Research on Aerodynamic Characteristics of Gliders with Different Wing Shapes

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Abstract. In this research, the effects of different wing shapes on the lift-to-drag ratio and aerodynamic characteristics of gliders were analyzed. Traditional research has many limitations, such as experimental conditions - air flow speed and airflow stability, which may affect the stability of research results. Therefore, in this research, repeated experiments were used to eliminate chance, and numerical simulation was combined with computer simulation of the lift-to-drag ratio of gliders under different aspect ratios to verify the experimental results. The results show that with the increase in aspect ratio, the lift-drag ratio of the glider increases. A glider that has a greater wing aspect ratio can generate more lift force at the same given speed, reducing the descent speed and extending the glide distance, showing better aerodynamic characteristics. By studying the aspect ratio, the optimal wing shape and size for a specific aircraft can be determined to improve the lift and drag characteristics of the glider. This research has important guiding significance for glider design, which can improve the performance and efficiency of gliders.

Keywords: Wing shape, Aspect ratio, Lift-to-drag ratio, Aerodynamic characteristics.

1. Introduction

A glider is an unpowered aircraft that relies on air currents and gravity for flight. Its design and performance directly affect the flight characteristics and flight performance of gliders. As an important part of the glider, the wing has an important effect on the movement characteristics of the glider. Therefore, it is of great significance to study the relationship between glider motion characteristics and wings for glider design and performance improvement. Aspect ratio and lift-drag ratio are two important parameters in glider design, that directly affect the lift and drag performance of a glider.

With the different aspect ratios, the lift-drag ratio is also different [1]. The research results show that with the increase in aspect ratio, the lift coefficient of the glider increases. This indicates that the aspect ratio has a significant effect on the lift and drag performance of the glider. Meanwhile, the lift-drag ratio of a glider has a significant effect on its gliding performance [2], A higher lift-drag ratio can significantly improve a glider's gliding distance and gliding time. According to some related research [3], Studies of low aspect ratio wings at Reynolds numbers relevant to vertebrate flight have shown that up to aspect ratios of ∼2, aerodynamic performance declines with increasing aspect ratio, But, at higher aspect ratios, aerodynamic performance increases with increasing aspect ratio [4]. Appropriate aspect ratio and lift-drag ratio can not only improve the aerodynamic stability of gliders and reduce the shaking and shock during flight but also improve the aerodynamic efficiency of gliders and reduce energy loss [5].

However, in the design of glider wings, there are many problems with the choice of aspect ratio and lift-drag ratio. Aspect ratio refers to the ratio of the length of a glider's wingspan to the length of its wing chord. A larger aspect ratio improves the lift coefficient and lift drag ratio of the glider, but also increases the wing area and structural weight. Therefore, lift performance and structural weight need to be weighed when choosing the aspect ratio. Lift-drag ratio refers to the ratio of a glider's lift coefficient to its drag coefficient. A higher lift-drag ratio increases the glider's glide distance and glide time, but it also reduces the glider's maximum speed and climb rate. Therefore, the flight mission and performance requirements of the glider need to be considered when optimizing the lift-drag ratio. To

sum up, the wing design of the glider needs to consider the two indexes comprehensively to achieve a more balanced and efficient design structure. The aspect ratio and lift-drag ratio of the glider interact with many parameters, such as the shape of the airfoil and wing cross-section and the elastic deformation of the wing. Therefore, when studying the aerodynamic characteristics of the aspect ratio and lift-to-drag ratio of the glider, it is necessary to consider the influence of multiple parameters. To solve the problem of multi-parameter interaction, a quantitative analysis method was adopted in this study, only changing the shape of the wing of the glider to change its aspect ratio and keep other parameters relatively consistent, to analyze the impact of aspect ratio on lift drag ratio, explore the specific relationship between the two, and analyze the flight performance of the glider under different aspect ratio and lift-drag ratio from its gliding track. Moreover, the innovation of this study on the relationship between the lift-drag ratio and aspect ratio of gliders lies in exploring a more reasonable and optimized design scheme to meet the needs of different flight missions.

2. Methodology

2.1. Overview of Gliders and Their Wing

The glider is a type of craft without an engine that relies on aerodynamic principles and gravity to fly [6]. A glider's geometry determines its hydrodynamic characteristics, having critical effects on glider dynamics, which in turn affects the performance and stability of glider motion [7]. The principle of how an airplane generates lift is that when the airflow blows through the airfoil at a certain angle of attack, the pressure difference is generated due to the airflow speed difference between the upper and lower airfoil. Usually, the airflow speed on the upper airfoil is faster and the pressure is smaller than that on the lower airfoil, thus lifting the wing upward and generating lift. So wing is an essential part of the glider, it assumes the function of generating lift force and controlling flight. In short, the wing of the glider is the key component of gliding flight, its airfoil, shape, and aspect ratio have an important impact on the performance of the glider. Through reasonable design and optimization of wing parameters, the lift and drag performance of the glider can be improved, so that it can achieve longer glide distance and better maneuverability.

The force analysis of the gliding state of the glider is shown in Figure 1. The glider flights at a glide angle θ. What matters in the direction of motion is the drag force, and the lift force is perpendicular to the direction of motion. The weight acts in the vertical direction.

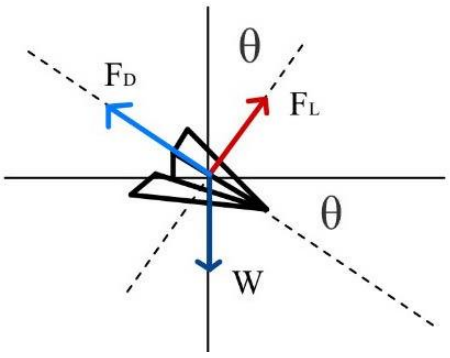


Figure 1. Free-body diagram.

Calculating F_D and F_L by free-body diagram:
Vertical:

$$F_L\cos\theta+F_D\sin\theta-W=0 \quad (1)$$

Horizontal:

$$F_L\sin\theta-F_D\cos\theta=0 \quad (2)$$

$$\frac{F_L}{F_D} = \frac{C_L}{C_D} = \frac{1}{\tan\theta} \tag{3}$$

Where F_L refers to lift force, F_D refers to drag force, W refers to the weight of the glider, θ refers to the glide angle, C_L refers to lift ratio, C_D refers to drag ratio.

Thus, from the horizontal equation, the equation above, through measuring θ, the lift and drag ratio can be inferred.

Therefore, according to the equation above, through measuring θ, the lift and drag ratio can be inferred.

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

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

As shown in Figure 2, the aspect ratio can be calculated.

$$AR = \frac{b}{C} = \frac{b^2}{s} \tag{6}$$

(Where AR refers to the aspect ratio, b refers to the length of the wing and c refers to the width of the wing, s refers to the area of the wing)

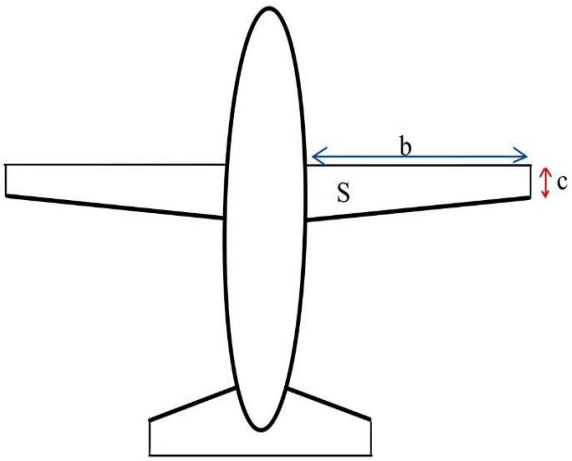


Figure 2. Glider model picture

2.2. Materials and Procedure

The materials used in the research included a paper glider, a mobile phone, a balance to weigh the plane, and Tracker software. Next is the specific choice of materials. Each paper glider is made from A4 paper of 623.7 square centimeters, 297mm long and 210mm wide, with no additional materials. The weight of each paper is 4.3659g. Then is the recording device, iPad Pro 2021 with a recording frame rate of 60fps.

(1) The research needs an environment without interference, the choice is the basement of the house, with almost no outside airflow.

(2) Assemble the paper glider.

(3) Weight of the glider (as the A4 paper is too light, the weight of the glider is calculated from the A4 paper area used to make it.

(4) Throw the glider smoothly from hand, and try to make sure it flies parallel to the ground with a consistent speed.

(5) Launch the glider and record its movement, while making sure there is a good contrast between the glider and the experimental background.

(6) Repeat this 5 times to get a good average. Try to make sure each time the glider is launched with the same speed, at the same height, and with the same launch angle.

(7) Change the shape of the wing by cutting. Measure the length and width of the new wing and then calculate the new aspect ratio. And record the weight of the new glider.

(8) Repeat the previous experiments another 5 times and measure the glide angle.

(9) Calculate lift-drag ratio.

2.3. Tracker software and computational method

Tracker software is a software used to deal with the video recorded during the research and import the captured video into the software a lot of information is available, and the position of different time nodes can be represented on a coordinate axis. Then use the digital information obtained and make numeric calculations through Excel and get the function graph according to the value.

3. Results and Discussion

3.1. Data Recording and Processing

First and foremost, select a lot of time nodes of the video record the position of the glider, and make sure the time interval is the same. Then several coordinates can be obtained from the ratio of the size of the glider to the distance of the position of the glider at different time nodes in the video. As the average x, and y coordinate values are known, A new track of gliding can be obtained through fitting, next using the distance difference in the X-axis and Y-axis direction, the tangent value can be calculated. Then through the function ATAN in Excel, the glide angle can be obtained. As the tangent value is known, the drag and lift ratio can also be obtained from the horizontal equation. Using the function AVEDEV and STDEVP in Excel the mean and standard deviation of the glide angle in each case can be calculated. Then use the function AVERAGE to get the mean glide angle of each case. To have a better understanding of the relationship between the glide angle and wing aspect ratio, drawing a graph of function is needed.

3.2. Aerodynamic Characteristics of Gliders under Different Aspect Ratios

Based on flight data, an outcome can be summarized, as time goes by in the process of gliding, the glide angle maintains an increasing trend, and according to the relationship between lift and drag ratio and glide angle, the lift and drag ratio maintains a decreasing trend. Meanwhile, after calculation, it can also be concluded that the drag force is increasing gradually, and the lift force is decreasing. To have a better understanding of the aerodynamic characteristics of gliders with different wing shapes, the research makes a study on the influence of wing aspect ratio on mean glide angle. As shown in Figure 3, the glide mean angle decreases from -24° to -29°, and then to -33° when the lift-drag ratio increases from 1.4 to 1.89, and then to 2.01. It can be concluded the higher the aspect ratio, the smaller the glide angle θ.

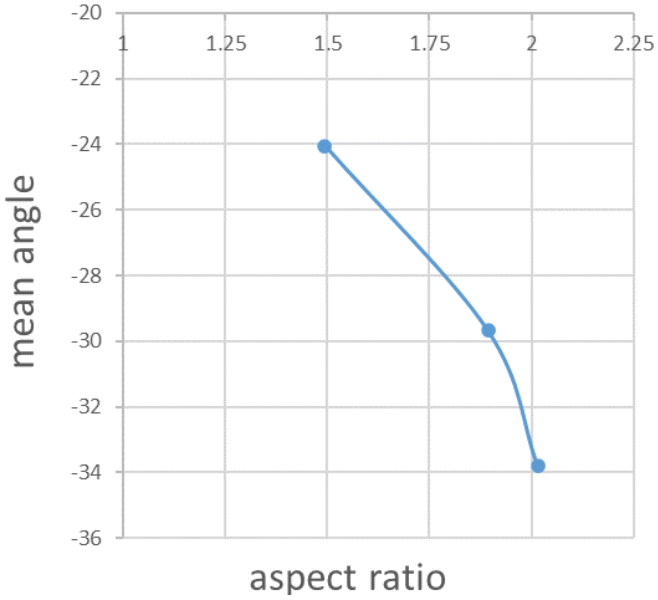


Figure 3. Glide angle function.

3.3. Discussion

The aerodynamic characteristics of the wing become better with the increase of aspect ratio [8]. Aspect ratio and lift-drag ratio are two important parameters in aircraft design and there is a certain relationship between them. Aspect ratio refers to the ratio of the wingspan of the glider to the wing chord, expressed by AR. The larger the aspect ratio, the higher the ratio of the wingspan to the wing chord, and the more elongated the wing surface. The lift-drag ratio refers to the ratio of drag to lift produced by the glider while generating lift. Lift refers to the vertical upward force generated by the glider in flight and drag refers to the force that obstructs the glider in flight. The higher the lift-drag ratio, the smaller the resistance the glider receives when generating unit lift, and the higher the flight efficiency. There is a certain relationship between the aspect ratio and the lift-drag ratio. In general, the greater the lift-drag ratio of the vehicle. This is because the airfoil of an aircraft with a larger aspect ratio is relatively slender, which can reduce turbulence loss and boundary layer drag on the airfoil, thereby improving the lift-drag ratio. In addition, the airfoil of an aircraft with a relatively large chord can also reduce the generation of wingtip vortices, further reducing the drag. According to the values in the research, this consequence can also be inferred. Figure 4 shows that the higher the aspect ratio, the smaller the glide angle, and it also means the greater the Lift-drag ratio, and vice versa. Meanwhile, as the consequence said before, at the same time node the glider that has the larger wing aspect ratio owns the smaller drag force. Under the influence of these factors, logically speaking the glider that owns the larger wing aspect ratio should achieve a better flight performance.

According to the experimental data, when the aspect ratio increases from 1.49 to 1.89, the gliding distance increases by nearly 45cm in the same time interval (about 0.5s). When the aspect ratio increases from 1.89 to 2.0, the gliding distance changes less, but it still increases a lot compared with 1.49. The mean glide angle decreased from -24 degrees to -29 degrees and then to -33 degrees, and it can be concluded from Figure 4, that the track of the three kinds of gliders with different aspect ratios shows that the higher the aspect ratio the track gliding more smoothly. Meanwhile, as the aspect ratio increases, so does the gliding distance.

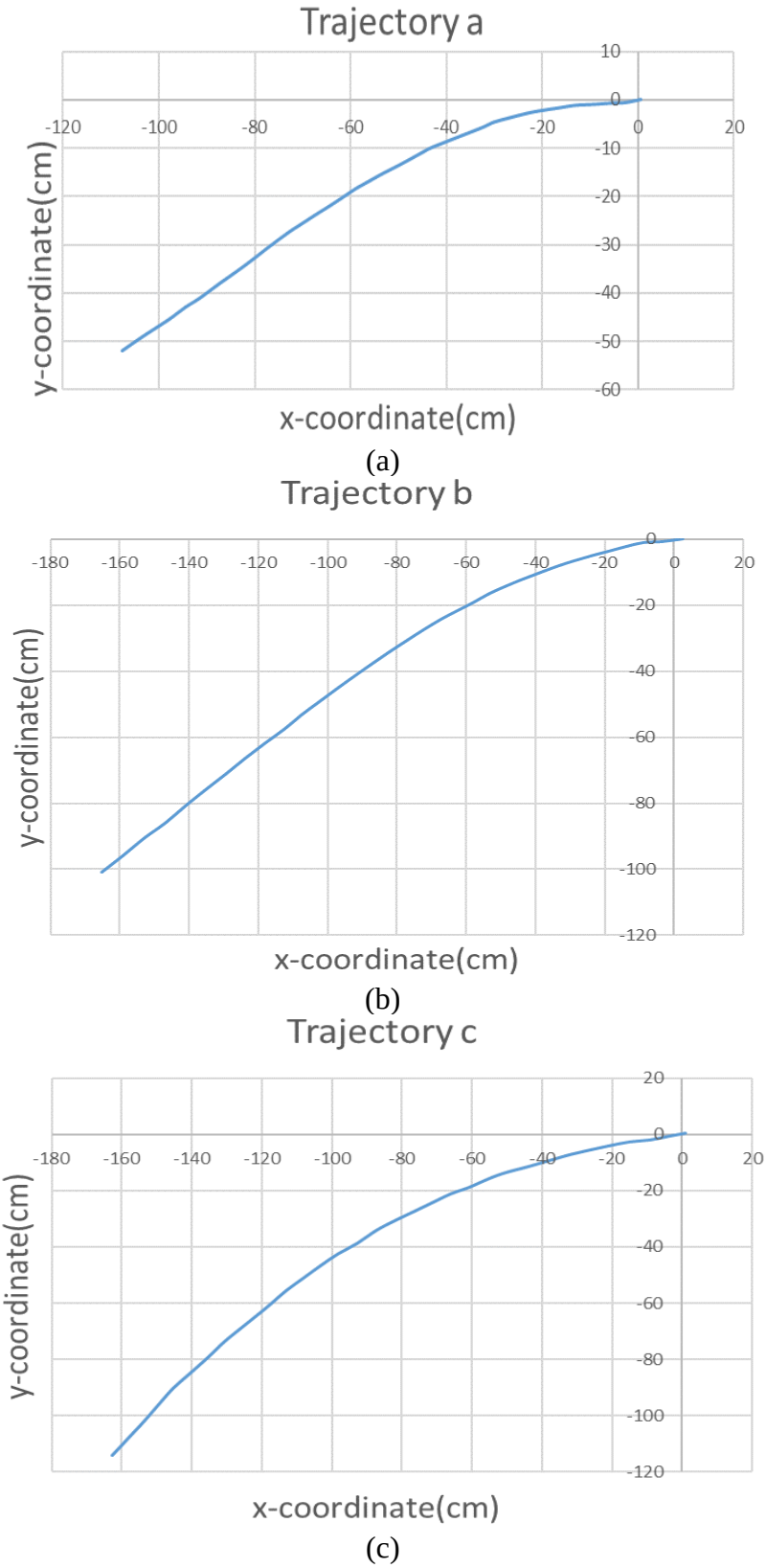


Figure 4. Track of gliding. (a) The trajectory of experiment a; (b) The trajectory of experiment b; (c) The trajectory of experiment c.

But it does not mean the higher the aspect ratio the better aerodynamic characteristics the glider has absolutely [9]. When a wing with a high aspect ratio has a large deformation, it has a great influence on the structural stiffness and aerodynamic distribution, which can reduce the critical flutter velocity and even change the flutter mode branches. So it is needed to increase the structural weight of the wing surface. In addition, the glider with a relatively large span is prone to stall and reduce

flight performance when flying at low speed due to the relatively long wing surface. The influence of geometric nonlinearity should be paid attention to in the design of a large flexible wing. Therefore, in the actual aircraft design, it is necessary to comprehensively consider the relation between aspect ratio and lift-drag ratio, and select the appropriate aspect ratio according to the specific requirements of the glider and flight conditions, to achieve the best performance. In this research, there are still many shortcomings, for example, the influence of the elastic deformation of the wing on the experiment is not considered [10]. Wings made of different frames have different aerodynamic properties. The lift performance of flexible wings is higher than that of rigid wings. The greater the flexibility, the more effective it is in improving lift coefficient and delay stall. For example, the deformation of the apex of the wing increases the leading edge angle of attack, and the angle of attack of the leading edge vortex advances accordingly, thus improving the lift coefficient of the delta wing, and it increases with the increase of elasticity. In addition, at a smaller angle of attack, the elastic wing has a higher lift-drag ratio. In the future, these factors that may affect the outcome should also be taken into account. Existing studies have not considered the influence of factors such as elastic deformation of wings, and these aspects will be comprehensively considered in future studies.

4. Conclusion

In the article, the research purpose was to analyze the influence of different aspect ratios on glider performance and then to provide the basis for the research to carry out experimental testing, calculate and simulate the data obtained, and establish a mathematical model between lift-drag ratio and aspect ratio using computer regression analysis. Then, by comparing with the results of the existing investigation and research, it is confirmed whether the mathematical model established in this research is reliable and accurate, and then the research results are displayed using chart data analysis. Finally, the research results and findings are summarized, and suggestions are put forward for the design and performance optimization of a glider.

Then, the obtained experimental data are compared and analyzed, and numerical simulation is carried out by computer. The function image of the length-to-width ratio and the lift-to-drag ratio is drawn by an Excel table to further analyze the relationship between them. Finally, the conclusion is that there is a certain relationship between aspect ratio and lift-drag ratio. With the increase in aspect ratio, the lift-drag ratio of the glider also increases. The less resistance the glider receives when generating unit lift, the greater lift force is generated, thus reducing the descending speed, extending the gliding distance, and showing better aerodynamic characteristics. Based on the research results, glider designers can optimize the design of glider wings, improve the performance and efficiency of gliders, and promote the application of gliders in various fields.

However, there are still many limitations in this study, such as the simplification of the model. In this study, a simple paper glider was used for the experiment, which may be different from the actual glider. Therefore, if conditions are permitted in the future, such research should take the real individual glider as the research object to get more practical and reliable research results. Meanwhile, the lift-drag ratio of gliders may also be affected by flight conditions, such as speed. However, in this study, it is difficult to ensure that the speed is consistent due to human throwing. Therefore, this variable needs to be controlled in future studies to obtain more accurate results. The number of models involved in this experiment is also relatively limited in aspect ratio. In some cases, it may not be possible to obtain corresponding results soled by computer simulation. In future research, more experiments should be conducted to ensure the accuracy of experimental results.

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