Design of Experiments
Lab 1: Helicopter Design

Joshua Amunrud, Andre Duarte, Nick Levitt

June 1, 2017

Introduction

In this assignment we set out to optimize the design of a paper helicopter, such that flight time is maximized. To do this, we designed a multi-factor experiment to determine how each cut and fold affects total flight time. Following the setup below, we came to the conclusion that having a larger wing length is beneficial, whereas a thinner body width was detrimental. Our final design is explained in the conclusion.

Experimental Design

Design Factors

For this experiment, we opted to limit ourselves to three design factors with two or three levels each:

- Wing Length (inches): 4, 5, 6
- Mid-Section Length[1] (inches): 1, 2
- Body Width (inches): 1, 2

Having the factors and levels set this way gives 12 conditions and therefore we have 12 different helicopters to build given our factorial approach. We limited ourselves to 12 for a few reasons, including environmental concerns for paper usage and also the time constraints of having to build every helicopter by hand. Ideally, we would have included more levels for each of these factors.

[1]The Helicopter Schematic specifies Wing Length and Body Length. Mid-Section Length is 11 (length of paper) less Wing and Body Length.

Nuisance Factors

We did not observe any nuisance factors within this experiment, and therefore did no blocking.

Allowed-to-Vary Factors

The dropping height and exact position were marked on a white-board and eyeballed by the dropper to his best extent. Some variability is expected there, but without any fancy apparatus, it was fixed to the best of our extent.

While folding the body of the helicopter, the flaps would not stay closed exactly the same way between each condition and even within a condition, since we decided not to use tape. This could also affect flight time because of air dynamics.

Experimentation

We tried to design our actual experimentation in such a way that is was both standardized and streamlined. To do this we distributed the building of each helicopter across all three group members: Andre did the measuring, Josh did the cutting and Nick did the folding. In this manner, we have minimized variation in the building of each helicopter. Similarly, we had Josh drop each helicopter from a fixed height, within a small room to minimize breezes and other external factors.

We decided to repeat every helicopter drop five times and take the average as our final result for each condition, under the assumption that a single drop may not always be representative of a helicopter's true performance. This allows us to decrease the variability of the drops.

Randomization was performed by not testing the helicopters sequentially as we built them. After all were created, we iteratively picked one at random to test. Since each helicopter and drop is independent, we don't know if this really affected our results in this experiment.

We did not perform any blocking in this experiment, although we could have included drop height as a factor to be blocked.

Results

Wing Length (in)	Mid Length (in)	Body Width (in)	t1 (s)	t2 (s)	t3 (s)	t4 (s)	t5 (s)	Avg(t) (s)
4	1	1	0.83	0.92	0.74	0.76	0.86	0.822
4	1	2	0.90	0.79	0.64	0.64	0.86	0.766
5	1	1	1.06	1.17	1.15	1.26	1.07	1.142
5	1	2	1.07	0.81	0.89	1.03	0.91	0.942
6	**1**	**1**	**1.59**	**1.60**	**1.70**	**1.64**	**1.47**	**1.600**
6	1	2	1.51	1.69	1.68	1.53	1.54	1.590
4	2	1	0.98	1.03	1.07	1.07	1.01	1.032
4	2	2	1.30	0.99	1.14	1.07	0.98	1.096
5	2	1	0.98	0.91	0.75	1.09	0.97	0.940
5	2	2	1.28	1.03	1.01	1.32	1.11	1.150
6	2	1	1.12	0.84	1.15	1.09	1.09	1.058
6	2	2	1.39	1.11	1.12	1.37	1.22	1.242

Analysis and Optimal Design

Out of the twelve distinct combinations of factors that we tested, a wing/mid/body length of 6/1/1 respectively performed the best. We found that a longer wing resulted in a longer flight time. This was especially true when combined with a shorter mid-length. The top two results both had a wing length of 6 inches (longest we tested) and a mid length of 1 inch (shortest of the two we tested). Interestingly, a body width of 1 inch performed better than a body width of 2 inches for all helicopters with a mid length of 1 inch. However, the reverse was true for helicopters with a longer mid length of 2 inches.

Optimal Design

The optimal design has a wing length of 6 inches, a mid-section length of 1 inch and a body width of 1 inch. In order to construct this helicopter you will need one (1) 8.5"x11" sheet of paper. Viewing the paper in portrait mode, make one six-inch cut from the top of the sheet dead-center (4.25 inches from each side). These two flaps will be your wings, fold one forward and the other one backward. 7 inches from the top make two 3.75 inch cuts from the sides of the sheet (one on the left and one on the right). The bottom-right and bottom-left sections should be folded on themselves into the middle. At the end, you will have a one-inch wide body that includes these pieces folded up into it. The folds may come apart from the body somewhat, but try to crease them as much as you can. To reproduce our results, the helicopter should be dropped from a height of a little under 6 feet with one hand on the end of each wing.

Conclusion

In this assignment, we implemented a (simple) factorial experimental design in order to investigate which factors contribute the most to the flight time of a paper helicopter. Per our analysis, we have determined that big wings and a wide body increase flight time (more surface of contact with air causes the fall to be slowed down). With this in mind, we decided to build one final helicopter with specifications that weren't in our original model: Wing Length = 8in, Mid Length = 1in, Body Width = 2in. After five repetitions in the same environment as all the others, this particular helicopter had an average flight time of 1.912s, which is indeed the highest observed out of all 13 total paper helicopters, which shows that our analysis was at least somewhat correct. Had we had more time (and a way to automate the helicopter building process), we would have liked to have more factors and levels to analyze and compare.