Effect of paper weight, paper length, and nose of paper plane on aircraft mileage in paper airplane game

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Abstract

Objective: To investigate the main influencing factors in the paper airplane game. **Methods:** Mixed-level factorial design. **Results:** Paper weight, paper length, and nose of paper airplane affect significantly with aircraft mileage. And have interaction between paper length and nose of paper airplane. Otherwise, there is interaction between paper weight with paper length and nose of paper airplane. **Conclusion:** The results show that paper weight, paper length, and nose of paper airplane affect significantly with aircraft mileage. And have interaction between paper length and nose of paper airplane. Otherwise, there is interaction between paper weight with paper length and nose of paper airplane.

Keywords: paper airplane; aircraft mileage; mixed-level factorial design; ANOVA.

Introduction

Games are among the ways to develop people's capabilities because they provide ways to train creativity, emotions, feelings, and coordination of bodily functions. Good games also improve the quality of human life.

Creating a paper airplane is a good game to play. Using commonly available materials, such as paper and tape, people may simulate how objects can be flown. Extra activities with paper airplane games, such as increasing weights and changing shapes, also teach how engineering concepts function in real life. The exploration of ideas on how paper airplanes work is also encouraged in many world competitions for paper airplanes [1]. Thus, these games are intuitive, interactive, and enjoyable.

However, the probability that the paper airplane can fly successfully is small. In contrast to remote-control planes, paper airplanes encounter difficulties in controlling the flying direction and path. Although the remote-control airplane is easier to control, it needs much space for flying and is also expensive.

This study was conducted to determine the main factor in successfully flying a paper airplane.

Literature Review

Factorial design has been used in many experiments for many cases because it is a powerful tool and the design can be adjusted as per the experimenter's purposes [2]. The factorial design is a statistical methodology that enables researchers to examine the effect of each independent factor and the interaction effects among various factors [5].

The most common and practical design, 2k factorial design, is usually applied in conducting screening factor experiments, which requires differentiating the factor that has a significant effect on the response variable. Whereas 2k factorial design is commonly used when the factors are quantitative, 3k factorial design is commonly applicable for qualitative and quantitative factors. The purpose of 3k factorial design is to understand the actual response of each factor that becomes an interest for researchers. Furthermore, the relationship in 3k factorial design can be quadratic with the middle value on each factor unlike the 2k factorial design that is generally linearly related. In 3k factorial design, the levels of each factor are usually low (denoted by 0), medium (1), and high (2). If the factor studied is quantitative, then the low, medium, and high levels are generally denoted by –1, 0, and +1. The regression of each factor response can be expressed by

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \epsilon \,. \quad (1)$$

However, we have to note that first, 3k design is not the most efficient way to model quadratic relationships. The superior alternative is response surface design. Second, the best way to obtain an indication of curvature is to use 2k design coupled with the center point. This alternative allows the researcher to keep the size and complexity of the design low while also obtaining protection against the curve. If the curvature is important, two-tier designs can be axially added to obtain a central composite design. This sequential experiment strategy is much more efficient than running a 3k factorial design with quantitative factors.

With regard to the methodology and comprehensiveness of the factorial design experiments, the level (value) of the variables tested in factorial experimental design was established in "one-variable-at-a-time" type preliminary tests conducted with a wide range of variable settings [3].

In addition to the aforementioned types of factorial design, a mixed-level factorial design can also be used. According to Montgomery [2], 3k design is commonly used when combined with two-level factorial design, especially when factors are quantitative and qualitative, where qualitative factors must be defined in three factor levels. This combined design is called mixed-level factorial design, where the definition of alias relationships on qualitative factors needs to be conducted with caution because it is more complex than the alias relationship in general 2k factorial design.

ANOVA is a decision tool for detecting the variation of process parameters, and is a statistical technique to determine the optimal level of factor for the verification of the optimal design parameters through confirmation experiments [4]. This study used ANOVA to find out the optimal condition effect of paper weight, paper length, and nose of paper plane to aircraft mileage on paper plane games.

The experiment in this study uses the mixed-level factorial design with two-level and three-level factors. This factorial design is applied on the paper airplane experiment, which has not only a linear relationship between the factors that affect the movement of the paper airplane when it is flown. In addition, the factors that affect the paper airplane are qualitative and quantitative. The nose of the paper airplane is a qualitative factor, whereas the paper weight and length of the paper airplane are quantitative factors.

Research Question

The objective of this study is to investigate the factors, such as paper length, paper weight, and nose angle of the paper airplane, which mainly influence the paper airplane game. Another objective is to find out whether the combination of paper airplane design affects the aircraft mileage.

Factors that affect the aircraft mileage are sufficiently large. Thus, the conditions of the game are limited to the following:

1. size of paper airplane design: length is 19 cm for the long paper airplane and 16 cm for the short paper plane;
2. paper weight using A4 with various weights: 40, 100, and 160 gr;
3. nose angle of paper airplane (either acute or obtuse); and
4. operator of the paper airplane: in the case of this study, four of the five-member research team.

Data Collection

In the paper plane experiment, we used ANOVA with a mixed-level factorial design with two two-level factors and three-level factors as described previously. The experiment is conducted 4 times with 4 different operators. Total runs for each combination of the three factors is 48 runs (2 levels × 2 level × 3 level × 4 operator/combination). The operators are defined as blocking in this experiment. The experiment was performed at the lobby of K building, Faculty of Engineering, Universitas Indonesia - Depok on April 23, 2018. Figure 1 shows the paper airplane used in the experiment. Figure 2 shows how the paper airplane was flown.

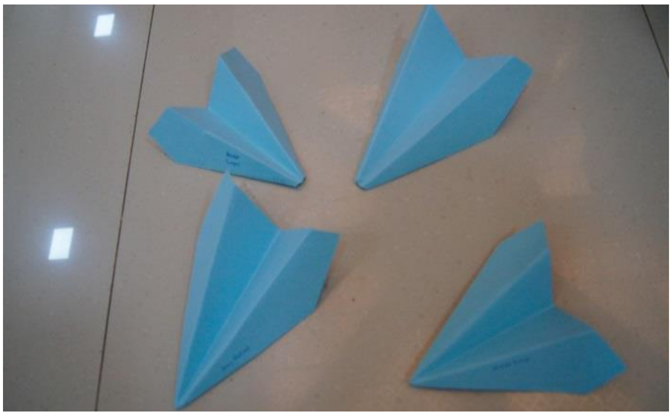


Figure 1. Paper airplane

Figure 2. Experiment on paper airplane

The paper airplane throwing sequence is conducted by randomization technique using random number in Excel. To reduce the variation of throwing results, we adjust the throwing position and throwing angle (angle of the upper and lower arms) at 45°. However, each of the four operators has different throwing capabilities. Thus, we use blocking on this operator by assuming replication as blocking.

Our throwing process is conducted in a large semi-indoor room to reduce the effect of wind and prevent the paper airplane from colliding with other objects, such as walls, that can affect the result. The aircraft mileage is calculated perpendicular to the straight line of the operator's standing position. Two different people performed the calculation to avoid miscalculation and recording errors. The tools include the following:

1. A4 paper with 3 types of weight as the main material for making paper planes;
2. 30-cm ruler for accurate measurement of the paper plane;
3. distance meter as a tool for calculating the throw distance of the plane;
4. protractor to keep the throwing angle fixed at 45°; and
5. paper observation and stationery for recording the results.

Table 1 reports the results of the plane distance for all combinations and each replication.

Table 1. Aircraft mileage of paper airplane (cm) for all factor combinations in each blocking

Factor	Long (19 cm)				Short (16 cm)			
	Blunt		Sharp		Blunt		Sharp	
A4 40 gr	432.8	492.7	350	330	608	600	494.8	517.7
	497.1	460	309.2	391	598	675.3	541.6	504
A4 100 gr	358.7	364	273.3	252.2	526.3	480	379	341
	351	315.5	253	249.5	508.4	499	364.8	373.7
A4 160 gr	202.1	231.3	163.2	187	421.5	376.1	231.8	207.5
	243.1	226.5	156.2	132.5	386	360	218	246

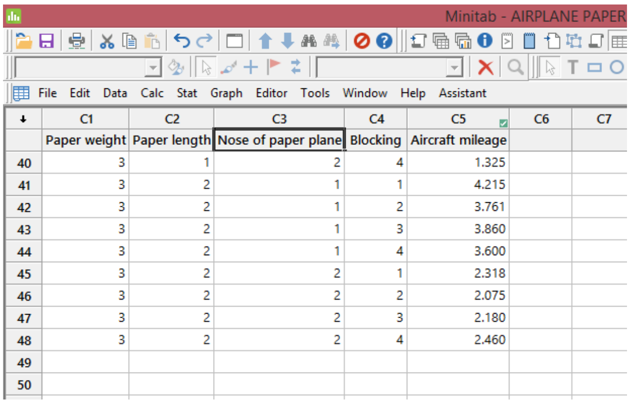
Methodology and Results

When all data have been collected, data analysis is conducted using Minitab 18 software. The data consist of three treatment factors (paper weight, paper length, and nose of the paper plane) and 1 blocking factor (operator). The details of each level factor treatment and blocking are listed in Table 2.

Table 2. Detail of each level factor

Factor		Level factor 1	2	3	4
Treatment	Paper weight (*a*)	A4 40 gr	A4 100 gr	A4 160 gr	
	Paper length (*b*)	Long	Short		
	Nose of paper plane (*c*)	Blunt	Sharp		
Blocking	Operator (*d*)	Operator 1	Operator 2	Operator 3	Operator 4

Paper weight (*a*) has three-level factors: A4 40 gr (1), A4 100 gr (2), and A4 160 gr (3). Paper length (*b*) has two-level factors: long (1) and short (2). The nose of the paper plane (*c*) has two-level factors: blunt (1) and sharp (2). The experiment was replicated with four different operators for blocking (Operators 1, 2, 3, and 4). The response is perpendicular aircraft mileage. Figure 3 shows a worksheet of the paper airplane experiment in Minitab 18.



↓	C1 Paper weight	C2 Paper length	C3 Nose of paper plane	C4 Blocking	C5 Aircraft mileage	C6	C7
40	3	1	2	4	1.325		
41	3	2	1	1	4.215		
42	3	2	1	2	3.761		
43	3	2	1	3	3.860		
44	3	2	1	4	3.600		
45	3	2	2	1	2.318		
46	3	2	2	2	2.075		
47	3	2	2	3	2.180		
48	3	2	2	4	2.460		
49							
50							

Figure 3. Paper airplane experiment worksheet in Minitab 18.

The data were analyzed with mixed-level factorial design with two-level factors and one three-level factors. Table 3 shows the ANOVA test results of the experiment in Minitab 18.

Table 3. ANOVA test results of paper plane experiment

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Paper weight	2	44.2056	22.1028	258.82	0.000
Paper length	1	23.1285	23.1285	270.83	0.000
Nose of paper plane	1	16.6219	16.6219	194.64	0.000
Blocking	3	0.1185	0.0395	0.46	0.710
Paper weight*Paper length	2	0.4850	0.2425	2.84	0.073
Paper weight*Nose of paper plane	2	0.0203	0.0102	0.12	0.888
Paper length*Nose of paper plane	1	0.7059	0.7059	8.27	0.007
Paper weight*Paper length*Nose of paper plane	2	0.5815	0.2908	3.40	0.045
Error	33	2.8182	0.0854		
Lack-of-Fit	32	2.4844	0.0776	0.23	0.954
Pure Error	1	0.3337	0.3337		
Total	47	86.6562			

From the ANOVA test results, we can see that the paper weight, paper length, and nose of the paper plane have a p-value of 0.000, which indicates a significant effect on the aircraft mileage. The paper length interaction F ratio has a p-value of 0.007, indicating interaction between the paper length and nose of the paper airplane. Furthermore, the paper weight interaction with the paper length and nose of paper airplane has a p-value of 0.0045, which indicates some interactions among these factors.

The paper weight has 2 degrees of freedom (DOFs) because $(a - 1) = 3 - 1 = 2$. The paper length and nose of the paper plane have 1 DOF because $(b - 1)/(c - 1) = 2 - 1 = 1$, while the blocking factor has 3 DOFs $(d - 1) = 4 - 1 = 3$. Total DOFs (N) are $(a \times b \times c \times d) - 1 = (3 \times 2 \times 2 \times 4) - 1 = 47$. The DOFs for error are the result of subtracting the total DOFs (N) on all factors and iterations, thereby resulting in 33 DOFs.

The next step is analysis of the residual from the experiment (residuals versus orders and fits) and normal probability plot residuals and histogram of residuals. Figures 4 and 5 show the graph residual versus order and fits.

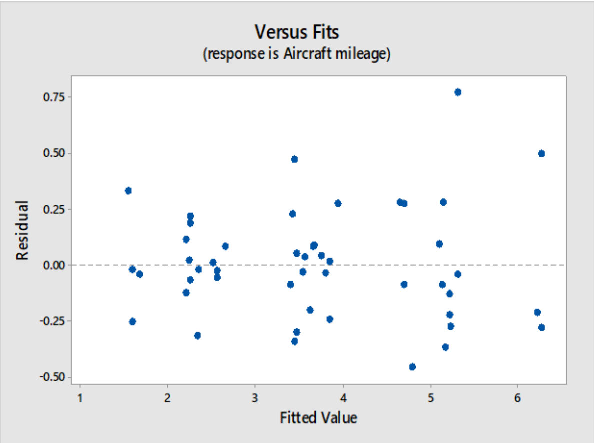


Figure 4. Graph residual versus fits

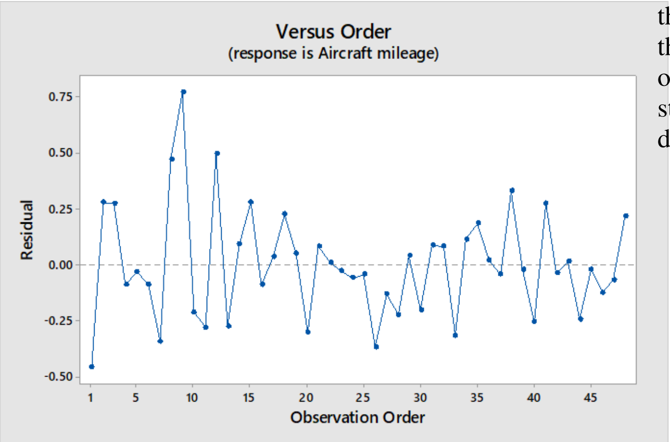


Figure 5. Graph residual versus order

Before the conclusions from the ANOVA are adopted, the adequacy of the underlying model should be checked. As before, the primary diagnostic tool is residual analysis. Figure 4 shows the residual value versus the fitted value $\widehat{y_{ijkl}} = \overline{y_{ijk.}}$, and Figure 5 shows the residual value versus the observation value y_{ijkl} for each observation.

A residual histogram for the response aircraft mileage is presented in Figure 6. The figure shows the frequency result of $e_{ijk} = y_{ijkl} - \overline{y_{ijk.}}$ for each observation plotted on the histogram. According to the figure, most of the observed values are the same as the fitted value.

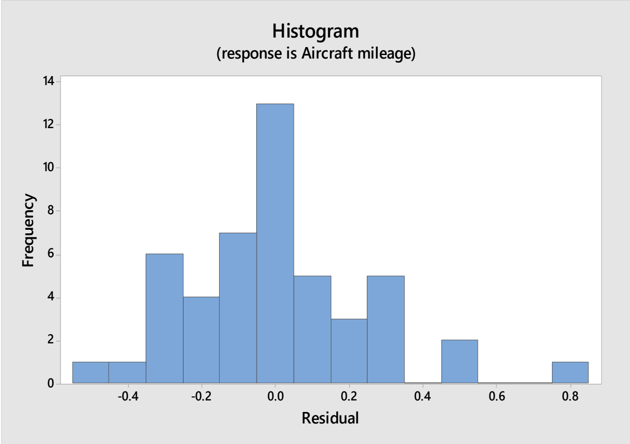


Figure 6. Residual histogram for aircraft mileage

The following histogram of residual suggests that the residual (and thus, the error terms) are not normally distributed or right skewed. The normal probability plot of the residual is approximately linear, which supports the condition that the error terms are not normally distributed. Figure 7 shows that the normal probability plot of the residual aircraft mileage from the data on the histogram. Figures 7 and 8 show three outliers (with a value more than 0.4). We assume that the outlier value cannot have a significant effect on the result. Although three outliers exist, the plot still shows almost no linearity. Thus, the normal distributed data assumption is not fulfilled.

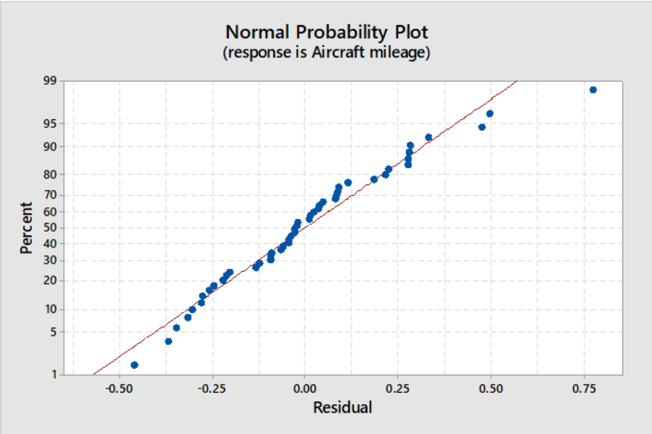


Figure 7. Normal probability plot of aircraft mileage

Conclusions

The objective of this study is to investigate the main factors that influence the paper airplane game. The results show that paper weight, paper length, and nose of the paper airplane significantly affect the aircraft mileage. And have interaction between paper length and nose of paper airplane. Otherwise, there is interaction between paper weight with paper length and nose of paper airplane. Future research aims to investigate the paper airplane game that uses three-factor design method with an additional qualitative factor such as throwing style.

Discussion

To ensure improved results in future research, we can add other important factors that influence the paper airplane game or modify and combine other experiment design methods, such as 2k factorial with response surface methodology or 3k factorial design with a quarter fractional factorial design, to determine the main influencing factors in the paper airplane game.

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