Analysis on the relation between the vertex angle of a tube airplane and its flying time

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Abstract. The tube is a type of airplane that is shaped as a hollow cylinder. In common sense, it seems impossible that an airplane has no wings, however, the tube airplane can fly even longer in the sky comparing with normal airplanes. In this paper, the practical experiment related to Bernoulli's theorem and Magnus Force will be introduced. In order to understand those equations more deeply with logic, a paper airplane model called "the tube" is going to be studied. The author makes the models with different shapes and angles so as to figure out the relationship between the angle of the index and the flying time of the airplane. Results show that the angle of the index has an impact on the time of the airplane staying in the sky, and the angle affects the angular and linear rotating speed of the airplane so that the time required for the airplanes varies.

Keywords: The tube airplane, Bernoulli's theorem, Magnus Force.

1. Introduction

The tube airplane is a kind of airplane which spins when flying and provides directional stability according to the spinning velocity. More importantly, it derives its lifts from the speed of spinning. This is because there is a special boundary effect on the vertices. The faster the tube airplane spins, the more likely it is to generate lifts with the surrounding air from interaction. As a result, the air is pushed in an opposite direction from the lifting direction. The center of gravity is in the middle of the airplane, which is not exist on the airplane but in the air. In this paper, the key concepts applied are Magnus Force and Bernoulli's equation. Magnus effect is achieved when the rotating cylinder drives the surrounding viscous air to rotate. It will form a boundary layer around itself, generating an induced velocity field. Moreover, if there is a free flow flowing on the cylinder, then, on the opposite side of the cylinder, the flow velocity will increase because the two velocity fields reinforce each other. According to the Bernoulli's theorem, a pressure difference will be formed between the two sides of the cylinder, then resulting a lateral force, which is perpendicular to both the direction of the incoming flow and the direction of rotation of the cylinder. And the method the author uses is to control the variables. More specifically, the vertex angle of the airplane will be changed and their flying time is going to be tested, so as to get the differences and conclude how the vertex angle can affect the tube plane's time-during in the air. This experiment is very beneficial for giving a better understanding of Magnus effect and Bernoulli's theorem. Moreover, since mechanical engineering requires many times of experiment and would experience obstacles frequently, this experiment is conducive to solving those issues and gaining related experiences.

2. Theoretical Background

2.1. The tube airplane

In 1864, Hermann Wagner wrote a book called *Every Little Boy's Book*, with detailed methods of folding a paper airplane [1]. In the late 19th century, more designers of airplanes tested their ideas with paper models to confirm their theories before testing the true one. However, the most significant period of airplane innovation was in 1899-1903, when Wright Brothers designed paper airplanes and tested them in their home-built wind tunnels, enabling them with a greater understanding of the forces exerted on the airplane during the flight [2]. Moreover, as the Wright Brothers observed how the forces were produced by bending the wings of their paper airplanes, they decided that the most efficient way of developing better airplanes is to use more refined ailerons and elevator control surfaces. Nowadays, people have been trying to design various kinds of airplanes with different shapes, colors, and functions. For instance, in the 21st century, John Collins designed various kinds of airplanes, including “the tube” airplane.

2.2. Bernoulli's theorem

Bernoulli’s theorem, in fluid dynamics, refers to the relationship among the pressure, velocity, and height of a moving fluid [3]. Its compressibility and viscosity, namely the internal friction of the fluid, are negligible, and it has a steady flow, or a laminar flow. The theory was conducted by a Swiss mathematician, Daniel Bernoulli, in 1738 [4]. He stated that the total mechanical energy of the flowing fluid contains the energy related to fluid pressure, gravitational potential energy at altitude, and the energy conservation in steady or streamlined flow of ideal fluids. It is the basis of many engineering applications [5]. The function of Bernoulli’s equation is $P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g h_2$. The variables P_1, v_1, and h_1 refer to the pressure, speed, and height of the fluid at the point 1, while the variables P_2, v_2, and h_2 refer to the pressure, speed, and height of the fluid at the point 2. Bernoulli’s equation fits for any 2 points in the fluid.

2.3. Magnus force

In 1853, a German physicist and chemist called H.G. Magnus first experimentally investigated the force that is responsible for the “curve” of a served tennis ball and football [6]. It is related to the Bernoulli’s theorem. When a rotating body is moving in a fluid, the pressure difference formed in the fluid due to the velocity changes caused by the rotating body causes it to deviate from its straight path. The Magnus effect is a particular manifestation of Bernoulli's theorem: as the velocity of a fluid increases, the pressure of the fluid decreases [7]. In the case of a spinning ball in the air, the spinning ball drags the air around it. From the position of the ball, the air roars in all directions. Resistance on one side of the ball (the direction of movement of the ball) will hinder the airflow, while on the other side of the ball, resistance will accelerate the airflow. The greater the pressure on the one side of the deceleration, the more likely the ball will be pushed toward an area of low pressure on the other side, where the airflow will increase relatively [8].

3. Methodology

3.1. Variables

There are two types of variables in this experiment. The first one is the independent variable, which is represented by the angle of the index on the airplane, and the other type of variable is the dependent variable, which is the flying time in this experiment.

3.2. Equipment

As shown in Figure 1, seven types of paper airplanes are used in this experiment to prove the relation between the index angle and the flying time. The 7 shapes are prepared as a triangle, square, pentagon, hexagon, heptagon, octagon, and circle. Except for the paper airplanes, the author also prepared a timer for keeping the time, a protractor for measuring the angle, and a wind source to make the airplane stay in the sky. In the experiment, the flying time is measured 3 times for one type respectively.

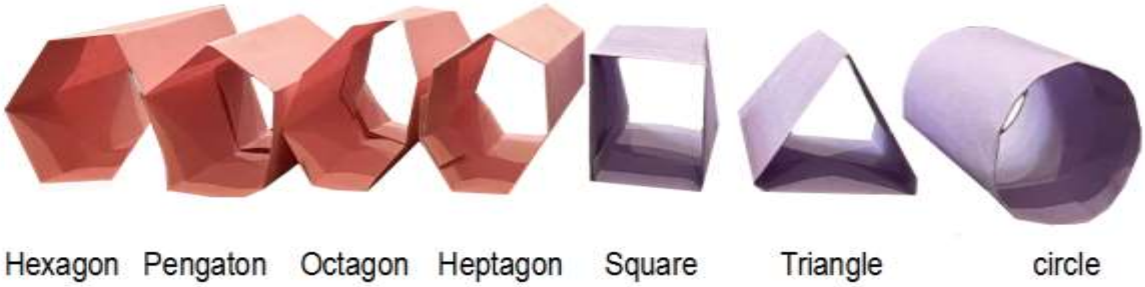

Figure 1. Seven types of paper airplanes used in the experiment.

3.3. Procedure

First off, put the wind source on the table to control the wind speed. Then measure the angles of different versions of airplane. Next, put the airplane in the wind source and measure the time it keeps in the sky and finally note the measurement and compare the time with different angle.

4. Result and Analysis

For the first set:

Vertex angle=$\frac{\text{sum of the interior angle}}{\text{number of angles}} = \frac{180°}{3} = 60°$

However, the manmade airplanes might consist of uncertainties, so the protractors are used to measure the angles, and the uncertainty of the angles are ± 1.

Average $\mathrm{T} = \sum_{i=1}^{5} \mathrm{T} = \frac{1.06+1+0.99+1.19+1.07}{10} = 1.06$ s

$\Delta\mathrm{T}_{\text{average}} = \frac{\text{Range}}{2} = \frac{\mathrm{T}_{\max} - \mathrm{T}_{\min}}{2} = \frac{1.19-0.99}{2} = \pm 0.1$ s

Because $0.05 < 0.1$, Therefore $\Delta\mathrm{T} = \pm 0.1$ s.

Therefore, the wind speed $\mathrm{T} \pm \Delta\mathrm{T} = (1.06 \pm 0.1)$ s.

Table 1. The raw data.

Set	Shape	Times	ΔTs	Set	Shape	Times	ΔTs
1	triangle	1.06	± 0.05	22	heptagon	1.59	± 0.05
2	triangle	1	± 0.05	23	heptagon	1.53	± 0.05
3	triangle	0.99	± 0.05	24	heptagon	1.58	± 0.05
4	triangle	1.19	± 0.05	25	heptagon	1.59	± 0.05
5	triangle	1.07	± 0.05	26	octagon	1.71	± 0.05
6	square	0.87	± 0.05	27	octagon	1.65	± 0.05
7	square	1	± 0.05	28	octagon	1.62	± 0.05
8	square	1.02	± 0.05	29	octagon	1.63	± 0.05

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Table 1. The raw data. (continued)

9	square	1.06	±0.05	30	octagon	1.65	±0.05
10	square	0.93	±0.05	31	circle	1.72	±0.05
11	pentagon	1.26	±0.05	32	circle	1.69	±0.05
12	pentagon	1.20	±0.05	33	circle	1.65	±0.05
13	Pentagon	1.33	±0.05	34	circle	1.78	±0.05
14	Pentagon	1.20	±0.05	35	circle	1.82	±0.05
15	pentagon	1.23	±0.05				
16	hexagon	1.46	±0.05				
17	hexagon	1.65	±0.05				
18	hexagon	1.4	±0.05				
19	hexagon	1.41	±0.05				
20	hexagon	1.51	±0.05				
21	heptagon	1.65	±0.05				

Table 2. The processed data.

Set	Shape	Vertex angle $\emptyset°$	$\Delta\emptyset°$	Times	ΔTs
1	triangle	60	±1	1.062	±0.1
2	square	90	±1	0.976	±0.1
3	pentagon	108	±1	1.244	±0.07
4	hexagon	120	±1	1.486	±0.13
5	heptagon	128.57	±1	1.588	±0.06
6	octagon	135	±1	1.652	±0.05
7	circle	180	±1	1.732	±0.09

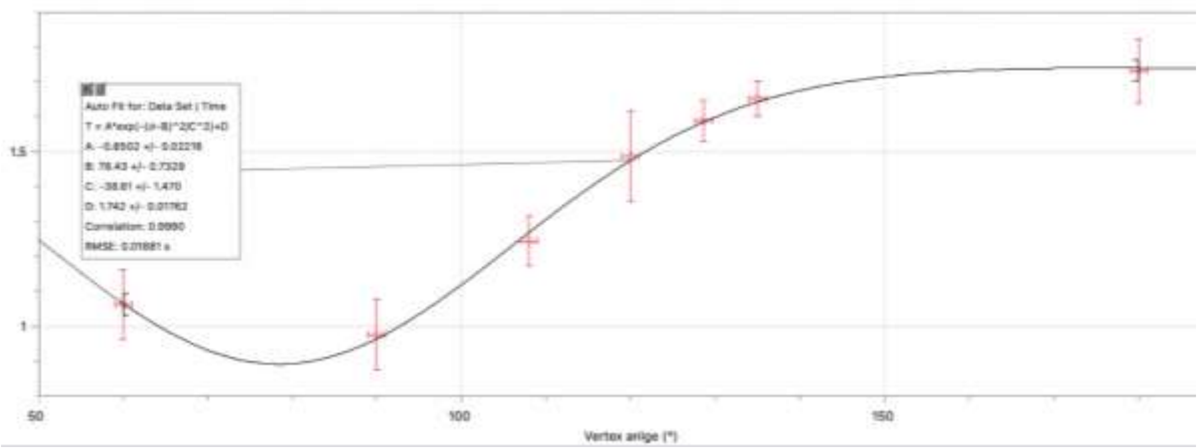

Figure 2. The relation between time and angle.

According to Figure 2, the shape of the graph fits with the Gaussian function, so it can be deduced that this situation can be explained by the Gaussian equation. In conclusion, the angle of the index affects the time that the airplane staying in the sky.

In the equation $F = \mu \times \omega \times v \times r^3 \times \rho$, F equals to the Magnus Force, μ refers to the coefficient of the tube, ω is the angular speed, v is the linear speed, and ρ represents the density of the fluid. Based on the data collected, the value of Magnus Force is affected by the angle of the index, and then affects the time the airplane stays in the sky. In this situation, when the angle is changed, the coefficient is stable first, the radius of the tube stays the same, and the density of the fluid is constant, however, the angular speed is varied and the linear speed is affected. Thus, a conclusion can be drawn that the angle affects the angular and linear rotating speed of the airplane, so the time required for the airplanes varies [9]. Folding the polygons does reveal a trend for the relationship, however, the sampling is still below expectations. There is a problem that folding is not a good way for some specific angles, especially for the polygons with less sides. Less sides represent a larger gap in angles between two near polygons, such as triangle and square. Although they have only 1 side difference, 30 degrees of angle difference exists. As seen in Figure 2, there is a minimum for the best fit between a triangle and a square. The situation cannot actually be mimicked with an airplane because there is no such angle that fits the index of an equilateral polygon.

5. Conclusion

Through this experiment, the hypothesis that the angle of the index affects the flying time of the airplane has been proved. In addition, when the angle is between 60 and 90 degrees, the flying time reaches minimum, and when the angle is reaching 180 degrees, in most cases, the time period is approaching maximum. However, the reasons why the time keeps minimum between 60 and 90 degrees, why it has obeyed the trend in majority, and why the slope cannot be linear are still needed to be figured out. In addition, when conducting the experiment, there were some unexpected problems. For instance, the paper airplane was too heavy to launch stably, so the material for folding the airplane was changed to lighter paper. Also, when exerting force on the airplane, the position was not the same during various times of experiments, so there is a need to put it on the same place and face it for the same direction to control the variables.

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