STA305 - Experimental Design

Effect of Type of Paper on the Flying Distance of Paper Planes

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Introduction and Motivation

The distance that a paper plane travels is associated with its aerodynamic design (Hinkle, 2015). Previous studies have highlighted that paper planes can travel over long distances if their design includes a balance of lift, thrust, gravity, and drag (Hinkle, 2015). The lift is determined by the shape of the wing, the thrust is from throwing the plane, gravity is the force pulling the paper down, and drag is determined by the tail of the paper plane (Hinkle, 2015). As such, in the past, paper airplanes have been designed to comply with scientific law. However, aside from the design, not much has been established regarding whether the type of paper can also impact distance flown. There are many types of paper, and each one has its own properties. Our main question of interest is to determine if the mean distance that paper planes can fly can be due to the type of paper. Thus, the purpose of the study is to investigate these phenomena and analyze the average distance travelled by each paper. This knowledge is important to the field as we can conclude that distance reached by throwing paper planes cannot solely be attributed to the design of paper planes. Lastly, the target population for this study was all paper airplanes and our experimental unit was a single trial run for each paper type.

Experimental Design

Variables of Interest

The response variable in our experiment was the flying distance of a paper plane measured in meters. Our factor of interest was the paper type with the levels: printing, gift wrapping, and lined. For each paper type, we conducted five trials, thus our experiment is balanced, for a total of fifteen trials. We applied replication at the treatment level because of variability between trials and so we wanted to make sure it was due to our factor. Our experimental unit, the object from which we record our response, is a single trial. Since our trials account for the different paper types and are independent from one another, we can call this a between-subjects design.

Description of the Experiment

In a trial, the experimenter stands at the same spot in the room, throws the paper plane in one single motion, measures the distance in meters using a ruler, and records the measurement.

Principles of Experiment

In our experiment, we strived to use the four principles of experimental design but some were simply not applicable or difficult to implement. We controlled for the design of the paper airplane, the room the paper airplanes were flown in, the direction the paper airplane was thrown, and the experimenter throwing the paper airplane.


Fig.1 Gift wrapping paper

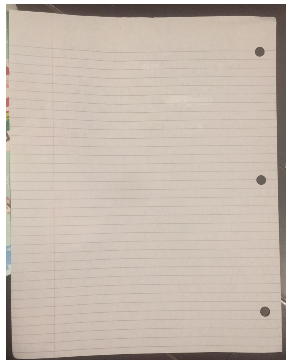
Fig. 2 Lined Paper


Fig.3 Printing paper

(all of the same A4 size)


Fig.4 Same plane design

Different designs and room conditions such as temperature can affect the aerodynamics of the paper airplane while in flight so we saw it fit to control these two variables. Throwing the paper airplanes in different angles changes the trajectory so the experimenter made sure to throw straight forward in all trials. There was only one experimenter because we wanted the height off the ground to be identical and the force applied when throwing a plane to be similar. There were no nuisance variables that could not be controlled and intrinsic to the experimental unit thus, blocking was not utilized. Randomization was difficult to ensure due to the design of our experiment. We used replication at the treatment level conducting five trials for each level to make sure the variability in distance is in fact due to paper type. Control group, placebo, blindness and double-blind were not applied in our experiment.

Data Summary

Table 1: Experiment Data

trial	lined	wrapping	printing
1	1.370	0.546	1.904
2	0.750	2.007	1.478
3	2.929	1.145	1.834
4	2.230	1.473	1.904
5	2.846	1.844	2.057

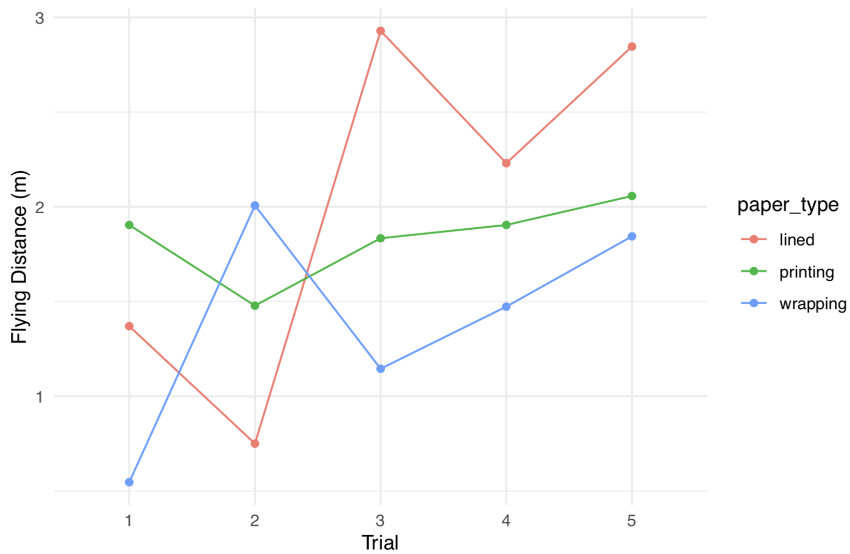

Fig. 5: Flying Distances by Paper Type

Based off of the data collected, figure 5 shows the distance covered by all 5 trials conducted for each type of paper plane. From this graph, we can see that the paper plane made of printing paper is the most consistent in terms of flight distance. Although both paper planes made of wrapping and lined paper show inconsistencies, lined paper appears to be the most inconsistent. However, despite the inconsistencies for lined paper, it also had the highest flight distances. Some plausible causes for the inconsistent flight distances for lined and wrapping paper are the drag or push force applied on the plane during its flight.

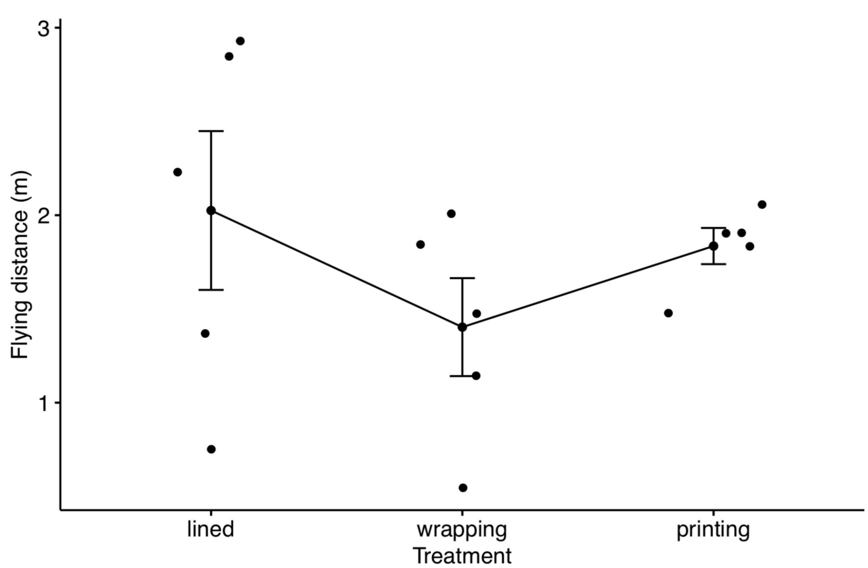

Fig. 6: Mean Flying Distance

This graph portrays the respective mean flying distance for each type of paper plane. From this, it is evident that lined paper has the highest mean. The vertical bars in the graph portray the amount of variation between each point recorded for a specific type of plane. This implies that the vertical bars show how consistent the data for each type of paper plane is. The larger the bar, the more variation the data has. Similar to the results seen in Figure 5, lined paper seems to have the biggest variation and printing paper has the smallest variation.

Data Analysis

Assumptions

Trials are independent from one another, where a trial is flying a paper plane and recording its distance. This means that conducting one trial has no effect on the results from another trial. This is proven by the results from the Durbin Waston test (refer Appendix), which concludes that they are independent from one another. It is also assumed that the data has normality. This assumption is supported by the Shapiro-Wilk test (refer Appendix). The results obtained from this test show no indication that normality was violated, thus proving that the data has normality. The Bartlett test (refer Appendix) was used to test for homogeneity of variance between the different types of paper planes. The results from this test show that the data collected has common variances between the groups.

Sample Size

Each paper plane has 5 trials in total, resulting in a sample size of 15. This size was chosen mainly due to time constraints. There was only a short window of time to collect the data. The fact that only one person could conduct these trials for the sake of controlling the study was also taken into consideration. Thus, 15 seemed to be a suitable size.

ANOVA Test

Based on the results from the one-way ANOVA test (the test used to check the difference in mean distance of the paper planes, refer Appendix) we conducted, it is concluded that the average distance covered by the three different types of paper planes is not significantly different. This implies that there is no significant evidence to show that one type of paper plane flies further than the other.

Since the test concludes that there is no significant difference between the average flight difference of each plane, we refrained from conducting any form of pairwise or multiple comparisons, where we simply compare each type of paper plane to one another individually.

Limitations

As we conducted the experiment, we noticed some challenges in collecting the data for analysis. Firstly, the sample size that we carried out the experiment on can be considered relatively small and might not be a good representative of the entire population of the paper planes. Secondly, some of the paper planes were not flying linearly but in a circular trajectory, which might have inaccurately affected the overall average flight distance of each type of paper plane, especially, given that there were not many trials of flying the paper planes. Besides, each paper has its own weight that varies within their own type and across the three types. Although the difference is not significant, we should take this into consideration. In addition, there could have been some measurement error as the experimenter only used a ruler to measure the distance from their feet to the landing point. However, the errors should not be remarkable. Finally, the experiment was carried out with only three types of paper and one design of paper planes. We might not be able to draw any conclusion regarding different types of paper or different types of plane designs.

Improvements

If we were to design this experiment again, there are a number of improvements we would like to make. First, we would increase the sample size so that our sample could be a good representation of the entire population of paper planes. In our experiment, each type of paper plane is thrown five times, creating a sample with fifteen observations in total; however, the sample size of fifteen may not be enough to well-represent the entire population of paper planes and it is difficult to figure out whether our outcome is a true finding. It is recommended that a greater number of repeated tests be performed in order to reduce the random error, since the larger the sample size is, the closer the calculated error gets to the true error. In general more tests would give a more reliable indication of each design performance. Another concern we had for our experiment was that a ruler was used to measure the flying distance of planes in each trial. Since the ruler was short and had to be moved several times for a cumulative measurement, the errors from moving and aligning the endpoints also added up cumulatively. For this reason, we would use a measuring tape in the future experiment to improve the accuracy of our measurements. Lastly, since our current experiment is inapplicable to other designs of planes, we would try to add more paper plane designs in the future experiments to check their effects on the flying distance of the paper planes.

Conclusions

The main goal of this experiment was to reach a statistical conclusion on how the distance of paper planes varies with different types of the paper planes. The statistical test (one way ANOVA) conducted to check the difference in mean distance covered by different paper types indicated that there was no significant difference in the mean distance covered by three different paper type planes. This result suggests that there may be more factors present, possibly in combination to the paper types, that might be responsible for the difference in distance coverages of the paper planes. Since there was no evidence found of the difference in the distance, we refrained from conducting pairwise analysis between the paper types. The results from this experiment can be used in similar future studies for comparison purposes. More experiments with different paper type designs are needed to understand the complex behaviour of the paper plane's flight distance.

REFERENCES

1. Hinkle, Melisse. “Science of Flight: Paper Airplanes.” *Cheapflights*, 26 June 2019, www.cheapflights.com/news/science-of-flight-paper-airplanes.

2. *One-Way ANOVA Test in R*. www.sthda.com/english/wiki/one-way-anova-test-in-r.

APPENDIX

Rcode

```
# Code for plotting figure 2
new <- data %>%
  mutate(trial = as.factor(rep(c(1,2,3,4,5),3)))

new %>%
  ggplot(aes(x= trial, y = flying_distance, color=paper_type, group = paper_type)) +
  geom_point() +
  geom_line() +
  labs(title = "Figure 2: Flying distances by paper type",
       y = "Flying Distance (m)",
       x = "Trial") +
  theme_minimal()
```

```
# Code for plotting figure 3
library("ggpubr")
ggline(data, x = "paper_type", y = "flying_distance",
       add = c("mean_se", "jitter"),
       order = c("lined", "wrapping", "printing"),
       ylab = "Flying distance (m)", xlab = "Treatment") +
  labs(title = "Figure 3: Mean flying distance")
```

```
# Code for plotting figure 4
data %>%
  ggplot(aes(x=paper_type, y=flying_distance, color = paper_type)) +
  geom_boxplot() +
  theme(legend.position = "none") +
  theme_minimal() + ggtitle("Figure 4: Boxplot of flying distance by paper type")
```

```
# Code for plotting figure 5
mod <- aov(flying_distance ~ paper_type, data)
plot(mod, main='Figure 5: qqplot of residuals', 2)
```

```
# Code for plotting figure 6
plot(mod, 1)
```

```r
# Checking normality
aov_residuals <- residuals(object = mod)
# Run Shapiro-Wilk test
shapiro.test(x = aov_residuals )
```

```
##
##  Shapiro-Wilk normality test
##
## data:  aov_residuals
## W = 0.96247, p-value = 0.7353
```

```r
# Checking for equal variance
bartlett.test(flying_distance ~ paper_type, data)
```

```
##
##  Bartlett test of homogeneity of variances
##
## data:  flying_distance by paper_type
## Bartlett's K-squared = 6.1442, df = 2, p-value = 0.04632
```

```r
# One way test
oneway.test(flying_distance ~ paper_type, data = data)
```

```
##
##  One-way analysis of means (not assuming equal variances)
##
## data:  flying_distance and paper_type
## F = 1.2283, num df = 2.0000, denom df = 6.1899, p-value = 0.3554
```

```r
anova(aov(flying_distance ~ paper_type, data = data))
```

```
## Analysis of Variance Table
##
## Response: flying_distance
##            Df Sum Sq Mean Sq F value Pr(>F)
## paper_type  2 1.0163 0.50817  1.1865 0.3387
## Residuals  12 5.1394 0.42828
```