Karl Roush

The Effect of the Angle of Rocket Fins on the Peak Vertical Flight Height of Rockets

17 December 2014
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Abstract

This experiment was designed to investigate the effects of the fin angle on the peak vertical height of rockets, which was measured in meters. In this experiment, the data produced by a rocket with fins placed at 90 degrees from the body was considered the control group, while the data produced by the rocket with fins placed at 45 degree from the body was considered the test group. It was predicted that the rockets with fins placed at a 45 degree angle to the body would result in a significantly higher peak vertical flight height than the peak vertical flight height of rockets with fins placed at 90 degree angle to the body. In order to test this hypothesis, a model rocket with 90 degree fins was launched twelve times, and a model rocket with 45 degree fins was launched twelve times. Peak vertical flight height was measured by an altimeter that was attached to the rocket and produced data in meters. A one-tailed t-test was used to obtain a p-value in this investigation. The p-value was $9.99999999653 \times 10^{-1}$, which was greater than the alpha of 0.05. These results have shown that rocket fins placed at a 45 degree angle to the body do not result in a significantly higher peak vertical flight height than the peak vertical flight height of fins placed at 90 degree angle to the body.

Introduction

Rationale:

For millions of people across the globe, model rocketry is an exciting hobby. Even though it appears to just be a simple pastime on the surface, precision is key in almost every attribute of it, and every little detail matters. Small adjustments to the rocket or the launch pad can have drastic effects on flight behavior (*Basic Rocketry Aerodynamics*). This experiment will be testing to see how the angle of the rocket fin affects the vertical flight height which is also known as the apex of the flight. The fins themselves are a key component of the rocket. They provide both stability and the ability to alter the flight path, whether it is beneficial, harmful or both (Nakka, *Richard Nakka's Experimental Rocketry Site*). Essentially, this research experiment examines the impact of changing the angle of the fins in relation to the body of the rocket on maximum vertical flight height. In order to ensure consistent results, the two rockets will have to follow congruent specifications that optimize their performance (*The Aerodynamics of Model Rockets Part 3- Rocket Design Analysis*). A full list of constants can be found on the Experimental Design Diagram (attached, last page). However, not everything can be kept constant, so several assumptions must be made which includes the margin of error on the altimeters and having the same amount of thrust produced by the rocket engines at every launch (full list of assumptions can be found the top of the next page).

It has already been shown in multiple studies in literature that changing various attributes of the rocket fins will produce a broad spectrum of flight behavior (Kim, Lee, and Tahk, *New Structure For An Aerodynamic Fin Control System For Tail Fin-Controlled STT Missiles*). This experiment will serve to clarify and further explore the results of flight behavior (in this case, peak vertical height in meters) in respect to different fin angles in relation to the body of the rocket. The results of this project could benefit more than only model rocket enthusiasts. Fins used for guiding projectiles can be found in a variety of other disciplines such as military sciences where fins on artillery shells are used to direct their path (Garner, Weinacht and Kaste, *Experimental Validation*

Of Elliptical Fin-Opening Behavior). As such, the results from this project would potentially allow for a more efficient use of the thrust produced in projectile propulsion.

Assumptions:

- Rocket engines will produce the same amount of thrust each time.
- Rockets will launch with the same angle relative to the ground.
- Slight deformities in the rockets due to repeated launches will not significantly impact the data.
- Altimeters have a margin of error less than 1 meter.
- The difference in weight between the rockets will not significantly impact the data.

Objective: The student researcher will determine if the fin angle in relation to the body of a model rocket can significantly influence the peak height of the rocket, and if so, which angle creates the highest apex height (in meters).

The student researcher expects that the rockets with fins placed at a 45 degree angle to the body will result in a significantly higher peak vertical flight height than the peak vertical flight height of rockets with fins placed at a 90 degree angle to the body. This would be due to the spin produced by the airflow over the angled fins which allows the thrust to be channeled most efficiently in the vertical direction.

Hypotheses

Alternate Hypothesis (H_1): *Rockets with fins placed at a 45° angle to the body will result in a significantly higher peak vertical flight height than the peak vertical flight height of rockets with fins placed at 90° angle to the body.*

Null Hypothesis (H_0): Rockets with fins placed at a 45° angle to the body will not result in a significantly higher peak vertical flight height than the peak vertical flight height of rockets with fins placed at 90° angle to the body.

Methodology

Materials/Equipment/Facilities

Name of Material	Source
2 model rockets Estes 2178 Hi-Flier Flying Model Rocket Kit	Karl Roush – http://www.amazon.com/Estes-2178-Hi-Flier-Flying-Rocket/dp/B0006N6NDY/ref=sr_1_3?ie=UTF8&qid=1399495670&sr=8-3&keywords=model+rockets
27 rocket engines (A8 size) Estes A8-3 Engine Pack (3-Each)- 9 packs	Karl Roush – http://www.amazon.com/Estes-A8-3-Engine-Pack-3-Each/dp/B0006ZVZ94/ref=pd_bxgy_t_text_y
Fiber blow-in insulation	Karl Roush- Home Depot
30 model rocket igniters Estes 302301 Model Rocket Igniters (pack of 5)- purchased 6	Karl Roush- http://www.amazon.com/Estes-302301-Model-Rocket-Igniters/dp/B0006NAQ64/ref=sr_1_1?ie=UTF8&qid=1399495851&sr=8-1&keywords=model+rocket+igniters

Name of Equipment	Source
1 rocket launch pad Estes Cox 1469 Tandem X Launch Set	Karl Roush – http://www.amazon.com/Estes-1469-Tandem-X-Launch-Set/dp/B002VLP67S/ref=sr_1_1?ie=UTF8&qid=1399495542&sr=8-1&keywords=model+rockets+launcher
1 control panel (for launch pad) Estes Cox 1469 Tandem X Launch Set	Karl Roush – http://www.amazon.com/Estes-1469-Tandem-X-Launch-Set/dp/B002VLP67S/ref=sr_1_1?ie=UTF8&qid=1399495542&sr=8-1&keywords=model+rockets+launcher
1 altimeter Jolly Logic AltimeterOne	Karl Roush – http://www.apogeerockets.com/Electronics_Payloads/Electronics/Jolly_Logic_AltimeterOne *Purchased by student, reimbursed and given to HTHS for use by future students
2 #2 pencils	Karl Roush- house
1 eraser	Karl Roush- house
Recording sheets with data tables (page 7)	Karl Roush- house
Computer with Microsoft excel	Karl Roush-house
Digital Camera	Karl Roush-house
1 bottle of superglue	Karl Roush-house
1 ruler	Karl Roush-house
2 9 volt batteries	Karl Roush-house
1 X acto knife	Karl Roush-house
1 pair of Scissors	Karl Roush-house
1 protractor	Karl Roush-house

Needed Area	Name of Facility/Availability	Usage
Area for rockets to be made	Karl Roush's house	Used on 10/16/14 and 10/17/14
Area for launches	Holmdel Park (open field area)	Obtained permit and launched on 10/18/14
Area for data analysis	Karl Roush's house	Used 11/18/14

Experimental Design Diagram: **(please see last page)**

Experimental Setup, Graphics, Illustrations

Materials

Figure 1: Altimeter

Figure 2: Parachutes

Figure 3: Rocket A8 Engines

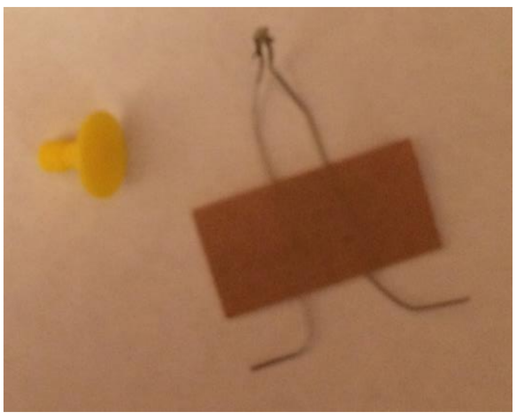


Figure 4: Engine igniter and engine plug

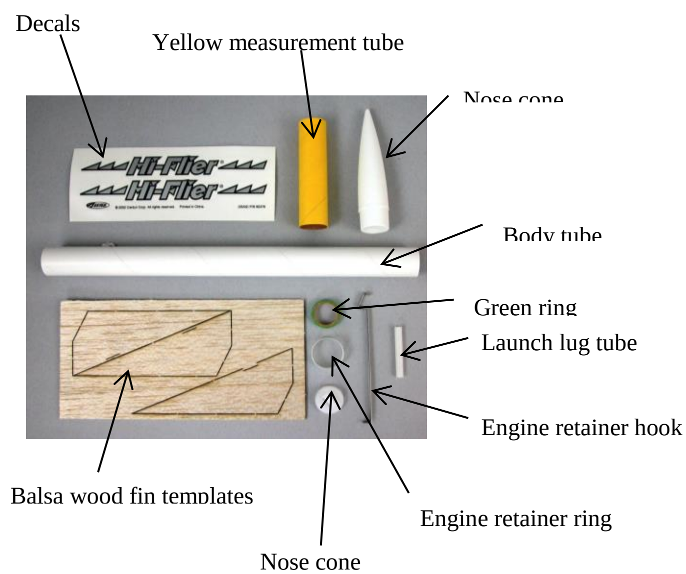


Figure 5: Labeled diagram of rockets pieces from Estes 2178 Hi-Flier Flying Model Rocket Kit

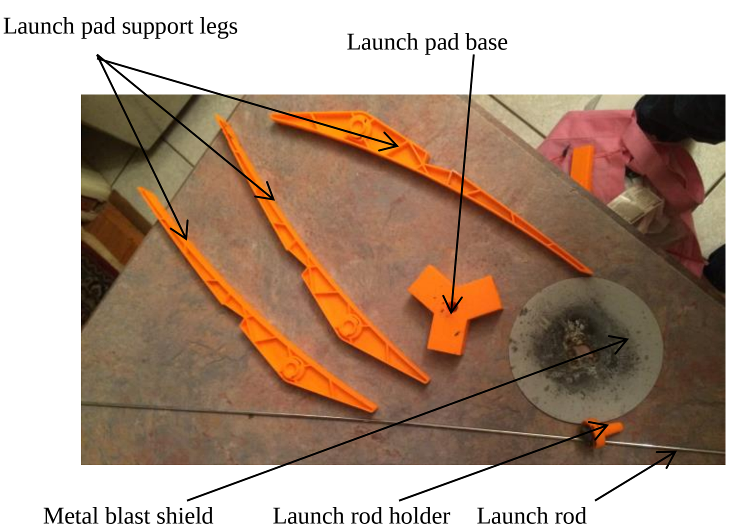


Figure 6: Labeled diagram of launch pieces from Estes Cox 1469 Tandem X Launch Set

Figure 7: Launch Controller with warnings

Construction

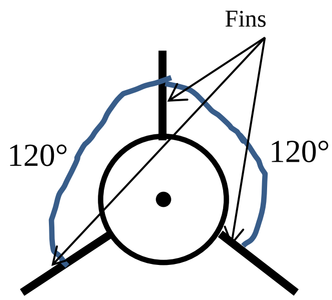


Figure 1: Top down diagram of a rocket with 90 degree fins

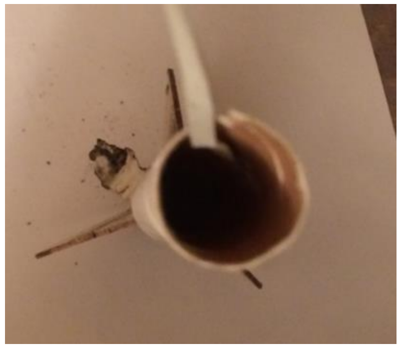


Figure 2: Top down view of a rocket with 90 degree fins (no nose cone)

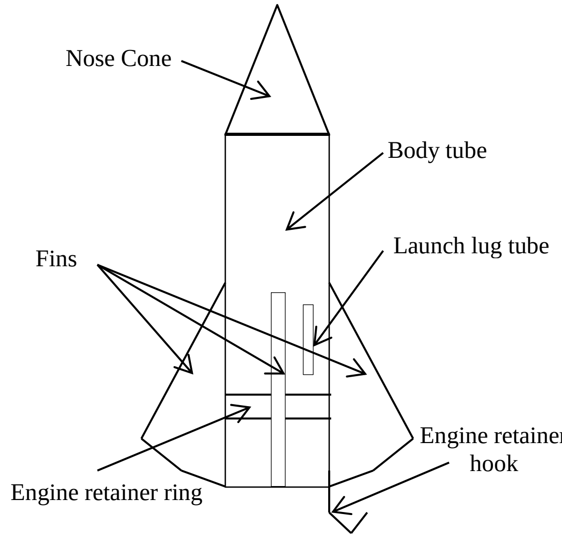


Figure 3: Side view diagram of a rocket with 90 degree fins

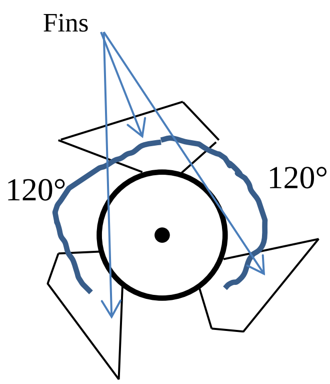


Figure 4: Top down diagram of a rocket with 45 degree fins

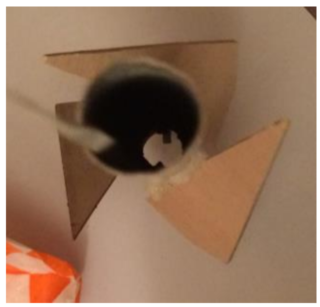


Figure 5: Top down view of a rocket with 45 degree fins (no nose cone)

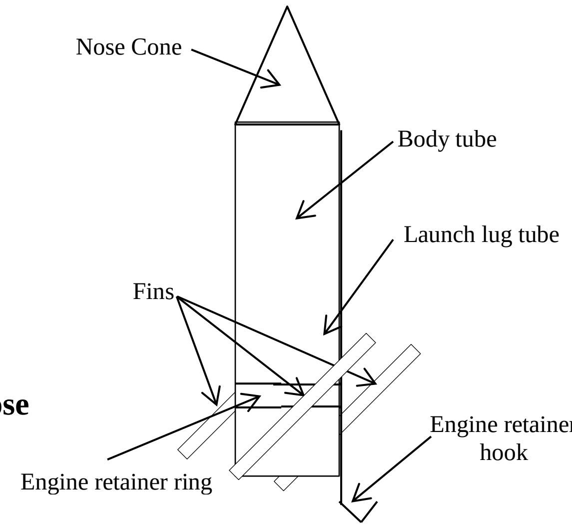


Figure 6: Side view diagram of a rocket with 45 degree fins

Figure 7: Side view of a rocket with 45 degree fins

Figure 8: Side view of a rocket with 90 degree fins

Figure 9: Launch ready engine (Engine, Igniter and Igniter plug)

Testing

Figure 1: Pre launch rocket setup (Rocket Engine with igniter on launch pad, launch controller attached)

Figure 2: Rocket liftoff from launch pad

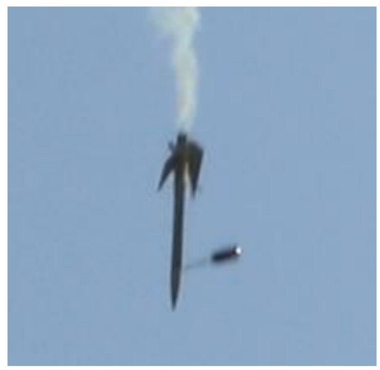


Figure 3: Rocket in flight with altimeter

Figure 4: In flight parachute deployment

Figure 5: Rocket landing and retrieval

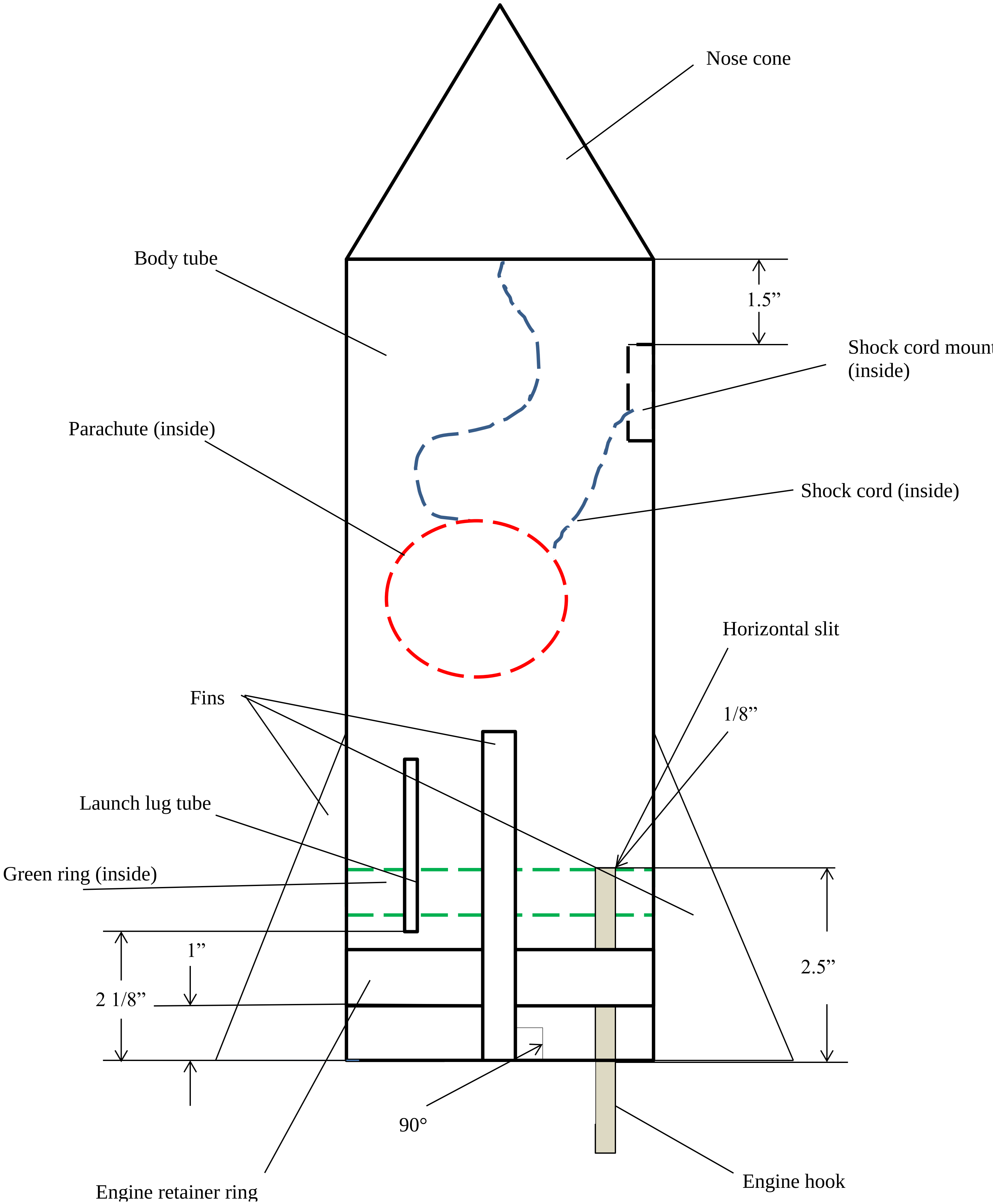


Figure 10: Dimensioned Sketch of Rocket (90 degree fins)

Methodology: Procedure

Construction

Materials in this section of the list are from the Estes 2178 Hi-Flier Flying Model Rocket Kit. A labeled diagram of parts can be found in Figure 5 of *Materials*, under the section **Methodology** (block of clay and instructions are not pictured). This procedure can also be found in the instructions which come with the kit. A dimensioned sketch of a rocket with 90 degree fins can be found in Figure 10 of *Construction*, under the section **Methodology**. For a rocket with 45 degree fins, simply change the angle of the fins (everything else is the same).

1) Take the cube of clay and push it into the tip of the nose cone.
2) Glue the nose cone insert into the open end of the nose cone using super glue.
3) Cut out the fins from balsa wood templates using the X-acto knife.
4) Cut out the tube marking guide from instructions.
5) Use the tube marking guide to mark the fin lines and the launch lug line on the body tube using a pencil.
6) Glue the green ring 2.5 inches into the base of the body tube using superglue.
7) Cut a 1/8” horizontal slit 2.5” from the bottom of the body tube using the X-acto knife.
8) Place the engine hook in the slot cut in step 7.
9) Glue the engine hook to the body tube with super glue.
10) Slide the engine retainer ring over the engine hook and the body tube until the bottom of the ring is 1” above the base of the body tube.
11) Glue the engine retainer ring to the body tube using super glue.
12) Glue the fins at a 90 degree angle (vertical) onto the fin lines marked on the body tube using super glue. Be sure to use a protractor to measure the angle.
13) Attach the launch lug tube onto the launch lug line 2 1/8” (marked on body tube in step 5) from the bottom of the body tube using super glue.
14) Cut the shock cord mount from the tube marking guide using scissors (tube marking guide was cut from instructions in step 4).
15) Glue the shock cord onto the shock cord mount using with super glue.
16) Glue the shock cord mount 1.5” from the top of the body tube.
17) Tie the shock cord to the nose cone using an overhand knot.
18) Tie the parachute to the shock cord using the same knot. Then carefully roll the parachute and place it in the body tube and push the nose cone into the tube, essentially sealing it.
19) Repeat steps 1-18 for the second rocket, adjusting step 12 so that the fins are mounted at a 45 degree angle.
20) Push the igniter into hole at the bottom of the engine as far as it will go.
21) Push the engine plug into the hole.
22) Bend the igniter wires 90 degrees so that the igniter it is horizontal.
23) Repeat steps 19-21 for the rest of the engines (29 more times).
24) Connect the orange landing support leg to launch pad base by sliding it into the hole on the side of the launch pad base and turning it 90 degrees clockwise.
25) Repeat step 23 for the other two support legs.
26) Slide the launch rod into the hole in the launch rod holder then place the launch rod holder into the hole of the launch pad base.
27) Slide the metal blast shield over the plastic components of the launch base.

Testing

A diagram of a launch ready rocket can be found in Figure 1 of *testing* under the section **Methodology.**

1) Place the launch pad in the designated launch area (specified in *facilities* section under **Methodology**).
2) Make sure an adult is present, due to safety reasons.
3) Slide the engine with the igniter and plug them into the body of the rocket from the bottom of the body tube.
4) Remove the nose cone and parachute.
5) Place three wads of insulation into the body tube (blow in insulation comes in predetermined wads). This insulation will protect the rest of the rocket from the heat when the engine ignites.
6) Re-roll the parachute, and place it in tube (a tight roll with all the parachute strings protruding from one end is sufficient).
7) Untie the shock cord and thread it through the mounting hole on the altimeter.
8) Re-tie the shock cord to the nose cone using a double overhand knot .
9) Place the nose cone into the body tube, sealing it.
10) Turn on altimeter by pressing the red button until the display lights up.
11) Slide the rocket launch lug tube (located on the side of the body tube) onto the metal launch pole (protrudes from launch pad).
12) Attach alligator clips from the launch controller to the metal wires protruding from the igniter.
13) Retreat twenty feet away from launch pad.
14) Push the button and key down on the launch controller until the rocket ignites.
15) If the rocket does not launch, wait 5 minutes before approaching the rocket. Then, replace the engine and repeat steps 3-13, excluding steps 4-9. If the rocket does launch, wait for it to land.
16) Retrieve the rocket.
17) Record the peak vertical flight height from the altimeter onto the blank raw data tables.
18) Reset altimeter by pressing the red button and selecting launch from the menu on screen.
19) Repeat steps 1-18 for the remaining 11 launches for that rocket.
20) Repeat steps 1-18 with the second rocket.

Findings: Observations/Data Tables/Graphs

Observations during experimentation:

- Six igniter failures
- One battery replacement at the tenth launch of the 45° rocket
- One engine failure (rocket did not launch and was repeated)
- Four parachute deployments
- Multiple instances where the rockets would land nose first and embed themselves in the ground
- Slightly cloudy
- Temperatures ranged from the high-50s to the mid-60s (degrees Fahrenheit)
- Air was relatively still with wind speeds <5 mph during the launches

The data produced from this experiment is quantitative since it is measured data, not observed data. The independent variable is fin angle and the dependent variable is apex height.

Raw Data Table of Apex Height for 90° and 45° Rocket Fin Angles (meters)

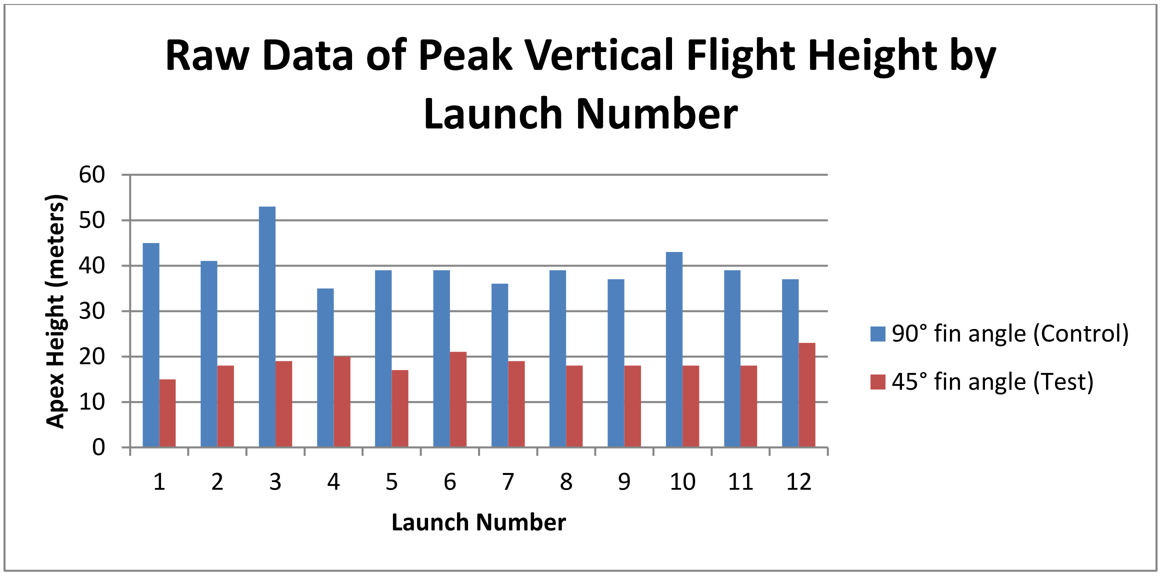
Launch Number	90° fin angle (Control)	45° fin angle (Test Group)
1	45	15
2	41	18
3	53	19
4	35	20
5	39	17
6	39	21
7	36	19
8	39	18
9	37	18
10	43	18
11	39	18
12	37	23

Summative Data Table of Apex Height for 90° and 45° Rocket Fin Angle (meters)

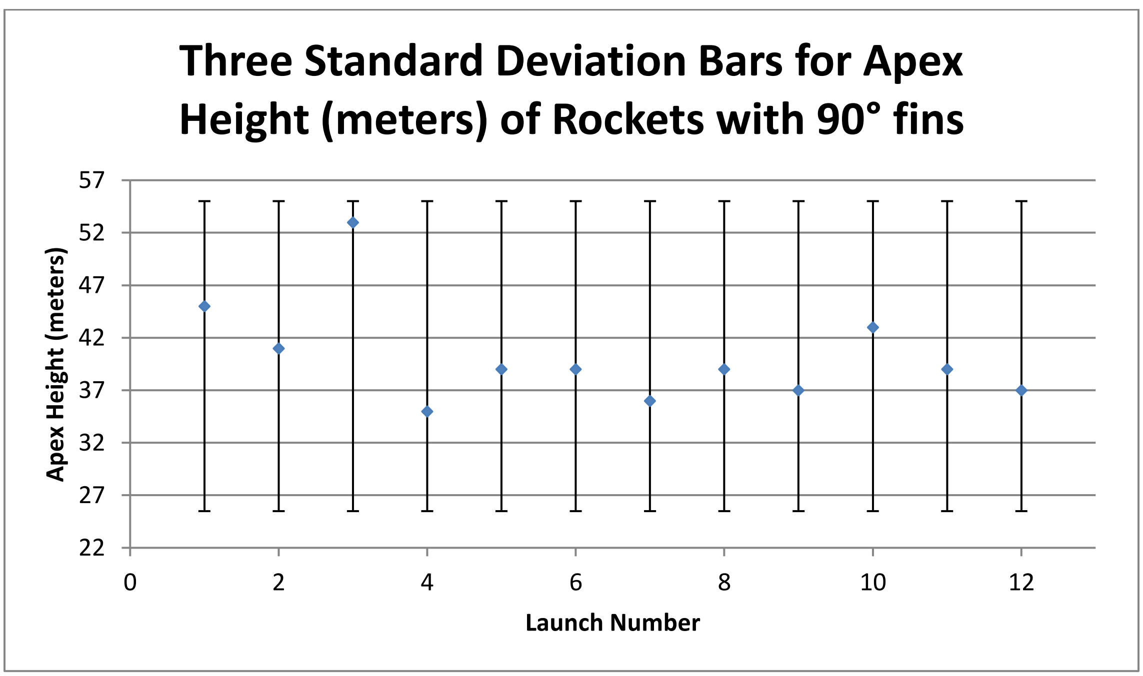
	90° fin angle (Control)	45° fin angle (Test Group)
Mean	40.3	18.7
Median	39.0	18.0
Mode	39.0	18.0
Range	18.0	8.0
Std. Deviation	4.9	2.0
var	24.2	4.1
n	12	12

"Mean" is the average of the data set.
"Median" is the middle value of the data set.
"Mode" is the most common data point within the set.
"Range" is the difference between the maximum and minimum values within the data set.
"Standard deviation" represents the extent of deviation for the data set.
"var" or "variance" is standard deviation squared.
"n" represents the number of trials per group, which in this case, would be 12.

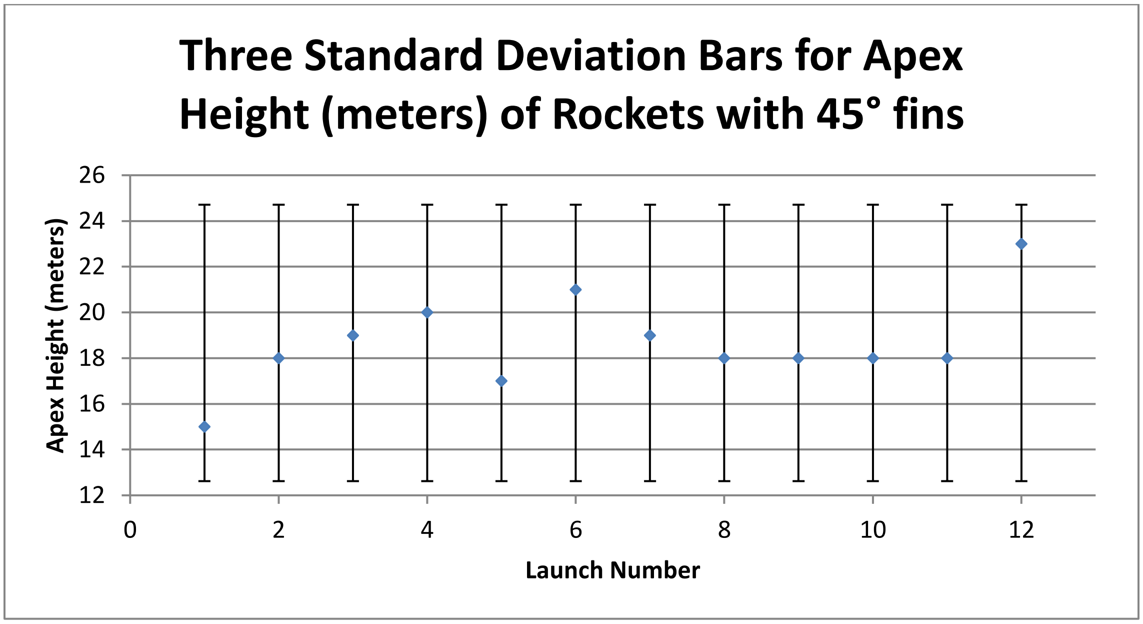
Outliers in the data are identified by being outside three standard deviation error bars.



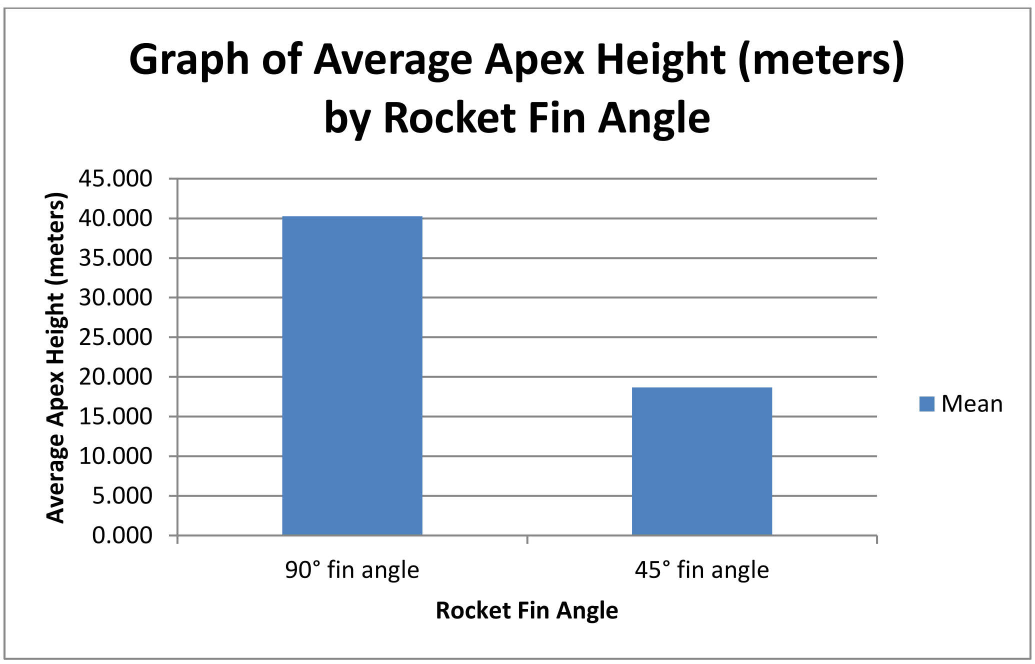
In this case, this type of graph does not identify outliers.



There were no outliers.



There were no outliers.



In this case, this type of graph does not identify outliers.

The P-value for the data was $9.99999999653 \times 10^{-1}$, which was greater than the alpha of 0.05. Ordinarily the p-value would be reported to three decimal places but in this case, that would cause it to round to 1. In order to avoid this error, the p-value is recorded with the least possible number of significant figures.

Results:

Inferential Statistics

In order to conclude whether or not the 45 degree fins produced a significantly higher peak vertical flight height than the peak vertical flight height caused by 90 degree fins, a one-tailed t-test was used to obtain a p-value.

T-tests are used to find the p-value of quantitative data, which is the type of data produced by this experimental design. T-tests have two arrays, the first of which is being tested and the second one being the control. In the context of the experiment, there will be a comparison of the array for 45 degree fins to the control array for the 90 degree fins. The t-test was one-tailed since the experiment was testing to see if the 45 degree fins would produce a significantly greater apex height than the 90 degree fins, instead of overall significant difference (which would require a two tailed t-test). It was also an independent t-test since the data had different subjects in the form of launches for each group. The t-test for this experiment produced a value of $9.99999999653 \times 10^{-1}$. The alpha value for this experiment, or level of significance, was 0.05. This allows the conclusions formed from the p-value to be statistically significant.

Discussion of Statistical Results

The p-value was found to be $9.99999999653 \times 10^{-1}$, which was greater than the alpha value of 0.05, which means that the data failed to reject the null hypothesis and the alternative hypothesis is not supported. In other words, the data do not support the research hypothesis proposed by the student researcher, which was that rocket fins placed at a 45 degree angle to the body will result in a significantly higher peak vertical flight height than the peak vertical flight height of rockets with fins placed at 90 degree angle to the body.

Discussion of Research Results

This experiment has shown that rocket fins placed at a 45 degree angle to the body will not result in a significantly higher peak vertical flight height than the peak vertical flight height of fins placed at 90 degree angle to the body. Although there was variance within the data set for each rocket, that is to be expected since each launch is a different flight of the rocket, and as a result, the data will not be exactly the same. However, the difference between the data from the rocket with 45 degree fins and the rocket with 90 degree fins is significantly different as demonstrated by the p-value of $9.99999999653 \times 10^{-1}$, which was greater than the alpha of 0.05

This p-value also demonstrated that changing the angle of the fins on a rocket did have a significant effect on the peak vertical flight height of the rocket. However, fin angle is not the only variable that can affect peak vertical flight height. Other variables include the weight of the rocket, its shape, and the power of the engine. In addition to this, variables such as wind, temperature, and precipitation can have an effect on each individual flight as a whole.

At the start of the experiment, it was expected that the rocket with 45 degree fins would have a significantly higher peak vertical flight height than the peak vertical flight height of rockets with 90 degree fins (this was the alternate/research hypothesis). However, both the raw data and calculated values, such as mean and the p-value, show that rockets with 45 degree fins do not have a significantly higher peak vertical flight height than the peak vertical flight height of rockets with 90 degree fins, which was the null hypothesis in the experiment. Essentially, the data produced a result that was contrary to the expected outcome. In terms of practical applications, if model rocket hobbyists or any scientists in field involving directed projectile propulsion, they should use the standard 90 degree fins instead of the 45 degree fin model which was tested in this experiment.

Suggestions for Further Study

This experiment could be improved with a more precise altimeter. The altimeter that was used in this experiment only produced measurements in whole numbers. An altimeter with a higher degree of precision would improve the experiment by producing more precise data.

In addition, this experiment only tested the effect of 45 degree fins on peak vertical flight height. Further study involving other fin angles could be done to examine the effects of a variety of different fin angles on peak vertical flight height instead of testing only one angle, which was the case in this experiment. Expanding the scope of further study, experiments that test the shape of fins could also be conducted. However, the best course of study would be to design an experiment to isolate the variables that have the largest effect on peak vertical flight height of projectiles. From there, experiments involving the most influential variables could then be conducted.

Bibliography

"Apex." *Merriam-Webster*. Merriam-Webster, n.d. Web. 15 Dec. 2014. <http://www.merriam-webster.com/dictionary/apex>.

This website provides a basic definition of what "apex" means. This information is relevant to this research experiment since it is measuring the peak vertical flight height, or apex height, of rockets. It is helpful to reference this definition.

"Basic Rocketry Aerodynamics"*Dark.DK Technotes*. Dark.DK. Web. 07 May 2014 http://www.dark.dk/archive/technotes/BaseAero.pdf

This article provides a basic explanation of model rockets as a whole. In addition, this article details how factors outside of the actual rocket, such as launch angle, can cause a variation in performance. To make the experiment as accurate as possible, these factors must be kept the same.

Garner, James M., Paul Weinacht, and Robert P. Kaste. "Experimental Validation Of Elliptical Fin-Opening Behavior." Shock & Vibration 10.2 (2003): 115. Academic Search Premier. Web. 7 May 2014.

This article discusses how the deployment of fins on an artillery projectile at various angles while in motion can change the overall precision in launching the aforementioned projectile. The information that this source provides is exceedingly relevant to this research experiment since a similar experiment will be performed. However, the rocket fins will be stationary and not deployed mid-flight.

Kim, Seung-Hwan, Yong-In Lee, and Min-Jea Tahk. "New Structure For An Aerodynamic Fin Control System For Tail Fin-Controlled STT Missiles." Journal Of Aerospace Engineering 24.4 (2011): 505-510. Academic Search Premier. Web. 7 May 2014.

This article discusses the effect of fins on a rocket in flight. It essentially states how with a slight change in the angle or position of a fin, the rocket's flight path can change drastically. Since the angle of the fins of the rockets will be changed, this article provides some basic information of what to possibly expect.

Nakka, Richard. "Richard Nakka's Experimental Rocketry Site." Richard Nakka's Experimental Rocketry Site. Nakka Rocketry, 26 Aug. 2001. Web. 02 May 2014. http://www.nakka-rocketry.net/fins.html

This article details the purpose of fins. It also explains the various forces that act upon the rocket fins and how to counteract forces that negatively influence the performance of the rocket. Within this article, there are also instructions that detail how to stabilize rockets, thereby more efficiently channeling the thrust produced by the engine.

"The Aerodynamics of Model Rockets Part 3- Rocket Design Analysis | Articles from Sigma Rockets." Articles from Sigma Rockets RSS. Sigma Rockets, 29 Apr. 2012. Web. 04 May 2014. http://www.sigmarockets.com/blog/2012/04/the-aerodynamics-of-model-rockets-part-3-rocket-design-analysis/

This article describes the parts of a model rocket and their influence on the overall aerodynamics and behavior. The article also details the optimal lengths and shapes for the various model rocket components in order to achieve maximum performance.

The Effect of the Angle of Rocket Fins on the Peak Vertical Flight Height of Rockets

Title: The Effect of the Angle of Rocket Fins on the Vertical Fight Height of the Rocket

Hypotheses:

Alternate:
Rockets with fins placed at a 45° angle to the body will result in a significantly higher peak vertical flight height than the peak vertical flight height of rockets with fins placed at 90° angle to the body.

Null:
Rockets with fins placed at a 45° angle to the body will not result in a significantly higher peak vertical flight height than the peak vertical flight height of rockets with fins placed at 90° angle to the body.

Independent variable: Angle of rocket fins in relation to the rocket body (degrees)

Levels:	90° fin angle	45° fin angle
# trials:	12 launches	12 launches
Control?	control group	test group

Dependent variable: Maximum Vertical flight height

Operational definition of dependent variable: The vertical flight height will be measured in meters using an altimeter placed in the rocket.

Constants:

Direction of travel
Wind speed (still air)
Launch pad (same one for all launches)
Temperature (<90°F and >40°F)
Location
Weather (no precipitation)
Type of rocket
Type of rocket engine
Material of rocket fins
Location of rocket fins on the rocket