Flight time analysis for paper airplanes

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***Abstract*—This project examines the flight time of paper airplanes with the goal of determining the optimal aileron position that gives the longest flight time. The aileron of the airplanes are fixed at the following angle configurations; -90°, 0°and 90°.**

***Index Terms*—ailerons, paper-airplane, angle configurations**

I. Introduction

In physics[Bam13] and aerodynamics[Ame+16] the optimal shape and angle of ailerons has been discussed many times over the decades. Finding the optimal shape and angle of ailerons can greatly increase the airplane's performance and hence reduce both fuel consumption and the environmental impact.

In this paper the scope is scaled down from real airplanes to paper airplanes as this is more feasible to test a hypothesis on. The idea is to investigated how three different angles of a paper airplane's ailerons change the flight time compared to each other. The paper tests three different angle configurations, -90°, 0°and 90°, which can be seen in figure 1.

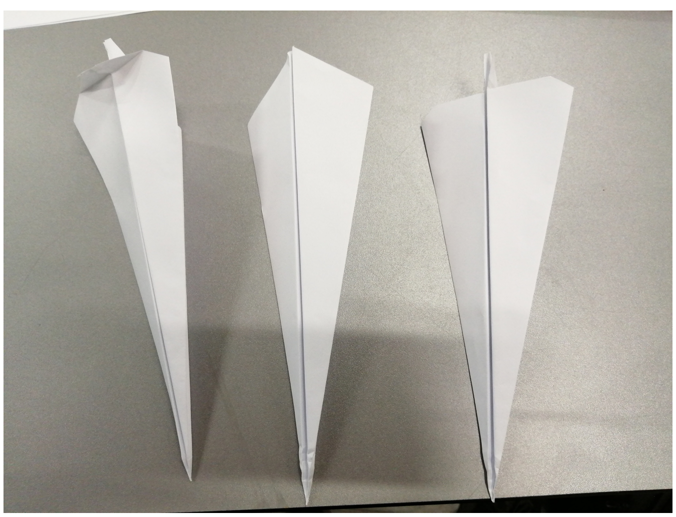

Fig. 1. Shows the paper airplane model with the three different angle configurations of it's ailerons

The paper airplane with the ailerons with the upward angle configuration of 90°is excepted to have the longest flight time.

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II. Methods

The experiments are based on folded paper-airplanes. The planes are folded by the same person in order to minimize bias as a result of different folding methods.

The statistical tests used to analyse the data are Levene's and the Welch-anova tests. Levene's test is used to test for homogeneity in the population variances and is therefore used to verify whether the variance for the three populations can be considered equal. Welch's anova test is used to compare the means of [k] normally distributed populations when the variances for the populations cannot be considered equal. The result from Levene's test determines whether an ordinary Anova test or Welch's anova test is needed. Depending on the result from the anova test, a two-sided paired t-test, with Bonferroni correction, is used to accept or reject the hypothesis. The Bonferroni correction compensates for the increased risk of making a type 1 error by correcting the α level of significance by the number of hypothesis tested.

All methods are based on the assumption that the collected data is normally distributed. To confirm this a model check is performed on the data including histograms, box-plots and QQ-plots. A histogram is an approximate representation of a distribution from numerical data. The box-plot is a graphical method for depicting numerical data skewness where an indication of the variance and outlier data is also incorporated. The qq-plots is a graphical method for assessing whether a set of data is plausibly from a theoretical distribution. To use it as an indication of normality the data quantities are plotted against a theoretical normal distributions quantities.

III. Experimental design

The experiment has three populations based on the three different ailerons position. Each population has been sampled 30 times to be able to use large sample theory. The experiment is designed in such a way that it introduces the least amount of bias as possible in the given time frame. To achieve this the paper airplanes, used in the experiment, was made by the same person to avoid one person being better at folding airplanes than others. Only 3 airplanes was folded and used instead of 90 different, as this approach reduces the risk of introducing unnecessary bias due to improvements in folding technique. Besides minimizing the risk of bias, utilizing only 3 airplanes

also minimizes the waste of resources.
The experiment was conducted by first folding 3 paper airplanes to be used in the experiment. The experiment is carried out by having one person throwing the paper airplanes and another person recording the flight time. Recording the flight time is done by utilizing a common stop watch, which in itself introduces variance to the experiment. An example of the experimental setup is shown in the following video.
The data is recorded in excel, exported as a ".csv" file which is imported and analysed in Matlab. Every test performed in Matlab uses a 95% level of significance, giving an α value of 0.05.
First the Levene's test of homogeneity is used to check for equal variance between the three populations. For this experiment it is expected that the Levene's test accepts the 0-hypothesis, that the variances are equal. If the Lavene's test should rejects the 0-hypothesis, the Welch's anova test is used to test for equality in the mean values for the populations. If the 0-hypothesis is accepted, a standard Anova test is instead used.
Based on the result from either of the anova tests it can be determined whether there is a significant difference in the means of the populations. Given the hypothesis, that the ailerons angled at 90°has a greater flight time, it is expected that the anova test rejects the 0-hypothesis, that all means are equal. On the contrary should the anova test accept the 0-hypothesis, we cannot definitively state that one aileron position is better than the other. If the anova test rejects the 0-hypothesis, a standard two-sided pairwise t-test is used to test whether the mean of the population with the ailerons at 90°is greater than the mean of the other 2 population means. Should both t-tests indicate that the aileron position of 90°has the greatest mean, we can with a 97.5% certainty state that it is better to have the ailerons at a 90°angle than 0°or -90°.

IV. Results

Descriptive statistics of the sampled data can be seen in table IV.

	ailerons 90°	ailerons -90°	ailerons NORMAL
Sample Mean	1.5s	1.9s	2.2s
Sample Variance	0.04s	0.10s	0.49s

In order to analyze the recorded data, it is first checked for normality. The normality check is done using qq-plots and Histograms, which can be seen in figure 3 and 4. The histogram hints at normality, but especially the histogram for ailerons in normal position does not convincingly show normality, whereas the claim of normality is better backed up by the qq-plots, which show no systematic deviation.

To verify the hypothesis, the means of the three samples are tested to see if they are equal. If the sample means are not equal this would indicate that one or more of the configurations has a superior flight time compared to the others. Before testing for equal mean, the variances need to be tested for equality, which is done using Levene's test. Equal

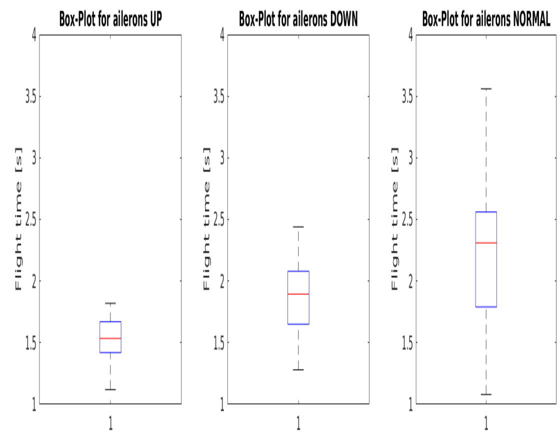

Fig. 2. Boxplot of collected data

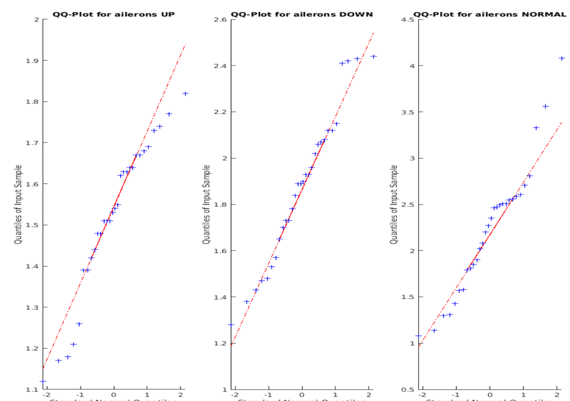

Fig. 3. QQ-plot of collected data.

variance between the three samples is rejected with a p-value of $9.3 * 10^{-7}$ at a significance level of 95%. Therefore Welsh-anova is used to test for equal means, and the test rejects the hypothesis, that the means are equal, with a p-value of $3.6856 \cdot 10^{-08}$ at an significance level of 95%.
The above result only indicates, that not all flight times are equal. To determine if the paper airplane with aileron configuration of 90° has the longest flight time, paired t-tests between ailerons 90 and 0 and 90 and -90 respectively is performed. The result can be seen in table I. The paired t-tests are bonferroni corrected by dividing the individual alpha levels by the number of comparisons of the dependent variable. In this case 2.

Aileron configuration	90° and 0°	90° and $-90°$
p-value	$3.3772 \cdot 10^{-5}$	$7.3861 \cdot 10^{-6}$
Significance level	0.025	0.025
Confidence Interval	[-0.5323 -0.1857]	[-1.0188 -0.4019]
Test statistic	-4.8970	-5.4442

TABLE I
Table of results from two-sided t-tests.

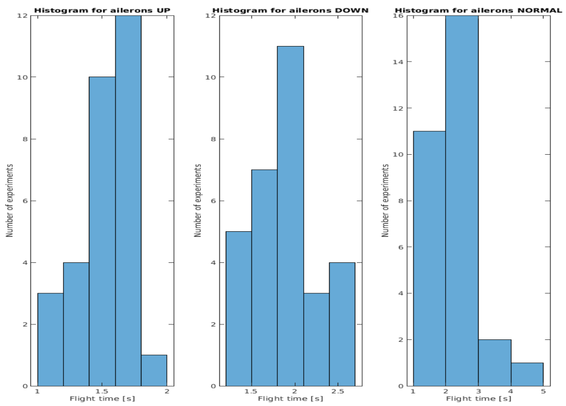

Fig. 4. Histogram of collected data.

From the comparison in table I it can be seen that the aileron configuration of $90°$ has a lower flighttime, than both the configuraion with ailerons in $-90°$ and $0°$ respectively. Thus the initial hypothesis is rejected.

V. Discussion

The results clearly states that the assertion of longer flight time for the $+90°$ aileron position is untenable at the $\alpha/2$ level of significance. From the results it is

VI. Conclusion

The results showed as expected that the three configurations did not have the same mean and hence leaving at least one of the angle configurations to be either superior or inferior to the others. The hypothesis was that the angle configuration, 90°, would have the longest flight time, however when tested using the T-test, it actually showed a shorter average flight time than the two other configurations.

References

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