How to fly a paper airplane optimally

Kazutaka Aso, Yuki Kinoshita, Akitomo Kuraku, Harutaka Kosugi, Yohei Manabe
Hyogo Prefectural KOBE High School Science Course First Grade

1. Purpose

Airplanes that are made of cardboard fly far depending on the initial speed. However, we thought, airplanes that are made of *origami* could not fly far if its initial speed is too large because it would be deformed. Also, the ease of deformation changes depending on the launch angle too. So, we will make paper airplanes and research flight distance by changing the initial speeds and launch angles.

2. Hypothesis

There is an initial speed where the flight distance reaches its max, and if the initial speed exceeds this, the flight distance will not increase. Also, if the launch angle is set to 18°~30°, the flight distance will become longer. However, the optimal launch angle will become smaller depending on the initial speed .

3. Method

1. Paper airplane launch pad

To launch various initial speeds, we made two types of launch pads.

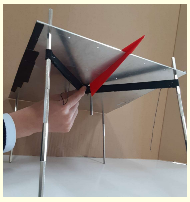

Fig. 3-1 Rubber style

■ Rubber style (Fig. 3-1)

We launched a paper airplane with the elastic force of rubber. So, as not to prevent the shape of the paper airplane from being deformed before launch, we used a rubber band with a width of 30 mm, and we adjusted the initial speed with the pull length of the rubber.

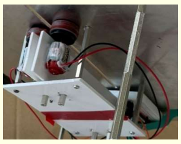

Fig. 3-2 Motor style

Materials

- Rubber band ring 514 mm (width: 30 mm)
- Aluminum board 300×300 mm (thickness: 2 mm)

■ Motor style (Fig. 3-2)

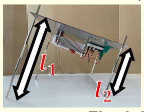

Fig. 3-3

Table 1 Launch angle

l_1(mm)	l_2(mm)	θ(°)
225	225	0.00
225	210	3.07
240	210	6.12
250	200	10.12
265	160	20.56
305	120	33.45
345	80	43.42
385	40	50.94
425	0	55.69

We put a paper airplane between two tires and launched it with rotational force. To increase the initial speed, we used a motor for a mini 4WD, because it has a very high rotation speed. We also used a single-board microcontroller "Arduino Micro" and MOSFET to adjust rotation speed. To control the launch angle (θ), we changed the lengths of the nuts put on before (l_1) and after (l_2) (Fig. 3-3, Table 1).

Materials

- Arduino Micro
- Nch Power MOSFET 60V 25A 2SK2232
- Semi-fixed resistor 10kΩ TSR-065-103-R
- TAMIYA Hyper-Dash 3 Motor
- Aluminum board 300×300 mm (thickness: 2 mm)

Fig. 3-4 Used paper airplane

2. Paper airplane

We made paper planes from square *origami* whose length and width are 176 mm (Fig. 3-4).

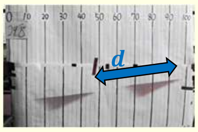

Fig. 3-5 movement of paper airplane

3. A way to launch and measure

● A way to measure initial speed

We placed a big paper showing the reference value next to the launch point and we take pictures from the opposite side with a high-speed camera at 60 fps. We calculated the initial speed and the launch angle from the difference in position between the two photos closest to the departure point (Fig. 3-5).

● A way to measure flight distance

Only when the paper airplane lands 45° forward, we measured between the launch point and land point.

4. Experiments, Results and Considerations

■ Experiment 1

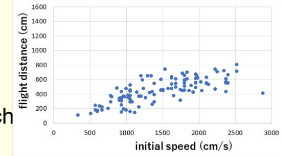

Fig. 4-1 Rubber style

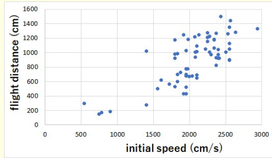

Fig. 4-2 Motor style

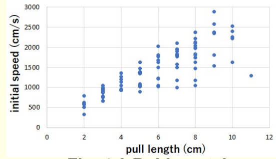

Fig. 4-3 Rubber style

Both the rubber style and motor style launch pads fixed at a horizontal angle launched the paper airplane. In fact, results are different from the hypothesis. As far as we searched, when the initial speed is larger, the distance is longer (Fig. 4-1, 4-2). So, we can't find the limit of the distance. However, about the rubber style, when the pull length became more than 9cm, its initial speed couldn't log (Fig. 4-3). And there were few paper airplanes whose initial speed was over 2500cm/s. And about the motor style, when rotation speeds became higher, there were also none. Both these different launching styles only logged 2500cm/s at maximum speed. That is why we assume the paper airplanes' maximum initial speed is 2500cm/s.

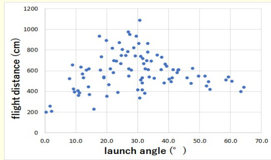

Fig. 4-4 1000~1500 cm/s

■ Experiment 2

In order to find the optimal launch angle, we fixed the initial speed from 1000~1500 cm/s and launched the paper airplane at various angles. The flight distance was increasing around 18°~30° , and beyond that, the flight distance became smaller (Fig. 4-4).

■ Experiment 3

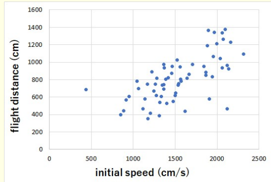

Fig. 4-5 18°~30°

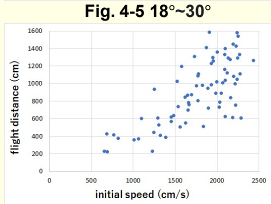

Fig. 4-6 10°~18°

We did an experiment with a different initial speeds at 18°~30° (Fig. 4-5), which is the optimum angle for the experiment 2, and we did it at 10°~18° which is a smaller angle (Fig. 4-6). Then, when the initial speed was 1000~1500 cm/s, 18°~30° flew farther, but when the initial speed was increased, 10°~18° flew farther. When the initial speed was 2500 cm/s which seems to be the maximum, 10°~18° flew farther, and the flight distance exceeded 14 meters. From the above, it can be said that if the initial speed is small, 18°~30° will fly more stably, but if the initial speed exceeds 2000 cm/s, 10°~18° will fly more stably.

5. Conclusion and Outlook

For the results above, the angle 18°~30°, and the initial speed of 2500 cm/s are the conditions needed to fly the longest distance. And we can think the initial speed has a limit, but the flight distance doesn't. But when human beings throw paper airplanes, other various factors are considered. We estimate the initial speed which is logged by a human as the equation below.

Initial speed = Speed impacted on paper airplane
× Efficiency of flying paper airplane.

However, the maximum speed impacted on paper airplanes is 2500 cm/s from Experiment 1. In other words, even if we launch the paper airplane at this speed, the initial speed will vary depending on the efficiency of flying. If the airplane is given 2500 cm/s and the efficiency is good, it can achieve 2500×1.5 = 3750 cm/s. So, no matter how fast a person launches a paper airplane, if the efficiency of the flight is low, we can predict that the paper airplane will not be able to fly farther or faster. We would like to research how much the way of flying the paper airplane has an affect on flight distance.