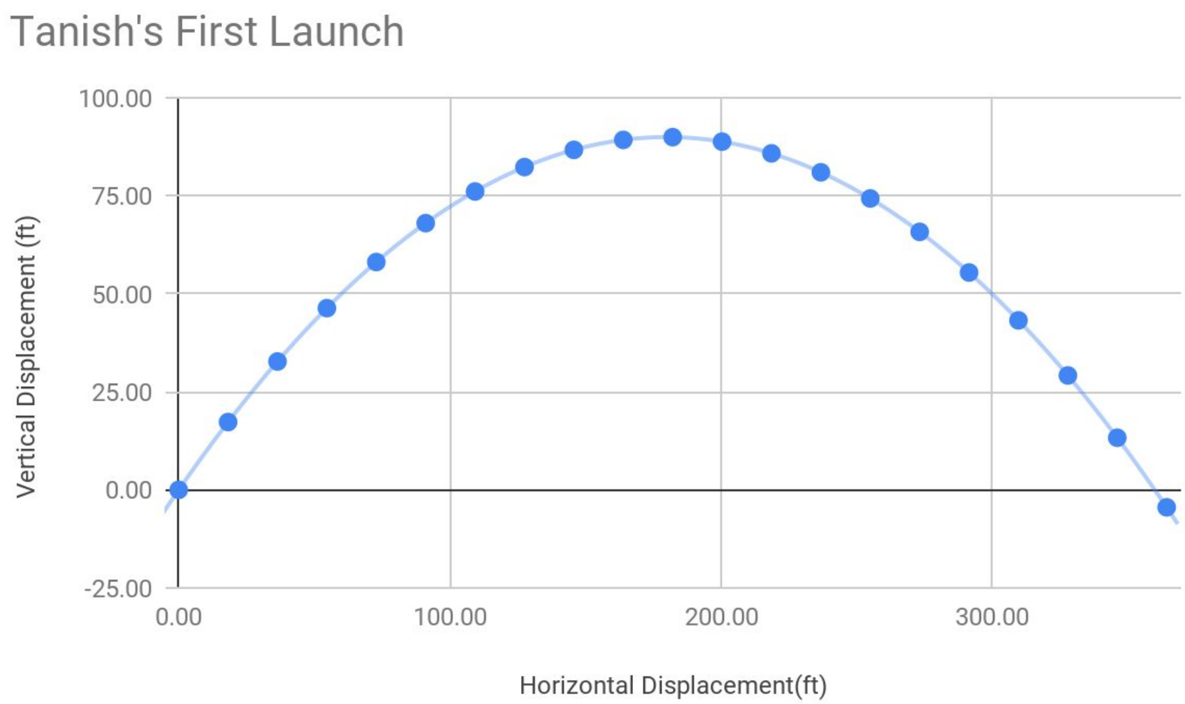
Recommendation

This rocket is recommended for flight in highly turbulent air, since the spiral of the rocket provides firm stabilization in the air. Some modifications required to this rocket is the usage of sturdier materials to build the body and cone, along with an increase in the overall weight of the rocket so that it doesn't warp in flight. A crucial modification is to increase the weight in the cone so that the rocket's center of mass is slightly in front of the midpoint of the rocket. The fins can also be made smaller so that they produce less drag as the rocket spirals. This rocket is good for getting straight, far flights in turbulent air.

Data Table

Launch 1				
Initial Velocity (ft/s)	107.3	Time (s)	X (ft)	Y (ft)
Angle (degrees)	45	0	0.00	0.00
Actual Horizontal Displacement (ft)	360	0.24	18.21	17.29
Theoretical Vertical Displacement (ft)	-4	0.48	36.42	32.73
Theoretical Horizontal Displacement (ft)	364	0.72	54.63	46.33
		0.96	72.84	58.09
		1.2	91.05	68.01
		1.44	109.26	76.08
		1.68	127.47	82.31
		1.92	145.68	86.69
		2.16	163.88	89.24
		2.4	182.09	89.93
		2.64	200.30	88.79
		2.88	218.51	85.80
		3.12	236.72	80.97
		3.36	254.93	74.30
		3.6	273.14	65.78
		3.84	291.35	55.42
		4.08	309.56	43.22
		4.32	327.77	29.17
		4.56	345.98	13.28
		4.8	364.19	-4.45

<u>XY - Scatter Plot and Horizontal Versus Vertical Displacement</u>



Pictures of Prototypes

Rocket #2


Description

The second rocket was built based on observations of the first rocket's flight, and information obtained from the field trip to Patriot Foundation. The largest issue with the first rocket was that the rocket was slightly bottom heavy, which led to the rear of the rocket dipping down below the cone, greatly increasing drag. This was solved by stuffing newspaper into the cone of the rocket, and making it longer to shift the center of mass to being top heavy, so that the cone could dip accordingly as the rocket descended. The observation was also made that the launcher had a constant power output to the rocket, so the only way to increase the initial velocity was to increase the duration of contact between the rocket and the launcher pipe, which could only be accomplished by increasing the length of the rocket. This modification succeeded in increasing the initial velocity from 107 ft/s to 125 ft/s in the second launch. The cone length was also increased based on advice from a professional at Patriot Foundation, who mentioned that a longer, thinner cone would further smooth out the drag curve by very gradually increasing the cross sectional area of the rocket. Another piece of information obtained was the utilization of the Area Rule, where the body of a plane was thinned around the fins to decrease the cross sectional area and therefore the drag. However, this was too difficult to implement on this rocket using only paper. The fins were created in proportion to the rockets seen on the field trip, which had very small fins compared to their size. Trapezoidal fins were also used after learning about their superiority on the field trip.

The rocket flew 484 feet in horizontal distance and reached a height of 121 feet. The duration of the flight was 5.7 seconds, and the calculated total theoretical distance traveled by the rocket is 555 ft (calculated by the arc length formula).

The actual flight values were close to the theoretical values, as can be seen in the table and graph below. This difference occurred because the distance recorded for flight assumed that the rocket flew exactly straight, when in reality it did not, which led to the theoretical horizontal displacement was slightly greater than the actual horizontal displacement, this time being larger since the rocket did not have the benefit of the spiral. The discrepancy in the vertical displacement can be explained by the fact that there was some wind higher up in the sky on the launch day since flags were waving in the wind in the direction of launch. This meant that the rocket flew slightly longer than expected due to the wind.

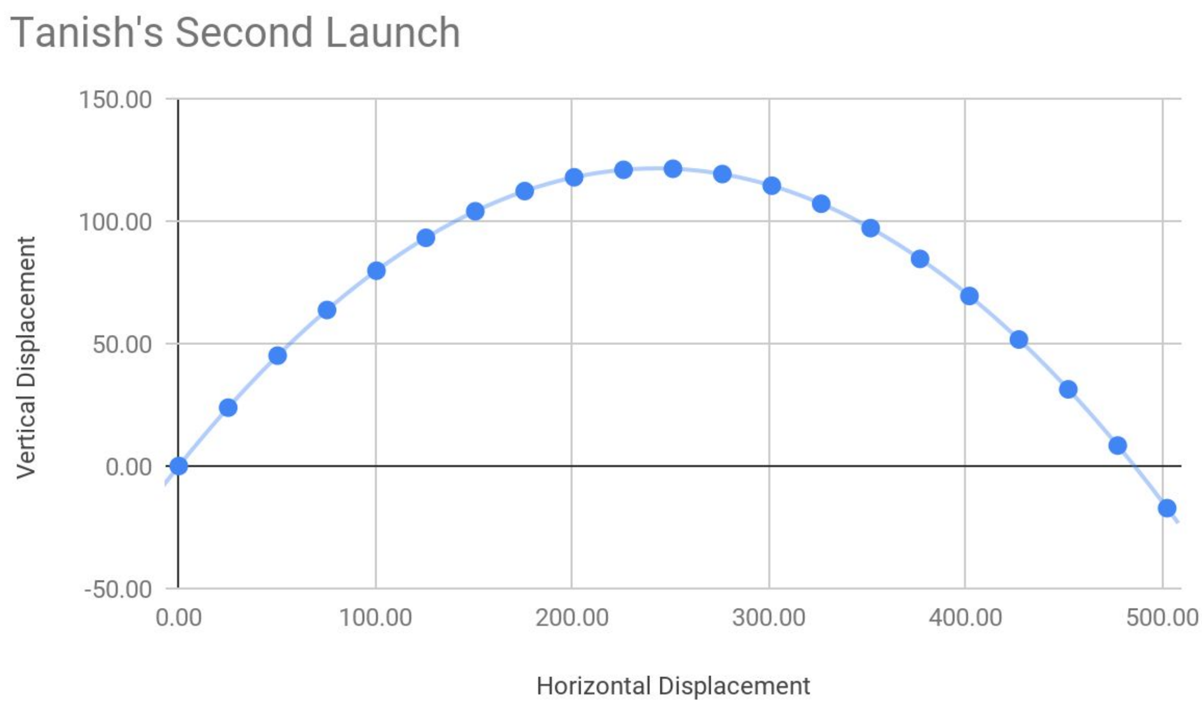
Recommendation

This rocket is recommended for a long flight in relatively calm air, since the small fins of the rocket provide less stabilization in the air. Some modifications required to this rocket is the usage of sturdier materials to build the fins of the rocket, as they started to warp by the third launch. A crucial modification that can be made to the cone is to switch it to a parabolic shape by fabricating a custom design of the cone. The parabolic shape of the cone provides the minimal drag force, and will increase the range of the rocket. The fins can also be tapered, with a thinner fin in front that gets thicker until the back, also reducing drag in the process. This rocket is good for getting far flights in calmer air, but still contains the stability to fly in slightly turbulent air.

Data Table

Initial Velocity (ft/s)	124.71	Time	X	Y
Angle (degrees)	45	0.00	0.00	0.00
Actual Horizontal Displacement (ft)	484	0.29	25.13	23.83
Theoretical Vertical Displacement (ft)	-17	0.57	50.26	45.07
Theoretical Horizontal Displacement (ft)	503	0.86	75.40	63.70
		1.14	100.53	79.73
		1.43	125.66	93.17
		1.71	150.79	104.00
		2.00	175.92	112.24
		2.28	201.05	117.88
		2.57	226.19	120.92
		2.85	251.32	121.36
		3.14	276.45	119.20
		3.42	301.58	114.44
		3.71	326.71	107.08
		3.99	351.84	97.12
		4.28	376.98	84.57
		4.56	402.11	69.41
		4.85	427.24	51.66
		5.13	452.37	31.30
		5.42	477.50	8.35
		5.70	502.64	-17.20

<u>XY - Scatter Plot and Horizontal Versus Vertical Displacement</u>



Final Recommendation

Overall our team recommends a long, sturdy rocket with small trapezoidal fins and a long, thin cone. This recommendation is based on three of the primary variables we controlled in our rockets: initial velocity, stability, and drag. The most important factor that affected the total distance flown by the rocket was initial velocity, since it was the basis for all of the calculations and allowed us to get as much energy transferred into the rocket by the launcher as possible. To increase velocity, we recommend a very long body for the rocket, which would allow it to be in contact with the launcher for a longer distance than a shorter rocket, therefore increasing the work done on the rocket by the launcher, since the launchers force fixed. The next most important factor was ensuring that the rocket would fly in a straight line unaffected by the wind, since the distance we were measuring was perpendicular to the starting line. We accomplished this by using fins that protruded a lot compared to their size, allowing them to control the air flow around the rocket and ensure stability. Another thing that was crucial to maintaining stability was the weight distribution of the rocket. Based on our observations, a bottom heavy rocket's cone lifted up in flight, causing it to spin violently in the air and lose momentum. A top heavy rocket however, had a clean, smooth parabolic flight which gave it the optimal distance traveled. To create a rocket that was undoubtedly top heavy, we weighted our cones with excess paper and duct tape to weigh the tip down. Finally, the last variable that we were able to control on our rockets was the amount of drag force it faced in the air. We ranked this factor last in significance because optimizing the amount of drag the rocket faced in the air on a reasonable aerodynamic rocket had a minimal effect on the distance traveled as opposed to the other two factors. Nevertheless, optimizing the drag force was important to create a successful rocket, because there was only so much we could improve upon the other factors. Therefore, to improve the drag, we recommend a long thin cone to smoothen out the drag curve by increasing the cross sectional area of the rocket gradually. We also recommend fins of the trapezoidal shape which have the least drag. It is important that the fins are very small, and in our case they were around 1 inch long at the base and 0.75 inches tall for a 15 inch rocket. Overall, these listed recommendations should create a rocket that travels the maximum distance.