Final Pstat122

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Introduction

Many people have a core memory of their childhood with paper airplanes whether it's just with friends or in class. Attempting to find the best airplane type that will go further than your friend's airplane. Looking at the scientific aspect of paper airplanes there is much more to it than simply the design of the plane and the power and angle. When throwing a paper airplane there are many factors to consider such as center of weight, aerodynamics, strength and angle of the throw, and environmental factors. In this study we decided to focus on the weight factor that affects the flight distance of a paper airplane.

This study builds upon Lab 2 from PSTAT 122, investigating how the placement of paperclips affects the flight performance of paper airplanes. In the Lab, we used a single airplane with a Basic Dart design to explore two conditions: with and without a paperclip. Each condition was tested five times for a total of ten observations, providing preliminary data. However, the small sample size and limited experimental factors restricted our ability to draw robust conclusions. In this study, we will use different placements of paperclips on the paper airplane to determine the effects of center of weight on the distance traveled.

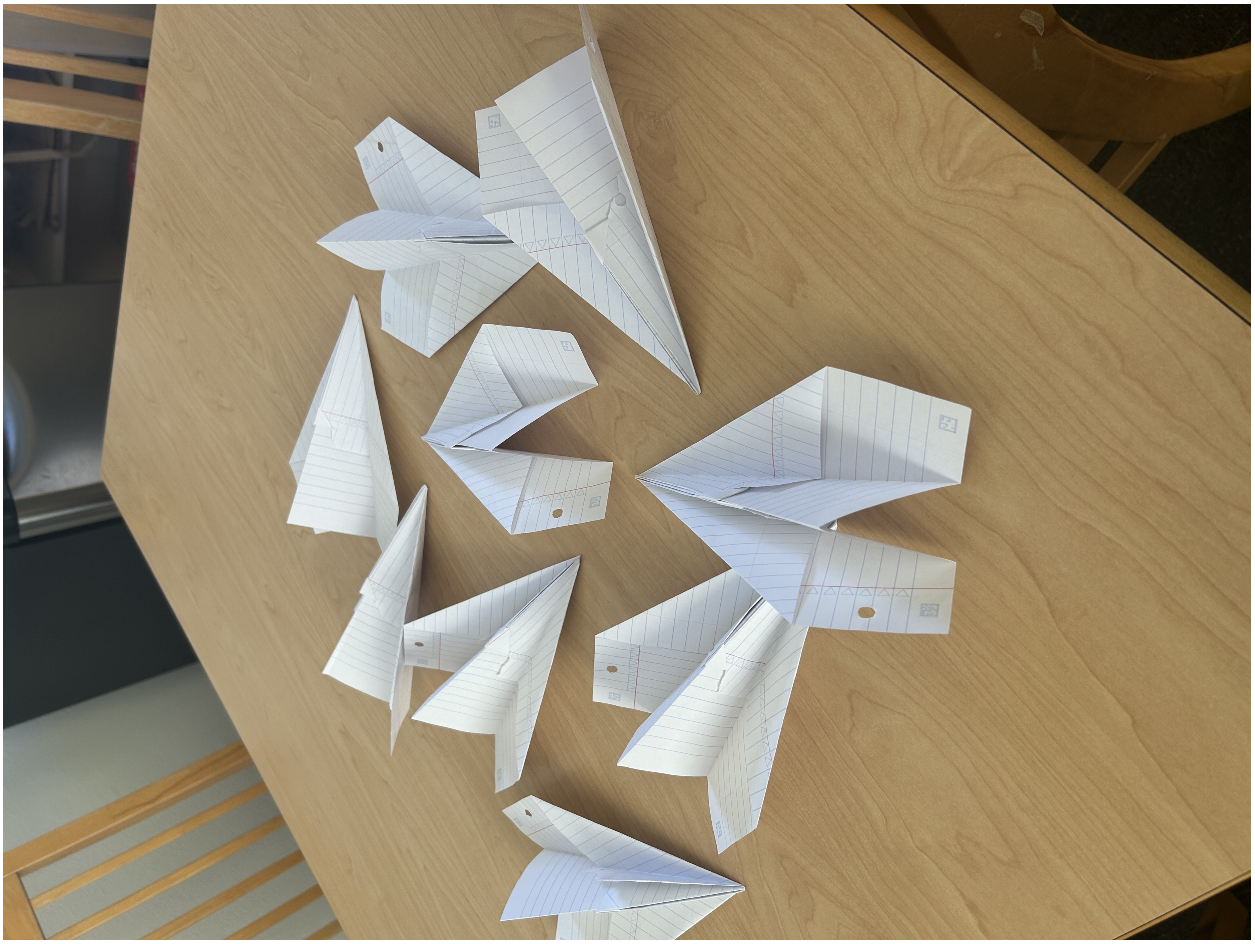
Now, the weight of an airplane is crucial in aerospace engineering and aerodynamics as it helps us understand and create effective models and design. The models and design of these airplanes ranges between passenger airplanes to fighter airplanes. Airplanes are known to be the most time effective method of transportation throughout the 19th and 20th century. Center of weight distribution is known to affect balance, stability, distance and air resistance, which in turn impact flight performance. For instance, adding weight at the nose of an airplane may stabilize its flight path but could reduce the overall distance traveled. Citation from a previous article explains how the weight at the nose of the airplane affects the airplane (Puspita, Angella Natalia Ghea, et al. "Effect of paper weight, paper length, and nose of paper plane on aircraft mileage in paper airplane game."). In addition, previous studies of aerodynamic efficiencies and drag coefficient can be found here (Ismail, Noor Iswadi, et al. "Aerodynamic performances of paper planes." Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 77.1 (2021): 124-131.)

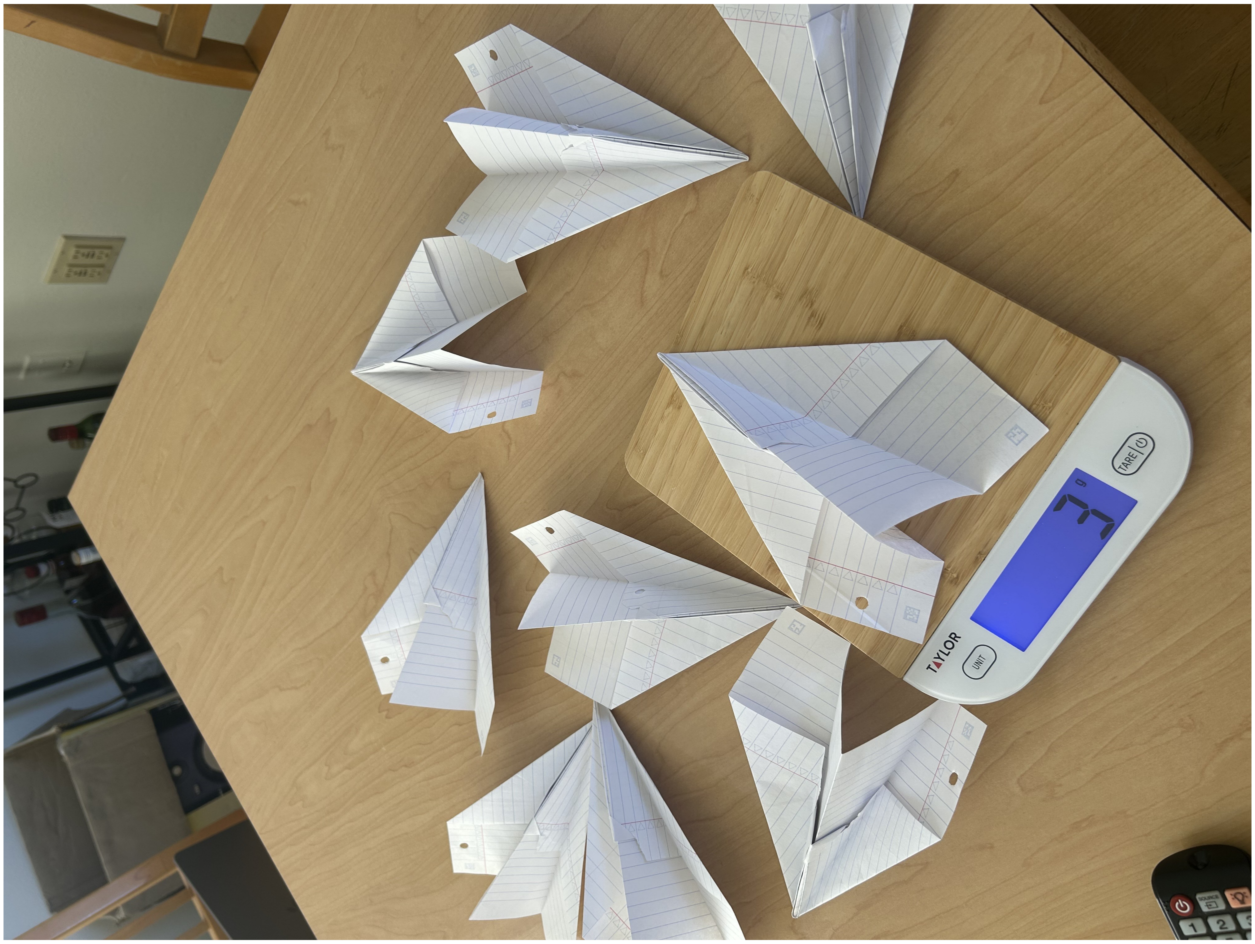
Methods

The experiment utilized a randomized complete block design (RCBD) to control for variability between airplanes. Each of 9 airplanes served as a block and was tested under four treatment conditions:

1. **Control**: No paperclip.
2. **Nose**: Paperclip attached to the nose.
3. **Middle**: Paperclip attached to the middle.
4. **Rear**: Paperclip attached to the rear.

All airplanes were folded using the same design to ensure consistency with lined papers of the same size and weight to reduce unaccounted variability. Flights were conducted indoors to minimize environmental variability such as changing wind speed, and distances were measured in meters using a measuring tape.





A one-way analysis of variance (ANOVA) was performed to test for significant differences in mean flight distances across treatments. Blocking was incorporated by using each airplane through multiple conditions to account for the variability among airplanes. This approach allows for a more comprehensive analysis of the effects of weight placement on flight distance, improving the reliability and generalization of our findings. Assumptions of ANOVA, including normality and homogeneity of variances, were satisfied and checked using residual diagnostics. All analyses and coding were conducted in R.

There were few technical issues that came up throughout the data collection process including damaged airplanes and outliers. During the throw on multiple conditions testing, one airplane hit ground or furniture hard and created a dent in the nose of the airplane which may have varied the data, one created an outlier and was removed from the data collection. The missing block was replaced by another airplane.

Results

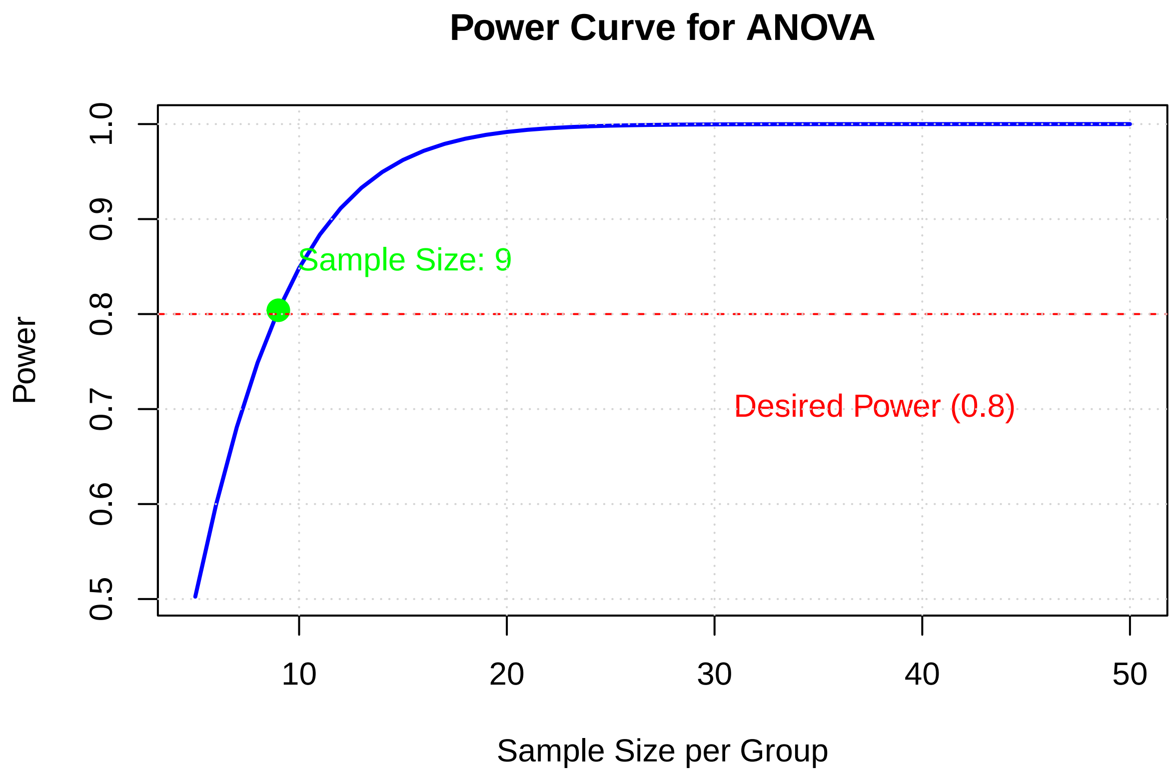



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Table 1: Data from Paper Airplane Experiment

Number	Control	Nose	Middle	Rear
1	231	209	222	191
2	228	207	209	194
3	240	204	195	187
4	239	214	211	201
5	236	196	192	182
6	249	218	225	213
7	234	209	219	192
8	229	208	237	193
9	233	211	217	182

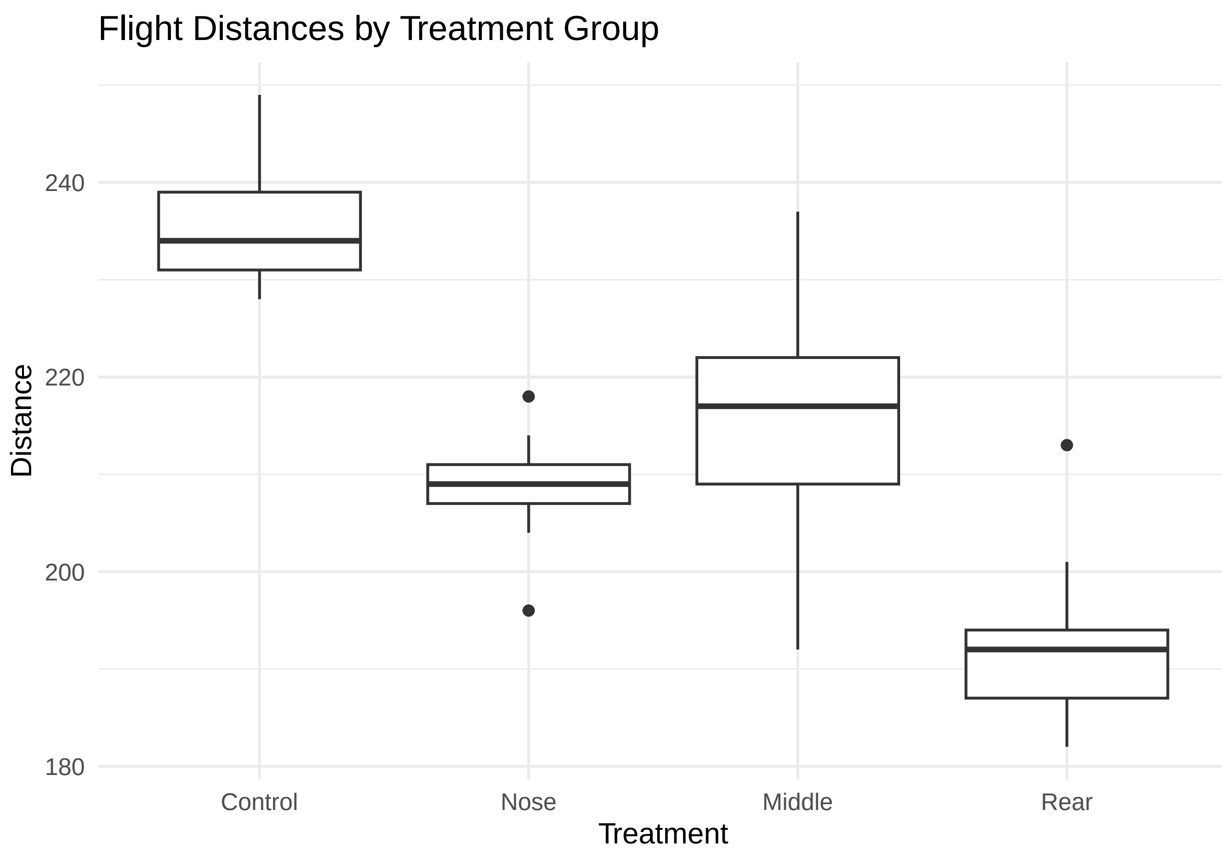
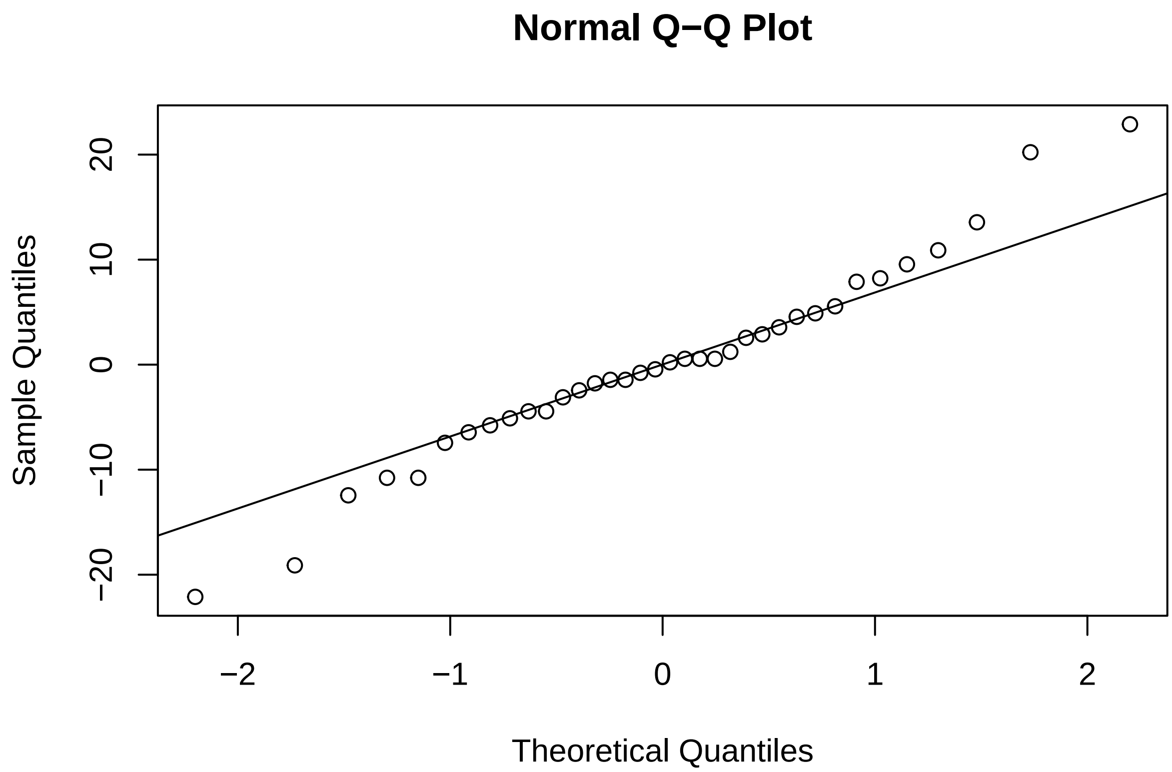


Table 2: ANOVA Results for Flight Distance by Treatment Group

Source	Df	Sum of Squares	Mean Squares	F-Value	P-Value
Treatment	3	8408.75	2802.92	29.67	2.2874e-09
Residuals	32	3022.89	94.47	NA	NA

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## Shapiro-Wilk test p-value: 0.575419
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The **p-value** for the treatment effect is **2.29e-09**, which is $<$ **0.05**, indicating that the treatment (different placements of the paperclips) has a statistically significant effect on the dependent variable (distance traveled). The F-value of **29.67**suggests a significant difference between at least one pair of treatment levels.

Shapiro-Wilk normality test returns **0.5754** which is greater than **0.05** meaning we fail to reject the null hypothesis of normality. It means that the residuals are normally distributed and the interpretation of the anova results are safe.

Discussion

In our paper airplane study involving different placement of the paperclip passed the model checks and throughout the ANOVA test, the p-value returned **2.29e-09**. This means that there is treatments have statistically significant effect on the distance traveled. This idea can be implemented in aerospace engineering as adding the weight to the airplane increases the drag requiring more force such as thrust from engines to travel the distance.

There are possible key limitation that can be improved upon future studies including different throwers and separation of time of data collection. In this study, all of the data was collected by myself one individuals throughout the span of one day. Some were collected in the afternoon and some were collected at night due to other classes. This could have changed and affected the results of the throws. In addition, the paper airplane weight varied between 3 grams to 4 grams which can also effect the results. Although each fold was done exactly the same the possible bend and fold length could have also affected the data. The understanding of the effects of the difference in the paper airplane folding can be seen here(Meyer, Daniel

Z., and Allison Antink Meyer. “Two Paper Airplane Design Challenges: Customizing for Different Learning Objectives.” *Journal of College Science Teaching* 41.3 (2012)).

Reference

Ismail, Noor Iswadi, et al. “Aerodynamic performances of paper planes.” Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 77.1 (2021): 124-131.

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