Experimental Study and Analysis of Aerodynamic Characteristics of Gliders with Different Wing Geometries

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Abstract. At present, airplanes are widely used in people's daily lives, and research on this means of transportation is of great importance. Currently, academic research still lacks the influence of different aircraft wing shapes and areas on aircraft flight conditions. This article analyzes the basic principles of glider flight and explores the aerodynamic principles of gliders through paper plane simulation. Firstly, this paper introduces the development history of gliders. Secondly, the mechanical analysis of the aircraft is carried out. The factors that affect the flight performance of the aircraft are analyzed by paper airplane simulation experiments. The experimental results are analyzed, and the future development direction is forecasted. From the final research results, there is a close relationship between the aspect ratio and the glide angle of the plane. In the experiment, lower induced drag allows the aircraft to move further horizontally while descending resulting in a smaller glide angle. This study reveals the relationship between aspect ratio and glide angle, which provides intellectual support for the development of the aircraft manufacturing industry.

Keywords: Glider, Mechanical analysis, Aspect ratio, Wing are.

1. Introduction

An aircraft wing is the main part of an aircraft used to generate lift. It generally has two left and right wings arranged symmetrically on the aircraft. In actual flight, some parts of the plane's wings can be moved. By changing these parts, the pilot controls the distribution of wing lift or drag to achieve the purpose of changing the attitude of the aircraft. Currently, the main forms of aircraft wings are divided into five categories: Liang wing, single wing, compound wing, sandwich wing, and integral wing [1].

Human beings have long dreamed of flying in the air like a bird. Da Vinci, the great artist and inventor of the 15th century, designed an ornithopter in which a person lies on his stomach and flies with wings driven by his hands and feet. Similar attempts were made by the ancient Chinese, Greeks, Babylonians, and Indians. But man did not have the muscles and bones of a bird, so their ideal could not be realized [2].

It was not until 1801 that Sir George Kelly of England studied the flight principles of birds and kites [3]. He tried out a glider in 1809. He wrote that the glider kept picking him up and carrying him a few meters away. In 1847, at the age of 76, Kelly built a large glider that twice lifted a 10-year-old boy into the sky. Four years later, a manned glider successfully flew for the first time without the towing device. Kelly conducted scientific research and experiments on the principles of flight, the Angle of airlift and wings, the shape of the fuselage, rudder, elevator, landing gear, etc., and he was the first to elevate flight from an adventure to a scientific exploration.

Otto Lilienthal was a German engineer and glider, and one of the world's aviation pioneers [3]. He was the first to design and manufacture practical gliders and is known as the "father of gliders". In 1914, the German Haas developed the first modern glider, which could not only glide horizontally, but also climb high with the help of rising heating, and its handling performance was more perfect. Since then, gliders have entered the practical stage. In July 2022, American scientists put forward a new idea - a high-altitude glider that can fly continuously for a day or even longer on Mars [4].

2. Background

2.1. Mechanical Analysis of Gliders

A glider is an aircraft that does not use thrust. A glider flying in equilibrium sinks slowly toward the ground at a glide angle determined by the balance between the vehicle's mass, gravity, and the lift and drag the glider experiences.

Consider the free-fall diagram shown below. The glider descended at an Angle of θ. Drag acts in the direction of motion, while lift acts perpendicular to the direction of motion of the glider. The weight of the glider acts vertically. Figure 1 is a mechanical analysis diagram of the glider [5-6].

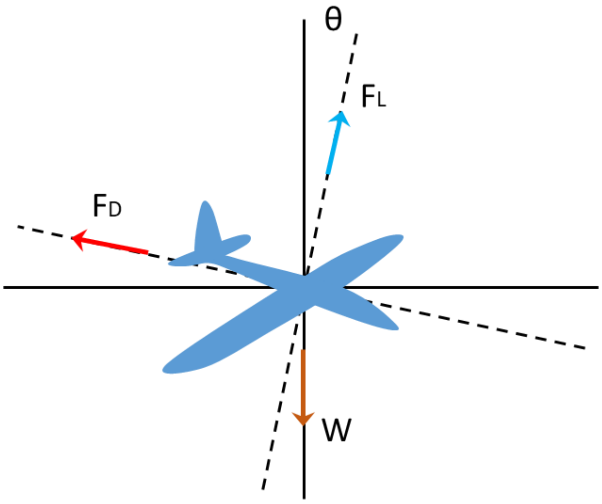

Figure 1. Mechanical analysis diagram of the glider.

(Where W is gravity, θ is Angle of descent, F_D is drag force, and F_L is lift force)

FD and FL are projected horizontally and vertically:

Vertical:

$$F_L \cos\theta + F_D \sin\theta - W = 0 \tag{1}$$

Horizontal:

$$F_L \sin\theta - F_D \cos\theta = 0 \tag{2}$$

From the horizontal equation,

$$\frac{FL}{FD} = \frac{CL}{CD} = \frac{1}{tan\theta} \tag{3}$$

Therefore, if the experimenter measures θ, the ratio CL/CD can be inferred. In the laboratory, the experimenter can experimentally measure the Angle θ of the paper airplane [5].

If the weight W is known, the drag and lift forces can be determined (using the vertical equation above):

$$F_D = \frac{W tan\,\theta}{cos\theta + sin\theta tan\theta} \tag{4}$$

$$F_L = \frac{W}{cos\theta + sin\theta tan\theta} \tag{5}$$

The values of FD and FL depend on many factors, including the shape and size of the wing (Figure 2 shows the shape and size of the wing). The area of the wing consists of

$$S = b \times c \tag{6}$$

Where b is the wing length, and c is the string length. Wing aspect ratio by

$$\mathrm{AR} = \frac{b}{c} = \frac{b * b}{s} \tag{7}$$

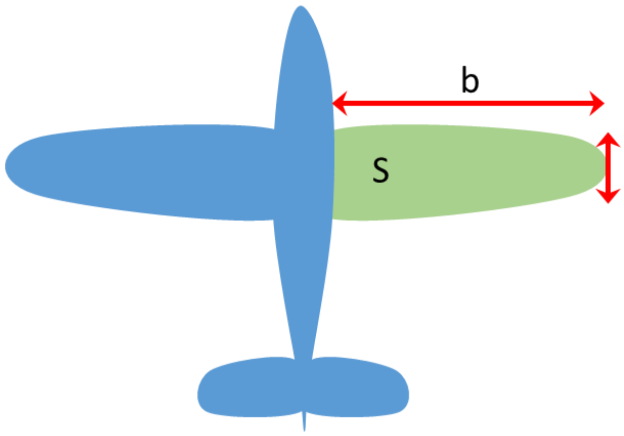

Figure 2. The shape and size of the wing.
(Where b is the wing length, c is the wing width, and s is the wing area)

3. Explanation of research methods and processes

3.1. Materials

Homemade paper airplanes were used in this experiment. At the same time, a camera was used to record the experiment. A balance is also used to weight the plane. At last, the tracker software was used to analyse experimental data.

3.2. Procedure

First, the experiment required a test area free of strong winds. Then, assemble a paper plane or wooden glider. Then weigh the plane. Practice gently launching the model so that the experimenter's hand is at the same speed as the ground - launching at near zero incidence reduces the impact of the model on the experiment.

The position of the wing and tail should be adjusted in the experiment to make the glider fly smoothly. Launch the model and record the initial flight with the camera. Make sure there is a good contrast between the plane and the background. Repeat this five times so the experimenter can get a good average. Every attempt to launch the model at the same speed, the same altitude, and the same launch Angle. Now, change the wing's platform and its aspect ratio by trimming it with scissors. It can change the span by cutting off the tip, reducing the chord, or both. Measure the new span chord and calculate the new aspect ratio. (See above). Try to make major changes, but the model should still function properly. Weigh the modified glider. Repeat the previous experiment and make five more test flights to measure the glide Angle. There are other modifications you can make, and more experiments you can do. Calculate CL/CD and discuss [7-8].

3.3. Recording

In this experiment, the experimenter used paper to make a paper airplane and each paper plane ran out of just one piece of paper to control the consistency of the quality variables. The experiment set four experimental groups. There were tests 1.1, 1.2, 2.1, and 2.2. The first experimental group was taken as the standard group, and all aircraft were made as a piece of paper folded to control the equal mass and the wings perpendicular. The appearance and the wing‘s parameters are shown in Figures

3 and 4. In this test 1.1, the wing's area is 8800 mm^2 and the weight is 1.6 g. In test 1.2, holds the same folding method, but the paper side length is reduced by one-third and the total area is reduced by the fifth ninth compared with test 1.1. its weight is 1.6 g and the wing's area is 3911 mm^2.

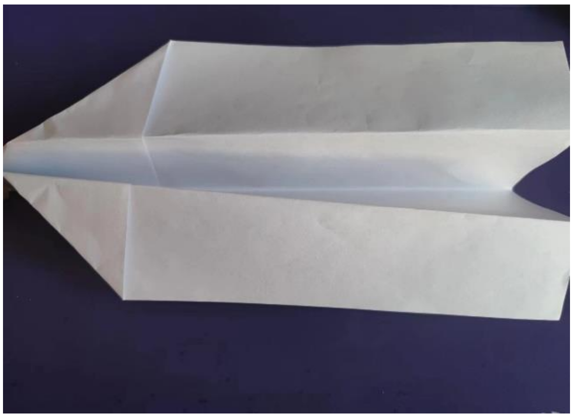

Figure 3. The appearance and the wings parameters in test 1.1

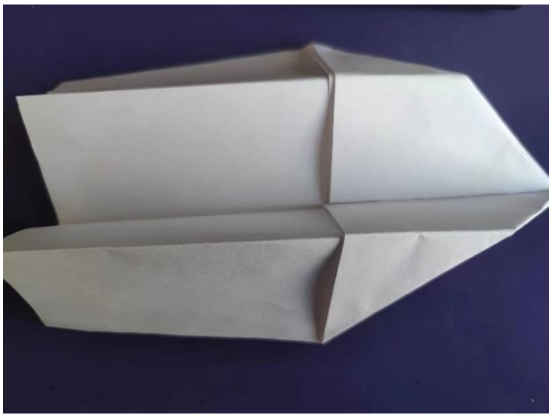

Figure 4. The appearance and the wings parameters in test 1.2

To test the influence of different shapes and wing width on the experimental result, the second fold and third-fold methods are used (Figures 5 and 6). The wings area in test 2.1 is 8800 mm^2 and in test 2.2 is 8600 mm^2. Their weight is 1.6g. The experiment was conducted in a room with no wind and a temperature of 24 degrees. The shooting device was an iPhone 12 Pro. The experiment was conducted on a white background, so it does not affect the tracking. The camera was located at the back of the flight path to record the stable gliding state. The period is 1/3 second. In the experiment, the experimenters did the following. Firstly, no collision in the video. Secondly, the flight track is stable, with no sudden rise and fall. Thirdly, the flight track is perpendicular to the video axis. The experiment uses the software tracker to track the aircraft's flight path. And selecting the first point of the aircraft appearing on the screen as the coordinate origin. The frame by frame. Analysis was carried out within one-third second. Four different aircraft gliding track and point data are obtained.

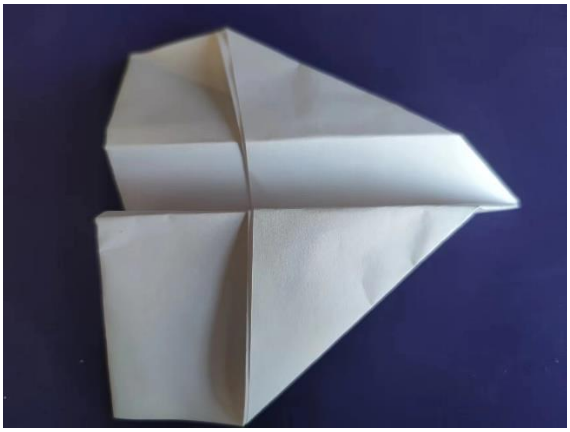

Figure 5. The appearance and the wings parameters in test 2.1

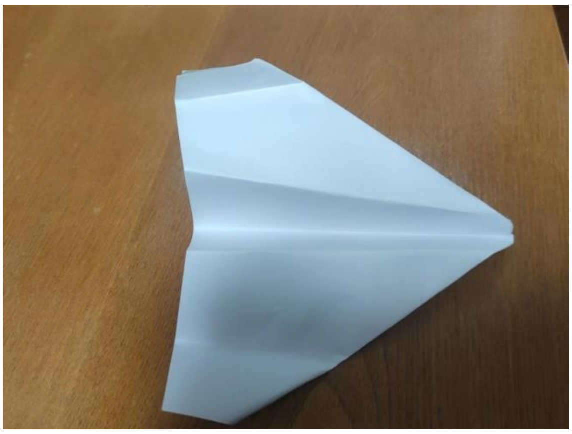

Figure 6. The appearance and the wings parameters in test 2.2

This experiment focuses on the relationship between glide angle and aspect ratio. The glide angle and aspect ratio are shown in Table 1. These results demonstrate that different aspect ratios can respond to different glide angles because it reduces induced drag which is generated by the production of lift. And that means, lower induced drag allows the aircraft to move further horizontally while descending resulting in a smaller glide angle. Conversely, a lower aspect ratio has a generous, more induced drag, leading to a large glide angle. However, in test 2.2, the aspect ratio is also small, but its glide angle is also small, the experiments of other groups in this experiment are different. Therefore, it can be found that the glide angle is also related to the shape of the aircraft.

In this analysis, particular emphasis has been placed on the aircraft's aspect ratio and drag and lift forces. Aspect ratio is a critical parameter in aircraft design, representing the ratio of the wingspan to the average chord length and directly influencing the aerodynamic performance of the aircraft. Through an in-depth exploration of aircraft simulations under various aspect ratios, the experimenter can unveil the impact of this parameter on the lift and drag forces, providing robust support for the optimization of aircraft design. The lift-to-drag ratio, a fundamental measure of an aircraft's efficiency in generating lift while minimizing drag, takes center stage in this exploration. By delving into the forces at play and dissecting their contributing components, this experiment attains a deeper understanding of the delicate balance required for optimal flight performance.

Aspect ratio, defined as the wingspan-to-wing area ratio of an aircraft, emerges as a crucial descriptor of wing slenderness. A higher aspect ratio signifies a slender wing, while a lower aspect ratio implies a shorter and wider wing [9-12].

Table 1. The experimental results

Test 1.1	Test 1.2	Test 2.1	Test 2.2
y=-0.3149x+9.7403	y=-0.4467x+30.5036	y=-0.2854x+101.4143	y=-0.1803x-2.3533
$\theta1 = -17.48°$	$\theta2$ =-24.07°	Θ3=-15.93°	Θ4=-10.22°
S1=8800mm^2	S2=3911mm^2	S3=8800mm^2	S4=8600mm^2
B_1=71.36mm	B_2=47.5mm	B_3=90.00mm	B_4=61.36mm
AR_1=0.5787	AR_2=0.5769	AR_3=0.9205	AR_4=0.4378

4. Conclusion

Based on the experimental method and the control variable method, this paper studies the relationship between the change of aircraft wing and glide angle. In conclusion, this selection of specific settings for this study has been strategic and aimed at unveiling the underlying principles that govern plane launching models. Through a process of rigorous experimentation and thorough analysis, the study aspires to contribute valuable insights to the field of aeronautics, ultimately advancing our understanding of the intricate interplay between design parameters and the resulting performance outcomes.

Furthermore, this investigation prompts a fundamental question: what is the relationship between lift and drag? Wings with a high aspect ratio typically yield greater lift and exhibit lower drag under identical lift conditions. This phenomenon arises from reduced induced drag, thereby enhancing efficiency during cruise flight. The exploration of such relationships adds a layer of complexity to the researcher's understanding of aircraft design and performance in various flight scenarios.

In real-world design scenarios, designers face the crucial task of meticulously selecting the aspect ratio. Wings with high aspect ratios prove to be ideal for applications involving extended cruising, such as those seen in commercial aircraft, where enhanced fuel efficiency is a key consideration. Conversely, low aspect ratio wings are better suited for missions that demand heightened maneuverability, as observed in fighter aircraft. This thoughtful consideration of aspect ratios plays a pivotal role in tailoring aircraft designs to specific operational requirements.

At present, this study is only a basic experiment. In the future, the experimenters will use more sophisticated aircraft simulation equipment to further explore the impact of different wing shapes on aircraft flight conditions and put forward relevant suggestions for actual aviation industry production.

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