Full Factorial Design Experiment: Paper Airplane Flight Distance

William Su

2025-06-11

Introduction

Flying paper airplanes has always been a source of casual amusement or an opportunity to compete for bragging rights; however, understanding and optimizing the factors that influence the gliding distance of paper airplanes offers more than just entertainment. Despite their simplicity, paper airplanes still follow the same aerodynamic principles that govern real aircraft. Thus, paper airplanes engage with core aerodynamic principles, encourage scientific investigation through experimentation, and model real-world engineering challenges in an accessible and engaging manner.

A key metric in aircraft design that flying paper airplanes measures well is aerodynamic efficiency. Optimizing flight parameters, even in small-scale models, provides insight into how design changes can translate into more efficient and stable performance in real-world applications (Li et al., 2022; Su, 2024; Zhang, 2025). Both experimental and computational studies demonstrate that aerodynamic factors have a significant impact on performance and efficiency.

Among the most impactful of these factors is mass distribution. Previous studies have shown that small changes in the placement of mass can significantly affect its stability, flight path, and distance traveled, such as adding weight to specific areas of a paper airplane (Lan et al., 2017; Li et al., 2022; Obayashi et al., 2023; Su, 2024; Zhang, 2025). These findings underscore the importance of the center of gravity as a pivotal factor in flight performance.

In addition to their scientific relevance, paper airplanes serve as a valuable tool in both introductory aerodynamic research and education due to their low cost, ease of construction, and accessibility. They enable controlled experimentation without the financial or logistical barriers typically associated with traditional aerospace testing (chatGPT). The accessibility offered by paper airplanes allows researchers and educators to explore key flight parameters, like weight distribution, wing geometry, and launch angle, with a level of flexibility and replication often unachievable in larger systems (Lan et al., 2017; Li et al., 2022; Obayashi et al., 2023; Su, 2024; Zhang, 2025). Beyond their utility in research, paper airplanes foster hands-on learning by providing a tangible link to abstract physical concepts. Activities like building and testing models help students develop critical thinking skills while deepening their understanding of force, motion, and stability (chatGPT). These simple experiments can also support computational models by providing validation data for fluid dynamics simulations, enhancing our understanding of real aerodynamic behavior (Puspita et al., 2019; Obayashi et al., 2023).

This study investigates the effect of minor weight adjustments (the placement of paper clips) on the gliding distance of paper airplanes. Specifically, we address the following research questions:

1. Does adding paper clips significantly affect flight distance?
2. How does clip placement (nose, middle, rear) individually affect flight distance?
3. Are there significant interactions among clip placements that influence performance?

Using a complete (2^3) factorial design, the study will systematically evaluate the effects of placing paper clips at three positions: the nose, middle, and rear of the aircraft. This design enables a thorough analysis of both main effects and interaction effects.

Although modest in scale, the study seeks to contribute to a broader understanding of aerodynamic design, support evidence-based physics education, and provide insight into fundamental principles that extend from classroom experiments to real-world aerospace challenges.

Methods

Data Collection Procedure

The researcher conducted an experiment to assess whether the placement of a single paperclip at the rear, middle, or nose of a paper airplane affected its flight distance. He folded the paper airplane the way his father once taught him. The exact design is shown in Figure 1:

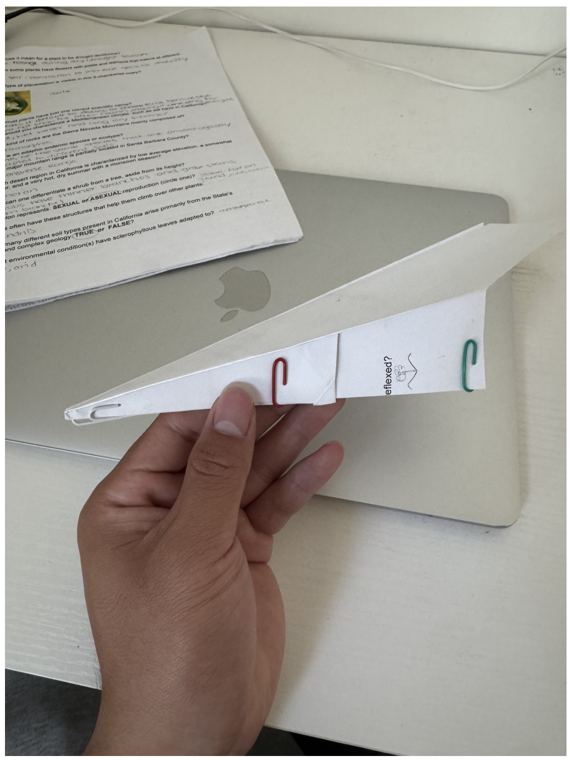


Figure 1: Paper Airplane with Paper Clips on all Three Positions

The researcher obtained paper clips from the UCSB library and conducted all flights in an alleyway behind his house to minimize wind interference.

The researcher laid out a tape measure along the alley to serve as the measurement axis. The distance flown by each airplane was recorded in centimeters, defined strictly as the distance from the launch point; the distance is measured by the start of the tape to the location where the airplane first made contact with the ground before any sliding occurred. The researcher aimed to consistently position the paperclip(s) across trials to minimize within-treatment variability. He also attempted to throw the airplane as straight and consistently as possible from behind the start of the tape measure, although minor deviations in flight direction did occur.

Figure 2 shows the damage accumulated to the airplane's nose after 88 throws.

Figure 2: Paper Airplane with Paper Clips on all Three Positions After all Replicates

The researcher defined each experimental condition by the presence or absence of a paperclip at one of three locations: the rear, middle, or nose of the airplane. These factors were three separate binary (yes/no) factors. To control for potential problematic variables, such as fluctuations in the wind, the researcher randomized the order of throws using the `sample()` function in R. This randomization helps satisfy the assumption of independence of residuals required for a valid analysis of variance (ANOVA).

Statistical Analysis

The collected data were analyzed using the linear modeling function `lm()` in R, followed by an ANOVA to evaluate the significance of the main effects of paperclip placement. ANOVA is used to assess whether the mean gliding distances differ significantly across the different paperclip configurations. It assumes that residuals are independent, normally distributed, and exhibit homogeneity of variance. Although the researcher did not verify these assumptions during the data collection phase, he assessed post hoc using residual plots and formal tests, as reported in the Results section.

Technical Considerations

Several practical challenges arose during the experiment. First, ensuring consistent paperclip placement proved challenging–particularly in the middle position–where the paperclip tended to shift during launch. Second, the airplane's nose became crumpled over repeated throws, altering aerodynamic performance; the researcher did attempt to smooth out the damage before each throw. Third, estimating the exact touchdown point was subjective, especially when the plane skidded after landing. The largest source of variability, however, was wind. Despite the sheltered location, occasional gusts influenced the trajectory and caused the plane to slide before the researcher could properly measure its distance. To mitigate this, the researcher delayed throws until the wind calmed and paid careful attention to initial contact points.

Results

Pilot Study and Sample Size Calculations

In order to calculate sample size needed to achieve 80% power, the researcher settled on conducting a pilot study (8 cells, 3 replicates each) before the actual experiment. He starts by randomizing the run order of the pilot study.

```r
# header for formatting from chatGPT

# determine run order for pilot study

set.seed(6112025)

treatments <- c(rep("000", 3),
                rep("001", 3),
                rep("010", 3),
                rep("011", 3),
                rep("100", 3),
                rep("101", 3),
                rep("110", 3),
                rep("111", 3)
                )
```

Run order: 011, 001, 110, 001, 011, 101, 001, 111, 110, 000, 010, 000, 000, 101, 011, 010, 111, 110, 100, 100, 010, 100, 101, 111 (chatGPT). Note: 0 = no, 1 = yes, hundred's place represents nose category, ten's place represents middle category, and single's place represents rear category. For example, 000 means no paperclips on the nose, middle, or rear of the airplane; 001 means no paperclips on the nose or middle, 1 paperclip on the rear.

```r
# pilot study data, 8 cells, 3 replicates per cell

library(readxl)

pilot_df <- read_excel("pilot_data.xlsx")

# factorize factors
pilot_df$nose <- as.factor(pilot_df$nose)
pilot_df$middle <- as.factor(pilot_df$middle)
pilot_df$rear <- as.factor(pilot_df$rear)
```

After inputting the data in to a data frame, he fits it to a linear regression model and outputs the summary of it. However, the researcher is only interested in the estimated coefficients (β's) and standard errors of the factors of interest as shown in Table 1:

```r
# fit pilot data to a lm
pilot_lm <- lm(distance ~ nose * middle * rear, data = pilot_df)

# output summary into table
output <- signif(summary(pilot_lm)$coefficients, 4)
output[,] <- as.character(output[,])
knitr::kable(output, caption = "Pilot Study Linear Regression Model Summary")
```

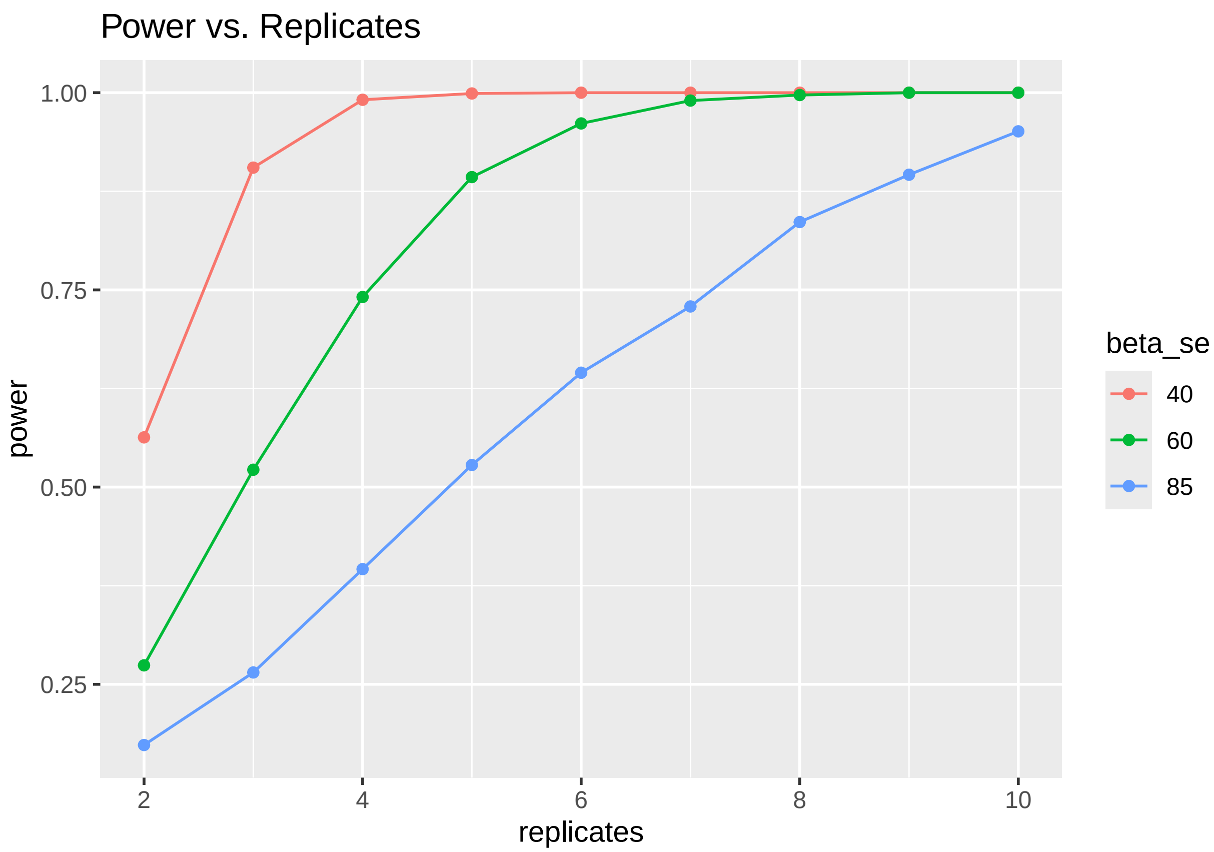
Table 1: Pilot Study Linear Regression Model Summary

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	678.3	30.32	22.38	1.684e-13
noseyes (nose)	-212.8	42.87	-4.964	0.0001406
middleyes (middle)	-146.3	42.87	-3.413	0.003559
rearyes (rear)	-272	42.87	-6.344	9.739e-06
noseyes (nose):middleyes (middle)	255.7	60.63	4.217	0.0006551
noseyes (nose):rearyes (rear)	260	60.63	4.288	0.0005643
middleyes (middle):rearyes (rear)	238.2	60.63	3.928	0.0012
noseyes (nose):middleyes (middle):rearyes (rear)	-300.5	85.74	-3.505	0.002935

The researcher proceeds to calculate the power given some β's, standard error, and sample size. One can see these calculations in a graphical form below:

```
# sample size calculation

source("power_factorial_23.R")

# taken from the lm estimated coefficients
beta_mean <- c(680, -210, -145, -270, 255, 260, 240, -300)

# roughly based off of lm coefficients' se's
beta_se40 <- rep(40, 8)
beta_se60 <- rep(60, 8)
beta_se85 <- rep(85, 8)

reps <- 2:10

power40 <- numeric(length(reps))
power60 <- numeric(length(reps))
power85 <- numeric(length(reps))

for (i in 1:length(reps)) {
  power40[i] <- power_factorial_23(beta_mean, beta_se40, reps[i], iter=1000, alpha=0.05)
  power60[i] <- power_factorial_23(beta_mean, beta_se60, reps[i], iter=1000, alpha=0.05)
  power85[i] <- power_factorial_23(beta_mean, beta_se85, reps[i], iter=1000, alpha=0.05)
}

power_df <- data.frame(reps,
                       power40,
                       power60,
                       power85)

library(ggplot2)

# graph sample size calculation
ggplot(power_df, aes(x = reps)) +
  geom_line(aes(y = power40, color = "40")) +
  geom_line(aes(y = power60, color = "60")) +
  geom_line(aes(y = power85, color = "85")) +
  geom_point(aes(y = power40, color = "40")) +
  geom_point(aes(y = power60, color = "60")) +
```

```r
  geom_point(aes(y = power85, color = "85")) +
  scale_color_discrete(name = "beta_se") +
  labs(x = "replicates",
       y = "power",
       title = "Power vs. Replicates")
```



Looking at the graph, he must plan for the worst case scenario (SE $\approx$ 85) and perform at minimum 8 replicates per cell to achieve at least 80% power.

Visualizing the data

Moving on to the actual experiment (8 cells, 8 replicates), the researcher randomizes the run order again.

```r
# determine run order for real data

treatments <- c(rep("000", 8),
                rep("001", 8),
                rep("010", 8),
                rep("011", 8),
                rep("100", 8),
                rep("101", 8),
                rep("110", 8),
                rep("111", 8)
                )
```

Run order: 011, 011, 001, 000, 110, 010, 111, 111, 111, 011, 010, 000, 011, 011, 010, 110, 100, 111, 000, 011, 110, 001, 100, 101, 101, 010, 000, 011, 001, 100, 100, 000, 100, 110, 000, 000, 011, 100, 111, 001, 110, 101, 110, 010, 110, 010, 000, 101, 001, 110, 010, 001, 111, 100, 010, 111, 101, 001, 111, 101, 001, 101, 100, 101 (chatGPT). Note: same logic as before.

```r
# data collected, 8 cells, 8 replicates per cell
airplane_df <- read_excel("airplane_data.xlsx")

# factorize factors
airplane_df$nose <- as.factor(airplane_df$nose)
airplane_df$middle <- as.factor(airplane_df$middle)
airplane_df$rear <- as.factor(airplane_df$rear)
```

He inputs the data in to a data frame, fits it to a linear regression model, and shows the summary of it:

```r
# fit data to a lm
airplane_lm <- lm(distance ~ nose * middle * rear, data = airplane_df)

# output summary as a table
output <- signif(summary(airplane_lm)$coefficients, 4)
output[,] <- as.character(output[,])
knitr::kable(output, caption = "Linear Model Summary")
```

Table 2: Linear Model Summary

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	662.8	15.81	41.91	5.616e-44
noseyes (nose)	-205.4	22.36	-9.184	9.116e-13
middleyes (middle)	-89.56	22.36	-4.005	0.0001846
rearyes (rear)	-258.5	22.36	-11.56	1.852e-16
noseyes (nose):middleyes (middle)	221.7	31.63	7.01	3.336e-09
noseyes (nose):rearyes (rear)	258.6	31.63	8.176	3.978e-11
middleyes (middle):rearyes (rear)	151.1	31.63	4.778	1.317e-05
noseyes (nose):middleyes (middle):rearyes (rear)	-219	44.73	-4.896	8.668e-06

Table 2 includes the estimated effect on distance of each factor/interaction, the average deviation of the estimate from the actual data (std. error), and how important each predictor is to the model (t-value and Pr(>|t|)).

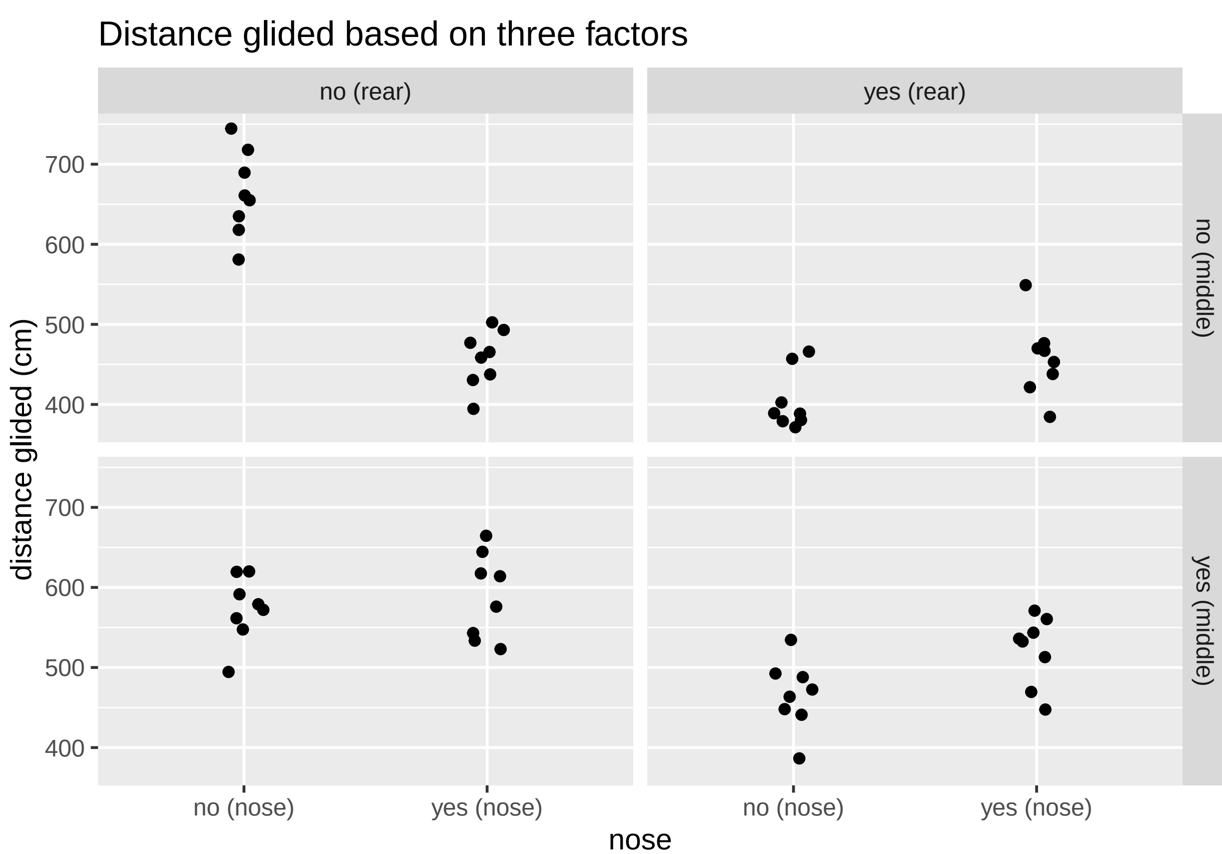
Here is another table outputting summary data of each cell:

```r
library(dplyr)

# summary table
airplane_sum <- airplane_df %>%
  group_by(nose, middle, rear) %>%
  summarise(
    mean = mean(distance),
    sd = sd(distance),
    n = length(distance)
  )

knitr::kable(airplane_sum, caption = "Data Summary")
```

Table 3: Data Summary

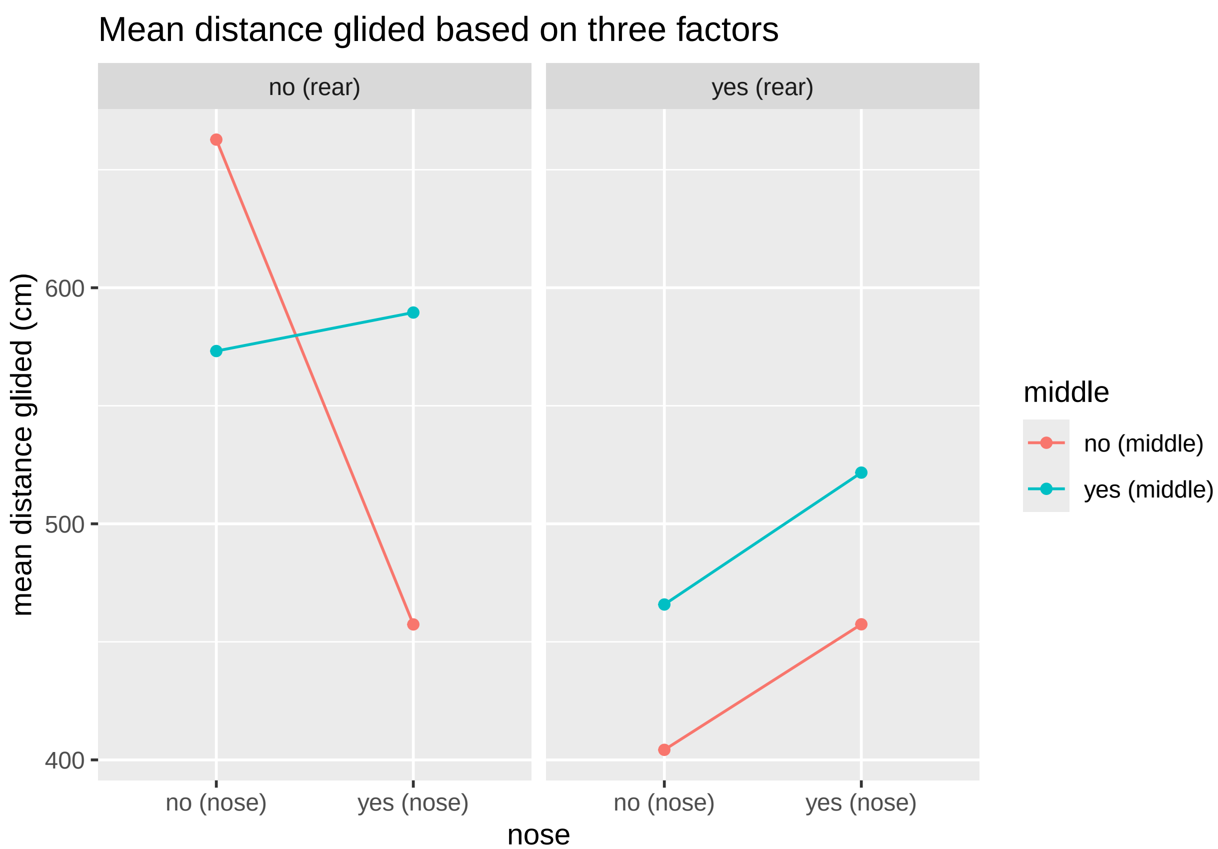
nose	middle	rear	mean	sd	n
no (nose)	no (middle)	no (rear)	662.7500	53.41214	8
no (nose)	no (middle)	yes (rear)	404.2500	36.55426	8
no (nose)	yes (middle)	no (rear)	573.1875	40.87432	8
no (nose)	yes (middle)	yes (rear)	465.8125	43.41818	8
yes (nose)	no (middle)	no (rear)	457.3750	35.51333	8
yes (nose)	no (middle)	yes (rear)	457.4375	47.81694	8
yes (nose)	yes (middle)	no (rear)	589.5000	53.36799	8
yes (nose)	yes (middle)	yes (rear)	521.6875	43.15829	8

```r
# graph data pts.
ggplot(airplane_df,
       aes(x = nose,
           y = distance)) +
  geom_jitter(width=0.08, height=0) +
  facet_grid(middle ~ rear) +
  labs(y = "distance glided (cm)") +
  ggtitle("Distance glided based on three factors")
```



From the facet grid, one can see the longest glide distances occur when both the rear and middle paperclips are absent, particularly when the nose is also absent (top left). In contrast, the addition of the rear or middle paperclips tends to reduce the gliding distance. The influence of the nose varies depending on the configuration of the other two components, indicating that there are interaction effects among the nose, middle, and rear paperclips in determining glide performance.

```
# visualize data

# find mean of each cell
airplane_mean <- airplane_df %>%
  group_by(nose, middle, rear) %>%
  summarise(
    mean_distance = mean(distance)
  )

# graph means
ggplot(airplane_mean,
       aes(x = nose,
           y = mean_distance,
           group = middle,
           color = middle)) +
  geom_line() +
  geom_point() +
  facet_wrap(~ rear) +
  labs(x = "nose",
       y = "mean distance glided (cm)") +
  ggtitle("Mean distance glided based on three factors")
```



This plot shows in the left panel (rear = no), the airplane without the nose and middle paperclips leads to the highest mean glide distance, while adding a nose or middle paperclip appears to reduce performance, especially when the middle paperclip is absent. In the right panel (rear = yes), adding the nose and middle paperclip tends to increase glide distance, indicating a different interaction pattern than when the rear paperclip is absent. The plot reveals that the effect of one factor depends on the other factors, emphasizing a clear interaction between the nose, middle, and rear paperclips in influencing glide performance.

Statistical Analysis

```
# chatGPT formatting
airplane_anova <- anova(airplane_lm)
pvals <- airplane_anova$`Pr(>F)`
pvals[pvals < 1e-4] <- "< 0.0001"
airplane_anova$`Pr(>F)` <- pvals


# table anova test
knitr::kable(airplane_anova, caption = "ANOVA Table")
```

Table 4: ANOVA Table

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
nose	1	6400.000	6400.000	3.199329	0.0790779515156408
middle	1	28350.141	28350.141	14.172097	0.000401892346549409
rear	1	188030.641	188030.641	93.995598	< 0.0001
nose:middle	1	50344.141	50344.141	25.166790	< 0.0001
nose:rear	1	88878.516	88878.516	44.429935	< 0.0001
middle:rear	1	6930.562	6930.562	3.464554	0.0679491987277753
nose:middle:rear	1	47961.000	47961.000	23.975469	< 0.0001
Residuals	56	112023.500	2000.420	NA	NA

Table 4 displays at significance level $\alpha = 0.05$,

1. nose: p $= 0.0790780 > \alpha = 0.05 \Rightarrow$ paperclip on the nose does not have a statistically significant effect on gliding distance.
2. middle: p $= 0.0004019 < \alpha = 0.05 \Rightarrow$ paperclip at the middle does have a statistically significant effect on gliding distance.
3. rear: p $< 0.0001 < \alpha = 0.05 \Rightarrow$ paperclip on the rear does have a statistically significant effect on gliding distance.
4. nose x middle (interaction): p $< 0.0001 < \alpha = 0.05 \Rightarrow$ paperclip on the nose:middle do have a statistically significant effect on gliding distance.
5. nose x rear: p $< 0.0001 < \alpha = 0.05 \Rightarrow$ paperclip on the nose:rear do have a statistically significant effect on gliding distance.
6. middle x rear: p $= 0.0679492 > \alpha = 0.05 \Rightarrow$ paperclip on the middle:rear do not have a statistically significant effect on gliding distance.
7. nose x middle x rear: p $< 0.0001 < \alpha = 0.05 \Rightarrow$ paperclip on the nose:middle:rear do have a statistically significant effect on gliding distance.

Therefore, at significance level $\alpha = 0.05$, the middle, rear, nose:middle, nose:rear, and nose:middle:rear factors have a statistically significant effect on gliding distance; nose and middle:rear do not have a statistically significant effect on gliding distance.

At Bonferroni-adjusted level $\alpha = 0.05/7 \approx 0.0071$ (7 predictors),

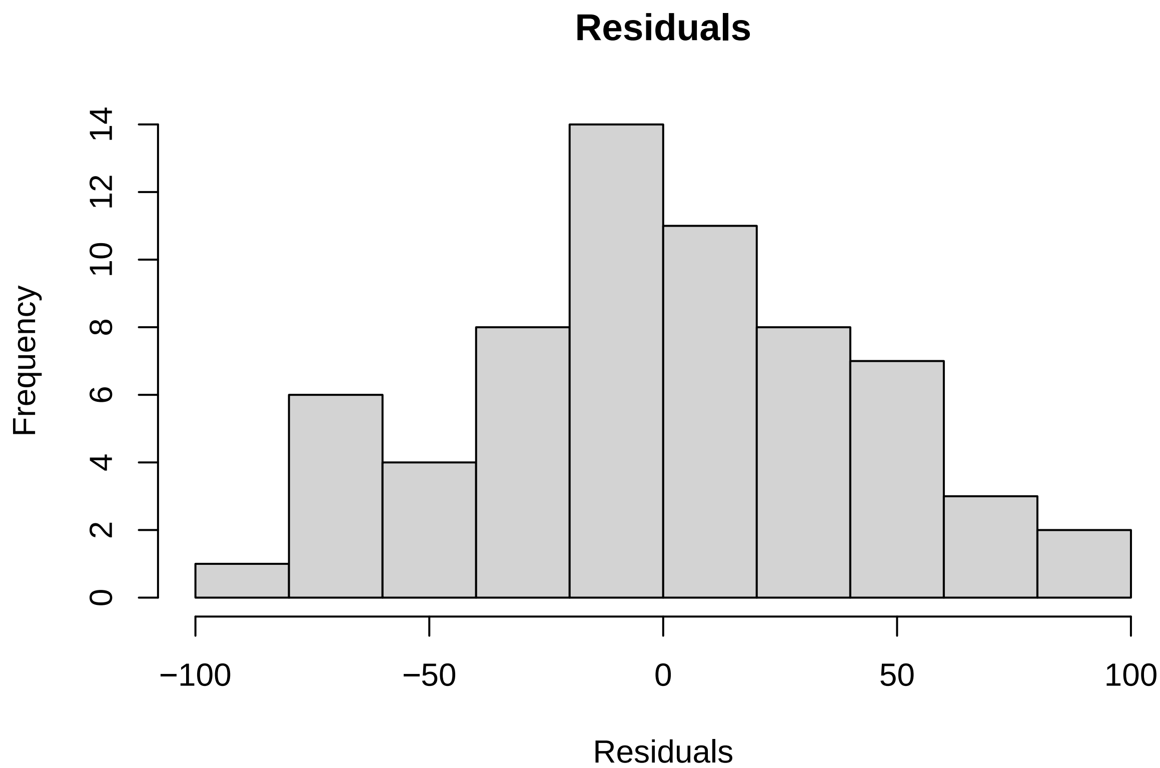
1. nose: p $= 0.0790780 > \alpha \approx 0.0071 \Rightarrow$ paperclip on the nose does not have a statistically significant effect on gliding distance.
2. middle: p $= 0.0004019 < \alpha \approx 0.0071 \Rightarrow$ paperclip at the middle does have a statistically significant effect on gliding distance.
3. rear: p $< 0.0001 < \alpha \approx 0.0071 \Rightarrow$ paperclip on the rear does have a statistically significant effect on gliding distance.
4. nose x middle (interaction): p $< 0.0001 < \alpha \approx 0.0071 \Rightarrow$ paperclip on the nose:middle do have a statistically significant effect on gliding distance.
5. nose x rear: p $< 0.0001 < \alpha \approx 0.0071 \Rightarrow$ paperclip on the nose:rear do have a statistically significant effect on gliding distance.
6. middle x rear: p $= 0.0679492 > \alpha \approx 0.0071 \Rightarrow$ paperclip on the middle:rear do not have a statistically significant effect on gliding distance.
7. nose x middle x rear: p $< 0.0001 < \alpha \approx 0.0071 \Rightarrow$ paperclip on the nose:middle:rear do have a statistically significant effect on gliding distance.

Thus, at Bonferroni-adjusted level $\alpha \approx 0.0071$, the middle, rear, nose:middle, nose:rear, and nose:middle:rear factors have a statistically significant effect on gliding distance; nose and middle:rear do not have a statistically significant effect on gliding distance.

Model Checking

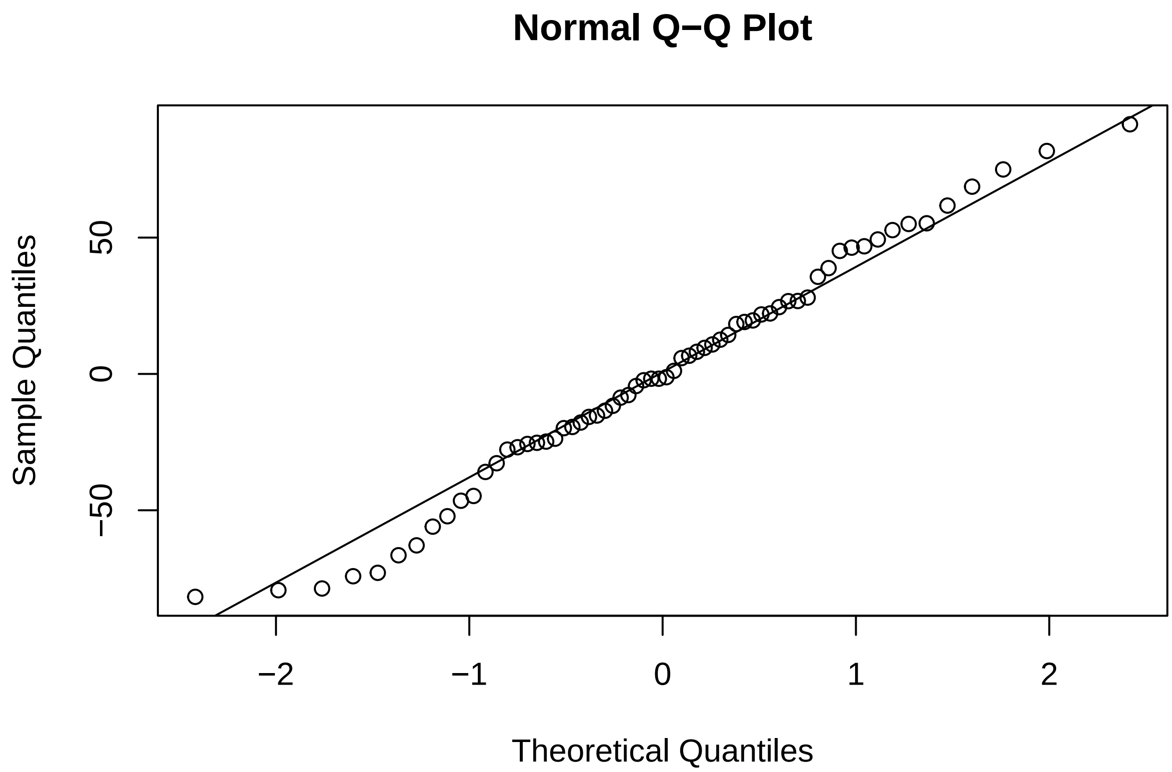
To validate the researcher's findings from the ANOVA test, he must verify all ANOVA assumptions are met.

```r
# histogram of residuals from lm
res <- residuals(airplane_lm)
hist(res,
     main = "Residuals",
     xlab = "Residuals")
```



The residual histogram shows residuals look roughly symmetric around 0.

```r
# normal q-q plot
qqnorm(res)
qqline(res)
```



Normal Q–Q plot: points stay close to the reference line, suggesting approximate normality.

```
#shapiro-wilk test
library(broom)  # chatGPT
knitr::kable(broom::tidy(shapiro.test(res)), caption = "Shapiro-Wilk Test")  # chatGPT
```

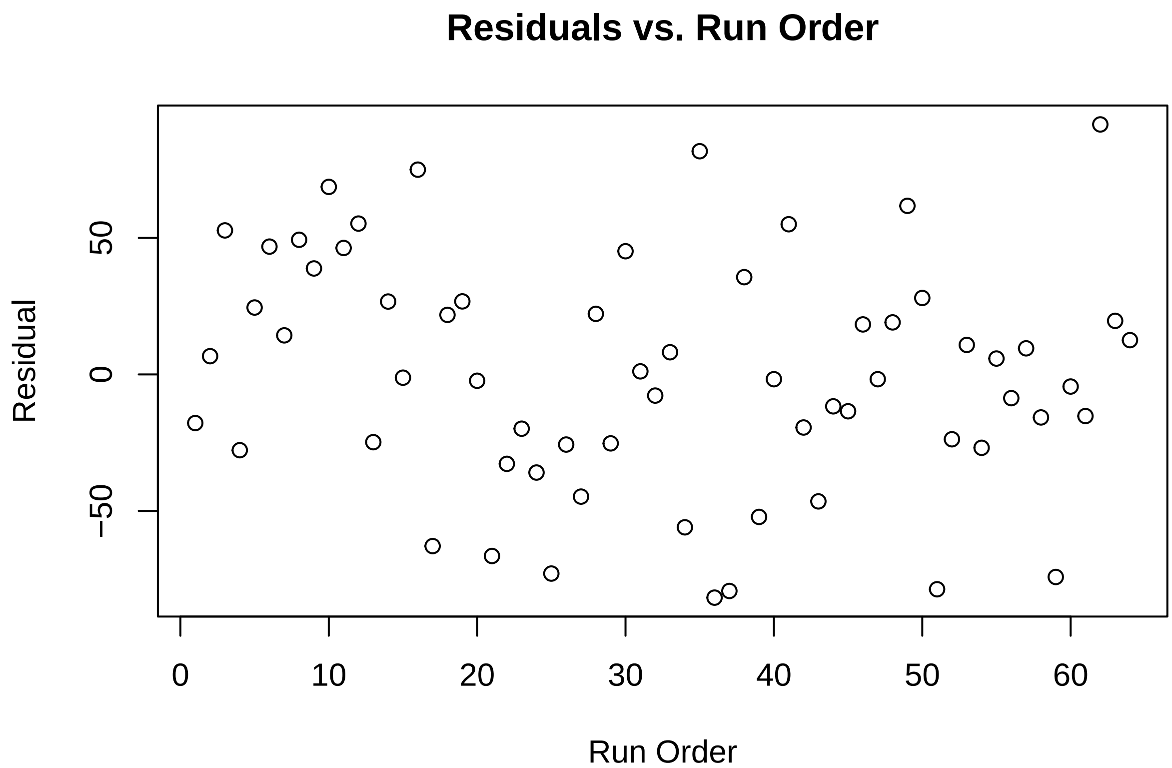
Table 5: Shapiro-Wilk Test

statistic	p.value	method
0.9847959	0.6180015	Shapiro-Wilk normality test

Shapiro–Wilk (W = 0.9847959, p = 0.6180015): at $\alpha = 0.05$, p = 0.6180015 $> \alpha = 0.05 \Rightarrow$ we fail to reject null hypothesis (residuals are distributed normally).

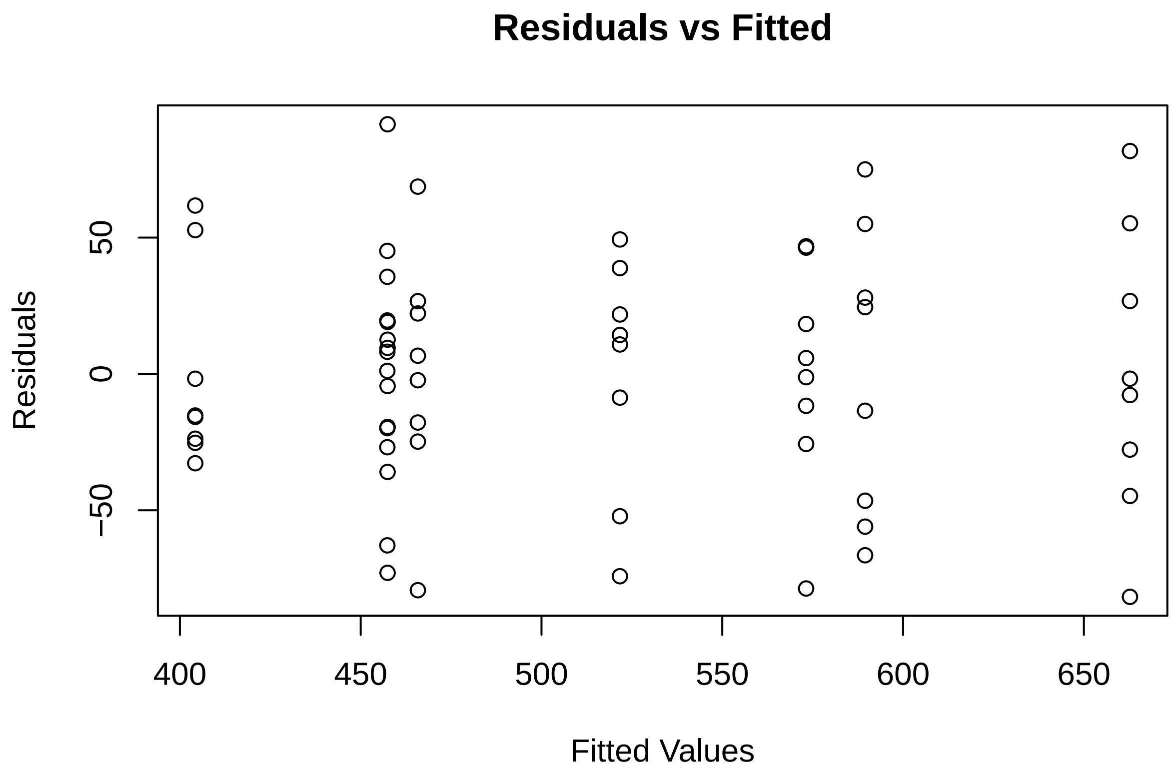
The researcher concludes the normality assumption holds.

```
plot(res,
xlab = "Run Order",
     ylab = "Residual",
     main = "Residuals vs. Run Order")
```



Residuals vs. run order: points look like a cloud, suggesting independence.

```r
plot(fitted(airplane_lm), res,
     xlab = "Fitted Values",
     ylab = "Residuals",
     main = "Residuals vs Fitted")
```



Residuals vs. fitted: no funnels and spread looks equal, suggesting constant variance.

In conclusion, all ANOVA assumptions (normality, independence, constant variance) appear satisfied and there is no need for a permutation test.

Discussion

This experiment investigated the impact of paperclip placement on the gliding distance of a paper airplane using a complete 2^3 factorial design. The study evaluated the individual and interaction effects of attaching paper clips to the nose, middle, and rear of the airplane. The results of the statistical analysis indicate that both the middle and rear clip placements significantly reduced flight distance, while the nose paper clip did not show a statistically significant main effect. However, significant two-way and three-way interactions involving the nose placement suggest that its effect on flight performance is highly context-dependent.

The middle paperclip showed a consistent and statistically significant negative effect on gliding distance ($p < 0.001$), possibly due to its disruption of the airplane's center of lift (Li et al., 2022; Su, 2024). Likewise, the rear clip placement resulted in the most pronounced reduction in distance ($p < 0.0001$), likely destabilizing the aircraft by shifting its center of gravity too far back (Li et al., 2022). While the nose placement alone did not significantly affect distance ($p = 0.079$), its role in interactions was substantial. For example, when combined with the middle or rear placement, the nose paperclip significantly altered flight outcomes, as evidenced by the strong nose × middle ($p < 0.001$) and nose × rear ($p < 0.001$) interactions. Furthermore, the three-way interaction (nose × middle × rear) was also statistically significant ($p < 0.001$), indicating complex dependencies among the placements (Lan et al., 2017).

These results support existing aerodynamic research, which emphasizes the importance of mass distribution in flight stability and performance (Lan et al., 2017; Li et al., 2022; Obayashi et al., 2023; Su, 2024; Zhang, 2025). The presence of significant interactions stress the need to evaluate multiple design factors simultaneously rather than in isolation, particularly in flight engineering, where aerodynamic balance is crucial.

From a methodological perspective, model diagnostics confirmed that the linear model met all required assumptions. The residuals showed no signs of skewness, heteroscedasticity, or autocorrelation, and the Shapiro-Wilk test indicated no deviation from normality ($p = 0.618$). Thus, the conclusions drawn from the ANOVA are statistically valid, and no permutation test was necessary.

A key limitation of this study is the inherent variability in manual airplane launches, which can introduce human error despite the use of standardized techniques. Additionally, external environmental conditions such as wind or slight inconsistencies in paper folding could contribute to variability. These factors were mitigated by randomizing the run order and conducting multiple replicates per treatment.

While the study used a controlled outdoor environment to minimize environmental variance, the sample was limited to a single aircraft design and material. Generalizing findings to other paper types, sizes, or folding patterns should be done cautiously. Future studies could explore whether results generalize across different paper types, folding styles, or clip weights, helping validate findings across broader conditions.

In educational contexts, this study reinforces the utility of paper airplanes as a hands-on learning tool for illustrating core concepts in experimental design and aerodynamics. The experiment's factorial structure also provides an accessible example of interaction effects, an often underappreciated element in introductory statistics education (chatGPT).

Overall, the findings offer practical insights into optimal mass distribution strategies for paper airplanes while reinforcing broader principles beyond just throwing paper airplanes.

References

1. Lan, T.-S., Chen, P.-C., & Chuo, C.-H. (2017). Lan, T.-S., Chen, P.-C., & Chuo, C.-H. (2017). Using artificial neural network on flight distance prediction for paper plane. Advances in Mechanical Engineering, 9(7), 1–6. https://doi.org/10.1177/1687814017714969

2. Puspita, A. N. G., Ambarwati, L., Ludfiyanti, E., Tejonugroho, D. P., & Zen, Y. (2019). Puspita, A. N. G., Ambarwati, L., Ludfiyanti, E., Tejonugroho, D. P., & Zen, Y. (2019). Effect of paper weight, paper length, and nose of paper plane on aircraft mileage in paper airplane game. UI Proceedings on Science and Technology, 2, 31–33.

3. Li, H., Goodwill, T., Wang, Z. J., & Ristroph, L. (2022). Li, H., Goodwill, T., Wang, Z. J., & Ristroph, L. (2022). Centre of mass location, flight modes, stability and dynamic modelling of gliders. Journal of Fluid Mechanics, 937, A6. https://doi.org/10.1017/jfm.2022.89

4. Obayashi, N., Junge, K., Ilić, S., & Hughes, J. (2023). Obayashi, N., Junge, K., Ilić, S., & Hughes, J. (2023). Robotic automation and unsupervised cluster assisted modeling for solving the forward and reverse design problem of paper airplanes. Scientific Reports, 13, 4212. https://doi.org/10.1038/s41598-023-31395-0

5. Zhang, Y. (2025). Zhang, Y. (2025). Forward or backward? Effects of center of gravity position on gliding distance of unpowered gliders. In Proceedings of the 3rd International Conference on Software Engineering and Machine Learning. https://doi.org/10.54254/2755-2721/150/2025.22694

6. Su, X. (2024). Su, X. (2024). Aerodynamics of paper airplanes: From basic physics to biomimicry research. Highlights in Science, Engineering and Technology EMIS 2024, 119, 641–643. University of Shanghai for Science and Technology.