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The Effect of Various Fin Designs on the Stability, Maximum Height, and Drag of Model Rockets to Maximize Efficiency

Varun Nagaraj*

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Abstract: The purpose of the research presented in this paper was to ascertain if different fins for model rockets impact their stability, maximum height, and drag in order to provide an optimal design for new rockets. This research addresses a current gap, a lack of research into the physical components of rockets. Using the OpenRocket software, three different model rockets were designed. These were then built physically and were launched multiple times, both physically and in simulations, to collect data. Then, the data were analyzed to find the differences between the performances of each of the fins and determine which fins maximized the efficiency of the rocket, according to the three tested variables while keeping launch velocity constant. The control group for this experiment was a rocket with trapezoidal fins, while the experimental groups had elliptical and clipped-delta fins. In the statistical analysis of both experimental and simulation data collected, we posed the experimental hypothesis stating that the trapezoidal fins would perform the best, whereas the null hypothesis was posed to state that there would be no difference in the three groups' performance. Overall, the data showed consistent results with clear differences in the experimental and control groups. In the data from simulated launches, the analysis of variance test showed statistically significant results with *p*-values below 0.0001, meaning that the null hypothesis was rejected, and that the experimental hypothesis was supported. The null hypothesis is rejected due to a higher level of reliability of the data from the simulated data set. These results show that there was a significant difference in the performance of the three fin models and that the control group's fins can be used to optimize the performance of rockets.

Author keywords: Model Rockets; Rocket Design; Drag Coefficient; Rocket Fins; Rocket Performance

Introduction

There are many parts of a rocket that are crucial to its successful launch and flight. Fins are one of the most important parts of a rocket. These are small, flattened projecting surfaces or attachments, which provide many benefits to the rocket. The shape of the fin can affect the rocket's stability (straightness of flight path or aerodynamic control), maximum height, and drag coefficient, among many other factors. High stability is critical as it will cause the rocket to have a less crooked flight path. This, in turn, will help the rocket to be more accurate in reaching its destination. The maximum height attained by a rocket is an important parameter to measure its performance. The drag coefficient is directly connected to this—it affects the friction that the rocket generates in the air, with a lower drag coefficient resulting in a higher maximum height. In this research, I carried out experiments on three rockets with different types of fins to identify the fins that would make the rocket maximally efficient with the same liftoff energy, as determined by three variables—stability, maximum height, and drag coefficient. This experiment used model rockets to mimic real rockets and collect data. Simulation software was used to collect additional data on the rockets. Three rockets were launched—one each with trapezoidal, triangular, and ellipsoid fins. This experiment addressed a gap, which is a lack of recent research into the physical components of rockets, such as drag.

The two hypotheses considered during the analysis of data are:

Experimental Hypothesis (H_E): If the rocket model with trapezoidal fins were designed to be the most effective of the three models, then it would achieve the highest maximum height, lowest drag coefficient, and greatest stability.

Null Hypothesis (H_0): All the rocket models would perform the same, and there would be no statistically significant difference in the performance of the three models.

Relevance to current events

In 2022, a record-breaking 180 rockets were launched into orbit, which is the most ever launched in a single year.[1–3] Recently, progress in aerospace-based research has led to many exciting advancements, such as improvements in rockets that vastly improve their performance in space.[2,4,5] For example, a design experiment by Bennewitz et al.[6] presented a novel design of a rotating detonation engine. The

*Corresponding Author: Varun Nagaraj.
Email: varun.nagaraj@gmail.com
High School, Naperville, IL 60564, USA

researchers studied this new engine in depth and presented in their paper different scenarios in which the engine design could be used. However, while technology-based research on parts such as avionics and engines has increased, research on the structural components of the rockets, or physical characteristics that improve the aerodynamics of the craft, has significantly decreased.[7–9] This shift in research focus has led to the same profile and the same aerodynamics for many rockets throughout the last several years. While a few improvements are still being made in this area, and some studies have been built around existing research in aerodynamics, there is a gap in this field. Very little active research has been on conducted on improving the aerodynamics of rockets, making them more stable and straight-flying in the air after liftoff, both due to turbulence and due to the rocket's own weight.[6,10–12]

Currently, research in aerospace is moving away from structural studies and into more technology-based investigations that improve the capabilities of rockets in space.[4–6] These include making improvements to the engine, making it more efficient, and introducing new blueprints of engines to the field.[6,13,14] Other, more complex research includes machine-learning systems that can take pictures from orbit and systems that can generate optimal flight paths for multiple distinct airplanes near an airport.[4,15,16] Of these various studies, the research that relates to rockets has been mainly focused on space; for example, the effects of reduced gravity on different granular substances or on the mental state of human pilots.[17,18,19]

Incorporating advancements discussed above into current aircraft will improve their fuel efficiency and other systems.[9,11,16] However, the drawback of implementing these complex mechanisms is that they build on the existing research on aerodynamics. If these fields advance further than the aerodynamics of the aircraft can accommodate, then the new technology might become unable to be implemented within the aircraft.

Recently, Wang et al.[9] performed a "physical" experiment that focused on tri-wing flight vehicles. This experiment studied how the flutter, or vibration, of the wings of these vehicles impacted their aerodynamics and their speed and performance in the air using both modeling simulations and physical data collection from tri-wing flight vehicles. Their simulations provided them with baseline data, which was then corroborated using their physical data collection.

The experimental study carried out in this research pertains to fin designs applied to model rockets, following the experimental procedure used by Wang et al.[9]. The experiment examined the effect of different fin shapes on the stability, maximum height, and flight speed of model rockets. This was measured through the straightness of the path and the altitude achieved. Model rockets were used to simulate real rockets since the aerodynamics of both are very similar.

Background

There are multiple forces that act on the rocket during its time in flight.[20–22] The main aerodynamic force acting on the rocket is broken into two components: the lift force, which acts perpendicular to the direction of motion, and the drag force, which acts opposite to the direction of motion. These forces are exerted on the spacecraft due to its contact with air, not because of any force fields or gravitational fields. Because of this, aerodynamic forces will only act on full-scale rockets when they are within Earth's atmosphere. Aerodynamic forces act differently on rockets than on airplanes. On airplanes, lift is used to overcome the obstacle of weight.[9,23,24] However, on rockets, thrust is used to overcome the weight of the rocket and propel it upwards. In this experiment, all rockets were launched directly upwards, negating any lift that the fins themselves might produce. Aerodynamics are more important for a model rocket, as opposed to a full-scale rocket. This is because model rockets spend the entirety of their flight time within the atmosphere, whereas full-scale rockets will leave the atmosphere after the initial liftoff phase of flight. This makes model rockets ideal for studying the effects of aerodynamics on rockets, as they will spend all their time within the atmosphere and will have aerodynamic forces applied to them throughout the duration of their flight. Drag is simply friction applied to airborne craft such as rockets and airplanes. One of the main sources of drag is skin friction between the air and the aircraft.[20–22] The magnitude of the skin friction depends on the attributes of both the solid and the gas, that is, rocket frame material, and fluid medium, such as air around it.

A smoother, waxed solid will produce less drag, whereas a rougher solid will produce more drag for an aircraft.[20–22] Drag can also be expressed as aerodynamic resistance to the movement of the craft through a fluid. This type of drag is known as form drag, as it is drag created by the shape of the rocket.[9,24] As air flows around a body, the local velocity and pressure are changed. Since pressure is a measure of the magnitude of a force distributed over a surface, a varying pressure distribution will produce a force on the body. The magnitude of this force can be determined by integrating the local pressure over the surface area of the entire body of the rocket.[9,20–22] Fig. 1 illustrates how an airborne model rocket is influenced by drag.

The drag coefficient (C_d) is a number used to model all the complex dependencies of drag on shape and flow conditions and is given by NASA.[22]

$$Cd = \frac{D}{\rho * A * \frac{V^2}{2}} \tag{1}$$

In Eq. (1), D represents the drag force, ρ is density, A is the reference area, and V is velocity. Rockets with a larger diameter are subjected to more drag because there is a larger surface area over which the pressure acts, therefore producing a larger force. Drag depends on the cross-sectional area of the object pushing through the air. Making a rocket as narrow as possible is an efficient way to reduce drag; however, this method has drawbacks, such as less configurability of the rocket's other parts and less payload area for transportation of materials. Fig. 2 shows the drag coefficient for various shapes, including those commonly found within the rocket body and nose cone.

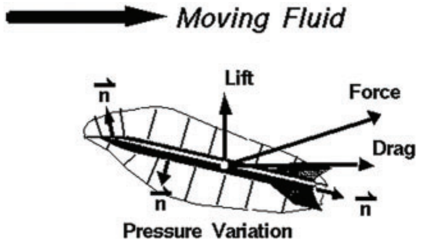

Figure 1. Aerodynamic forces on a rocket in flight. Source: Adapted from NASA[22]

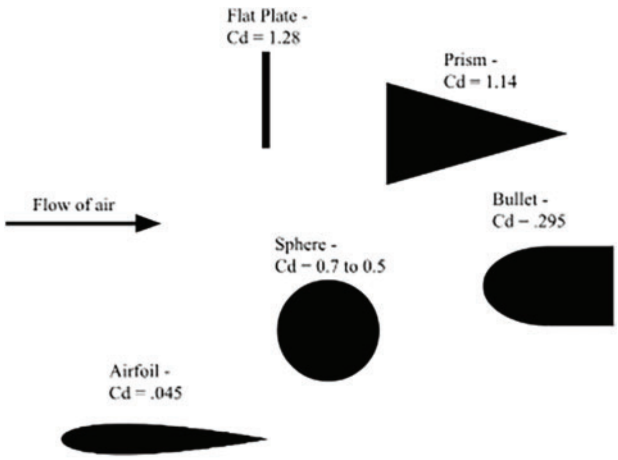

Figure 2. Drag coefficients of various object shapes. Source: Adapted from *Shape Effects on Drag*, by the National Aeronautics and Space Administration[22] (https://www.grc.nasa.gov/www/k-12/rocket/shaped.html)

In this experiment on model rockets, three experimental model rockets were designed and launched, each with a different fin shape (trapezoidal, elliptical, or clipped-delta). After the initial rocket model was tested, it was then redesigned to include a different shape of fin and was then physically built. In each iteration, the model rocket was first designed within OpenRocket and was subjected to many reiterations. After a physical launch, the OpenRocket software was used to run 30 simulated launches for each fin design and gather additional data. After three repetitions of this process for each fin shape, the most effective fin that had the highest maximum height, most stability (determined by observing the rocket's flight path), and lowest C_d was identified. The physical launches were done within 2 consecutive weeks wherein the atmospheric conditions (wind speed, air temperature) were almost identical and would not have affected the data in any significant manner. Within the simulations, the weather data was copied exactly from one of the launch days and was kept consistent across all the simulations.

The results of this experiment add to the current research on the aerodynamics of various existing aircraft and can supplement aerospace-based future research by providing some baseline information and data so that future researchers will have current research to work with.[7,9] This research will help to make knowledge about the aerodynamics of these rockets more widely known.

Materials and Methods

The procedure for this experiment was split into three phases: the initial design phase, the build phase, and the testing phases, as illustrated in Fig. 3. Three models of the rocket were built, each using different fin shapes to collect data on a variety of fin shapes and analyze the effects of each on the stability and performance of the rocket. The rockets were designed using the OpenRocket software, which facilitated the design process through its interface that allows for easy access and editing to any part of the rocket. The specifications of each part used in the rocket body are presented in Table 1. The entire rocket body, other than the fins, was kept the same in all three models. This was done so that only the fins would affect the aerodynamics of the three rocket models. Data on the performance of all three rockets were collected through rocket launches.

Experimental procedure

Time frame

The experiment was conducted over a period of 9 months—August 2023 through April 2024. This time was spent primarily in the construction phase, wherein the physical rocket was built. The total time taken for this experiment was approximately 35 hours for the initial design, 50 hours for construction and rebuilding of the rocket, and 25 hours at launch sites to gather experimental data from the launch of each model rocket, with an additional 10 hours spent running simulations and analyzing data. Safety protocols were always followed while at the launch site.

Construction and launch procedure

The rocket was constructed using the materials that are outlined in Table 1. First, two body tubes were measured and cut to the correct length. Then, four fins were cut out from a sheet of balsa wood using a laser cutter. These fins were inserted into slits in the rocket body. Then, a transition was used to connect the two body tubes together. An engine mount was created by fixing two centering rings to a smaller inner tube and was inserted at the back of the rocket. Finally, a parachute was fixed to the inside of the rocket for easy recovery. A nose cone was added to the top, and some mass was added to stabilize the rocket and complete the building. The mass of the rocket was kept constant in all models and launches and was controlled using an additional mass component. All gluing was done using Titebond wood glue, and 5-Minute Epoxy was used on the plastic transition piece. Fig. 4 shows the construction of a rocket. Fig. 5 shows the designs of trapezoidal, elliptical, and clipped-delta fins. Fig. 6 shows the construction of rockets with trapezoidal and clipped-delta fins.

For launching, a commercial rocket motor produced by Estes, consisting of APCP propellant, was used. The same type of motor—an E30-7—was used for all launches to

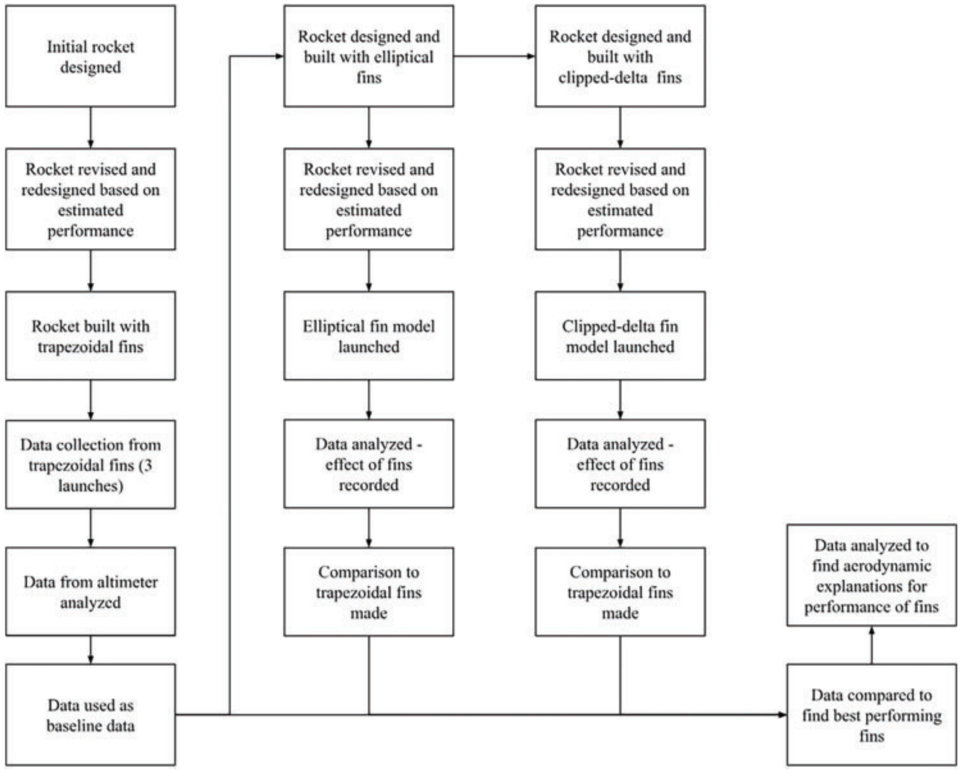

Figure 3. Flowchart showing design, fabrication, testing, and data collection on model rockets

Table 1. Parts detail of base rocket design

Part name	Mass (g)	Length (cm)	Outer diameter (cm)	Material
Nose cone	21	5.08	Ellipsoid	Balsa
Body tube	16	22.9	5.72	Cardboard
Mass component	78	–	–	Sand
Altimeter	10	–	–	–
Transition	41	5.08	6.35	Plastic
Ballast	6	–	–	Sand
Body tube	30	35.6	6.35	Cardboard
Parachute	10	2.54	–	Ripstop nylon
Shroud lines	0	30	–	Elastic cord
Parachute protector	9	–	–	–
Inner tube	3	10.2	2.45	Cardboard
Centering ring	4	0.2	6.05	Balsa
Centering ring	4	0.2	6.05	Balsa
Launch lug	4	3	1	Plastic

Figure 4. Construction of rocket body

ensure the thrust produced was the same. This motor provides continuous thrust for around 1 second before burning out. A digital altimeter was used to record the maximum height of the rocket. This was placed in the top half of the rocket, and it measured height according to pressure readings. To launch, the rocket was placed on a launch rail with the motor inside it, and the motor was ignited from a safe distance using an electrical charge. Unfortunately, one launch was canceled due to bad weather; hence, the second experimental group (E2) was unable to be tested physically.

The control group in this experiment was the model rocket with trapezoidal fins. This is because trapezoidal fins are a very common fin shape found in many modern spacecraft, including rockets.[3,9,20] The experimental groups E1 and E2 comprised the other two models of rocket, which each used differently shaped fins—elliptical and clipped-delta. The constant in this experiment was the rocket body and altimeter used throughout all three models. The altimeter was the

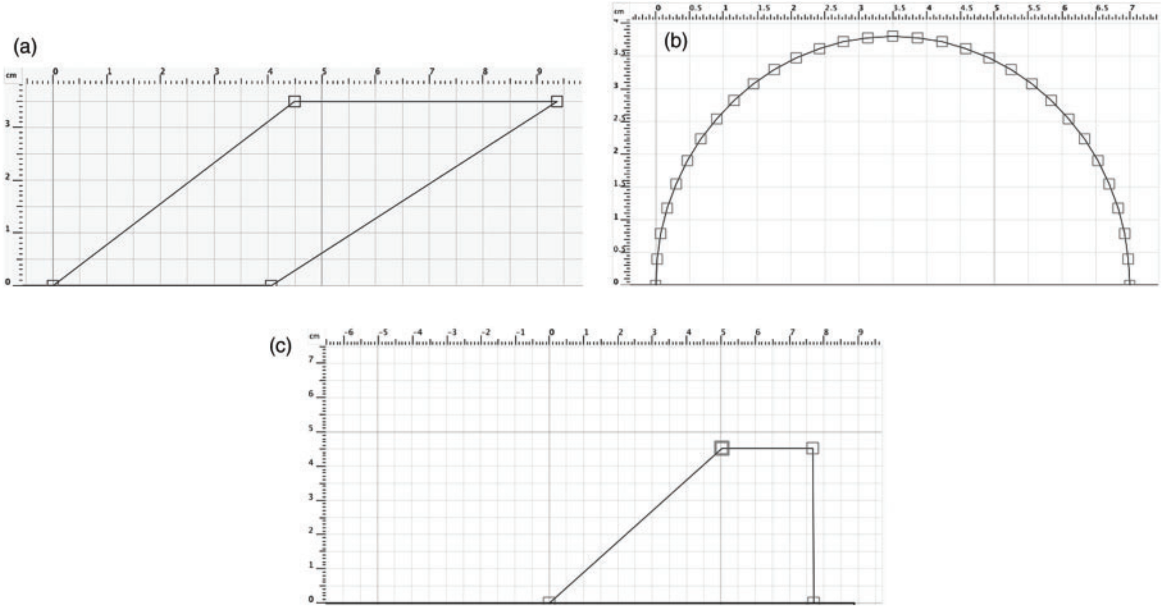

Figure 5. Design of fins: (a) Trapezoidal, (b) Elliptical, and (c) Clipped-Delta

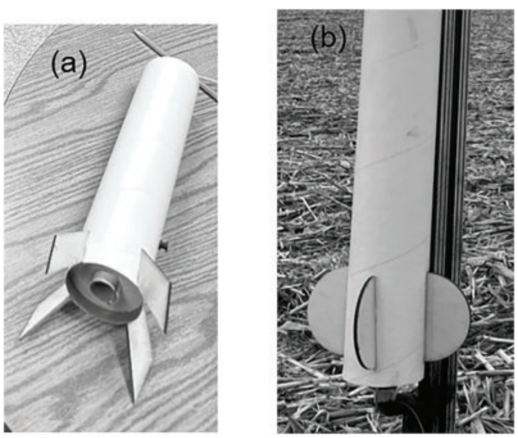

Figure 6. Fins on model rockets: (a) Trapezoidal and (b) Elliptical

device used to collect experimental data from the launch of the rocket, and that was also kept constant throughout the experiment. The dependent variables were the maximum height, flight time, and top speed of the rocket, whereas the independent variable was the type of fins used in the model rocket. For each model, three trial launches were done, which allowed for cost-effectiveness while also gathering effective data from each. There is very little current experimental data that compares various commonly used fins against each other; therefore, this experiment is unique and contributes to the field of aerospace.

Research results

Three launches were performed for the control group and for E1, the model with elliptical fins. We could not conduct more launches because of weather and cost limitations. This limited the size of the physical data set. Fig. 7a presents the maximum height data with 95% confidence interval (CI) bars for rockets with trapezoidal and elliptical fins. To supplement the limited physical data sets, we performed simulations using OpenRocket software to create a second set of data through 30 trials for rockets with each of the three fins. Fig. 7b presents maximum height data from the simulated data set. It is observed that the mean heights from both physical and simulated sets for the three rockets are almost the same.

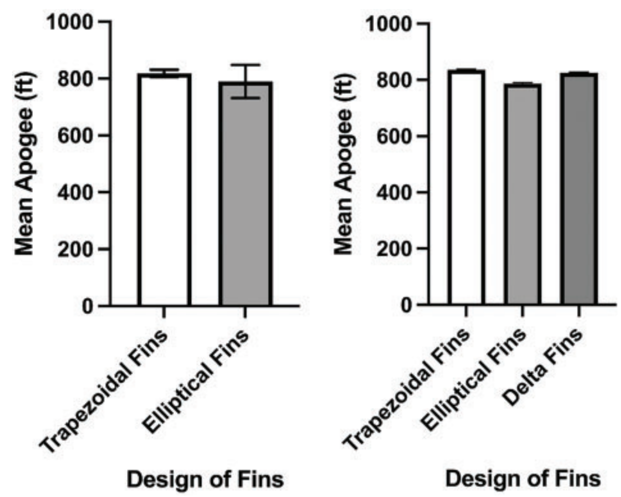

Figure 7. Mean height data (a) from two physical launch groups with 95% CI and $n = 3$ and (b) from three simulated launch groups shown with 95% CI and $n = 30$

The OpenRocket software was also able to calculate C_d (drag coefficient) for each of the three models, along with C_d for each of the fin designs. These C_d values are shown in Table 2. The physical data was analyzed using a Welch's t-test and an F-test. These results are presented in Tables 3

Table 2. Drag coefficients for rockets and fins only from simulated data

	Cd—Full model	Cd—Fins only
Trapezoidal	0.481	0.021
Elliptical	0.492	0.032
Clipped-delta	0.486	0.030

and 4. Due to the simulated data's larger sample size, a one-way analysis of variance (ANOVA) test was used to analyze the data. This test showed that $p < 0.0001$ for simulated data and an F-value of 371.01, as presented in Table 5. The F-value represents the ratio of the variance between group means to the variance within the groups, with a higher value correlating to more variance between the groups.

Discussions

Overall, the data show very different relationships for the physical and simulated data sets. The simulated data highlights the performance of the trapezoidal fins as the best of the three models and lends support to the experimental hypothesis, as it had the highest apogee and lowest drag coefficient. It can be concluded that the simulated data does follow the pattern of the physical data and, therefore, is considered trustworthy, as the simulated data was generated using the physical design and weather data as a baseline.

Due to the relatively small sample size of the physical data set ($n = 3$), those statistical analyses have a higher chance of being imprecise and providing information that does not accurately represent the data inside the physical data set. When $p < 0.05$ in the statistical tests, the data are considered statistically significant, and the null hypothesis is rejected. The physical data seems to accept the null hypothesis due to its smaller sample size and the fact that only two of the three models were tested.

Statistical analyses

Statistical analyses were used to determine whether the null hypothesis was able to be rejected based on the collected data. Before running statistical tests, basic information was collected on the data, such as mean, standard deviation (SD), standard error of the mean (SEM), and 95% CI. The mean is the average of the data and helps to compare the overall data sets to each other without looking at individual data values. The SD indicates how much the data varies from the mean; a higher SD means that the data is spread over a higher range. The SEM, on the other hand, is used to quantify the uncertainty in the estimate of the mean. A lower SEM would indicate higher accuracy in the calculation of the mean. The 95% CI indicates a range wherein 95% of the data within the data set is contained.

For example, within the physical data set, the mean maximum height of the control group was 818.333 feet (Fig. 7a). The SD was 4.19 feet, the SEM was 2.963, and the 95% CI range was ±4.741, meaning that 95% of the maximum height data was within 4.741 feet of the mean value of 818.333 feet. However, this does not mean much because there were only three data points in the physical data set.

Within the simulated data set, however, more accurate data was able to be gathered since there were 30 data points. For the control of the simulated data set, the mean was 836.333, the SD was 6.745, the SEM was 1.252, and the 95% CI range was ±2.413. Within this data set, the SEM and 95% CI range were both smaller, which suggests more reliability.

Next, multiple statistical tests were run on both the physical data set and the simulated data set. A Welch-corrected t-test, and an F-test were used to analyze the physical data.

Table 3. Physical data—Welch-corrected T-test results

Model	p-value	One- or Two- tailed	Welch corrected t, df	Significantly different?
Trapezoidal vs elliptical	0.1631	Two-tailed	2.069, 2.191	No

Table 4. Physical Data—F-Test Results

Model	p-value	F, DFn, DFd	Difference in means ± SEM	Significantly different?
Trapezoidal vs elliptical	0.0915	20.86, 2, 2	28.67 ± 13.25	No

Table 5. Simulated Data—One-Way ANOVA Test Results

ANOVA table	SS	DF	MS	F (DFn, DFd)	p-value
Treatment (between columns)	40089	2	20045	F (2, 87) = 371.01	$p < 0.0001$
Residual (within columns)	4700.4	87	54.028		
Total	44790	89			

Table 6. Simulated Data—Tukey's multiple comparisons test results

Multiple comparisons test	Mean diff.	99% CI of diff.	*p*-value
Control vs. E1	49.267	43.589 to 54.944	$p < 0.0001$
Control vs. E2	11.067	5.3890 to 16.744	$p < 0.0001$
E1 vs. E2	−38.200	−43.878 to −32.522	$p < 0.0001$

The *t*-test was used to determine whether the mean values of the control and E1's maximum height data had statistically significant differences. This test concluded that ($p > 0.05$) in this data set, which meant that the mean values of the two groups were not significantly different. This conclusion was most likely reached due to the small sample size of the physical data set ($n = 3$). The *F*-test, used to determine whether the variances of the two populations were equal, also concluded that the differences were not statistically significant.

For the simulated data set, an ANOVA test was used to analyze the variance of the data. This test concluded that the data is statistically significant, most likely because the larger sample size ($n = 30$) allows the test to be more effective. A multiple comparisons test (Table 6) was also used to find the largest mean difference in the data, which was found when comparing the control group with E1. The mean difference in this case was 49.267, implying that the control rocket flew 49.267 feet higher than E1 on average.

When analyzing the results from the physical data set, the null hypothesis was unable to be rejected regarding the control and E1, and that the data does not exhibit variance at values of ($p > 0.05$). As seen in the *t*- and *F*-test, the *p*-values are greater than 0.05. However, this observation is refuted by the ANOVA test of the simulated data set, wherein ($p < 0.0001$). This lends support to the experimental hypothesis, as it shows that the data are statistically significant and do exhibit notable variance in their means.

In this experiment, the simulated data set is more trustworthy simply due to the larger sample size, which increases the effectiveness of statistical tests such as the performed ANOVA test. While the physical data set only has three data points per model, the simulated data set has 30 data points per model, which is a significant difference. From this data, it can be concluded that overall, the experimental hypothesis is supported due to the comparatively stronger reliability of the simulated data set.

Looking at the comparison between the drag coefficients (C_d) of the three models, while the control (trapezoidal fins) had the fins that produced the lowest drag, E2 (clipped-delta fins) overall had the least drag coefficient. This could be due to the way that the fins streamlined the rocket body, as all aspects except for the fins were identical throughout the three rockets. This data rejects the experimental hypothesis, however, as E2 did have a comparatively lower C_d than the other two models.

The physical maximum height comparison strongly supports the experimental hypothesis. The control had a higher mean maximum height than E1. The control was also more consistent than E1, as shown by the fact that the control had a much smaller 95% CI range. These findings were also consistent through the simulated maximum height comparison. The rocket with trapezoidal fins had the highest mean maximum height out of the three models and was also the most consistent of the three. While not evident due to the scale of the bar graph, the 95% CI range of the control is much smaller than that of both E1 and E2 within the simulated data set. This supports the experimental hypothesis that the model with trapezoidal fins would have the best maximum height of the three models.

Looking at the qualitative data from the physical launches of the control and E1, the control had a consistently straighter flight path than E1. E1 tended to wobble in the air after takeoff, while the control was again much more consistent and straight-flying in the ~1 s interval following takeoff. This can be attributed mainly to the fins, as the other atmospheric conditions had very little variation between launches and the rockets themselves had the same amount of mass. Through these observations, it was determined that the control also had the highest stability.

Error analysis

In this experiment, Type I and Type II errors were a definite possibility, where a Type I error is a false rejection of the null hypothesis, and a Type II error is a false acceptance of the null. Due to the very small sample size of the physical data set, the *p*-values produced were quite high and seemed to reject the null hypothesis.

Based on conflicting data from the simulated data set, the null hypothesis was ultimately rejected. This creates a chance of causing a Type I error; however, the chance is low, as the simulated data set is 10× as big as the physical data set and has a much lower chance of introducing statistical anomalies due to its larger sample size of $n = 30$.

Limitations

The most significant limitation of this experiment was the small sample size of the physical data set. While the simulated data set provided data that was mostly reliable, collecting all the data purely through physical launches would have been ideal, as all the data would have come from a real launch scenario, which would make it much more realistic. Another, comparatively minor limitation is that the experiment was done using model rockets and not real rockets. While the aerodynamics between the two are virtually the same, model rockets are subjected to forces such as wind and air pressure, which do not affect full-size rockets nearly as much due to model rockets being inherently more flimsy and therefore more vulnerable to these forces. A third limitation is that while three commonly used fins were tested, there theoretically is an infinite amount of fin designs that can be created by slightly modifying existing fin designs that can be proven effective. Because of this, there is no one fin shape that can be established as "the best," as new innovations are being made, and new research is being conducted constantly.

Future research

There is much room to build on this research. New fin designs could be tested that outperform these fins, or fins that are not referenced at all in this research could be tested against each other. Additionally, there are many more attributes than just fins to a rocket which are just as important to the rocket's performance. Nose cones, surface materials, and especially engines could be designed in future research to further improve the efficiency of rockets in the aerospace field. Finally, due to the various limitations of this experiment, further research would be necessary to fully confirm the experimental hypothesis and say that the control's fins performed the best out of the three fin models tested. These experiments have the potential for massive positive impacts that strengthen the basis of the field and further the available knowledge in this field. This impact, in turn, will cause advancements and positive impacts in other sectors related to it. The next step would include testing this fin prototype in a full-size rocket scenario, possibly at NASA or another aeronautics company such as SpaceX. There are many scholarship and research opportunities at NASA where experiments like this could be performed on larger-scale rockets, one of which I am pursuing to further my knowledge and understanding of this science. While one fin cannot be proven the "most" effective, there are definite differences in the performance of each fin, and choosing the right one can have huge impacts on the efficiency and optimization of a rocket.

Conclusion

In this research, we have investigated the effect of different types of fins on the aerodynamics of rockets. Overall, the data supported the experimental hypothesis, which is that the trapezoidal fins would perform the best, achieving the greatest stability, highest maximum height, and lowest drag coefficient. Utilizing the experiment framework used by Wang et al.,[9] reliable data were collected on the performances of the different fin types. Although all three fins were reliable and performed well, the trapezoidal fins performed optimally regarding these three variables. The data showed consistent results with clear differences in the experimental and control groups. In the simulated data set, the ANOVA test showed statistically significant results with p-values below 0.0001, meaning that the null hypothesis is rejected, and that the experimental hypothesis is supported. This experimental design has also been followed by other researchers to test or compare the performance of designs, which proves its validity.[6,11,13,18] The only insignificant results were found in the physical data set, which was due to the small sample size of this data set. Despite the physical data set's results, the null hypothesis is rejected due to the higher reliability of the data from the simulated data set. The data from both the physical and simulated data sets supports the experimental hypothesis, although a final decision cannot be reached without further research on the performance of these fins. The experimental hypothesis is supported with respect to the fact that the control had the highest maximum height, the highest stability, and was the most consistent out of all of them; however, E2 did have a lower drag coefficient, meaning that the experimental hypothesis cannot be fully accepted. This experiment builds on the work of scientists such as Barrowman[20] who researched and wrote a dissertation on the aerodynamics of rockets. Using that research and the work of other scientists such as Ding et al.[24] and Jiang et al.,[21] this experiment was able to be performed, and other research can then build from this in the future. In conclusion, while there is scope for improvement and further research, the experimental hypothesis is supported in that the control's fins performed the best overall out of the three models tested.

Acknowledegments

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About the Author

Varun Nagaraj is an 11th grader studying at Neuqua Valley High School in Illinois, USA. His research interests include aerospace engineering, mechanical engineering, and physics. He has won many awards at science competitions for his research, including multiple gold awards from IJAS (Illinois Junior Academy of Science) and Second Place at the prestigious JSHS—Junior Science and Humanities Symposium. He enjoys model rocketry and is currently Level 1 Certified for high-power rocketry.