Research on the Aerodynamic Characteristics of the Relationship between Lift-to-drag Ratio and Wing Shape of Gliders

Baoyun Liang *

Minxin Hong Kong School, Guangzhou, 511453, China

* Corresponding author: mx20220979@minxinnansha.org.cn

Abstract. A glider is a special type of aircraft without a power unit, which relies on the lift of airflow to resist weight. The characteristics of a glider are essential to its flight performance, which includes aspect ratio, sweepback, and taper ratio. Proper design of the wing shape can help achieve good performance, so research on these elements can be helpful. This paper aims to calculate the relationship between the aspect ratio and lift-drag coefficient which affects the performance of gliders. By calculation, this paper found out that high aspect ratio aircraft could generate more lift force and was optimum in designing gliders. Then an experiment with a paper plane was designed to show the impact of aspect ratio on glider performance. Then a paper airplane experiment was designed, and the changes in different aspect ratios were achieved by reshaping the wings of the paper airplane, while flight performance was estimated by the lift drag coefficient and descent angle of the glider. After data collection, calculation and analysis, different flight routes were recorded, and based on this, the lift drag coefficient and descent angle were calculated. The experimental results indicate that aspect ratio is one but not the only factor affecting the flight performance of gliders. Through theoretical analysis and experiments, this study verifies the basic mechanism of the influence of wing shape, especially aspect ratio, on glider flight, providing new ideas for improving glider performance.

Keywords: Gliders, Aspect ratio, Lift-to-drag coefficient.

1. Introduction

A glider is a special kind of aircraft that has no engine. A glider has only three main forces acting on it: lift, drag, and weight [1]. Research on the flight performance of gliders can help us understand the optimum and efficient designs of other aircraft without adding the thrust variable.

A glider needs a lift to counteract its weight to fly. The glider must go through the air to produce lift. Drag is produced when the glider moves through the air. The engine's push fights drag in a powered aircraft. Nevertheless, the glider lacks an engine to produce propulsion. The glider rapidly slows down when the drag is not being fought until it is unable to provide enough lift to resist the weight [2].

A lift that opposes its weight is essential for the glider to fly. The glider moves through the air and transfers potential energy into kinetic energy to fly, since the glider has no engine to produce thrust, the drag force is unopposed, and the glider slows down until it cannot generate any lift force.

Understanding vehicle geometry is essential in trying to improve the performance and stability of flight vehicle design. The hydrodynamic properties are determined by the glider geometry and have an additional impact on the efficiency and stability of vehicle motion [3].

Current gliders are designed to have a high aspect ratio for a high lift-drag coefficient. High aspect ratio wings have increased structural flexibility and higher stress levels at the wing root, which are intrinsic structural design problems [4]. For a glider, there are two somewhat clashing streamlined necessities. To begin with, the airplane must be competent in tall execution amid its voyage stage which is concerned with the least drag for the most wing airfoil and adding up to wetted range on the sailplane. Furthermore, a tall execution during the climb arrangement that's usually subordinate to the lift coefficient of the airfoil and an optimized wing plan for actuated drag needs to be accomplished [5]. Even if having a large aspect ratio offers several advantages, gliders still face problems when trying to increase the aspect ratio such as a change in mass. Alternate effects by increasing aspect

ratio lack discussion in the current research on effective glider designs. This article proposes an alternative perspective for effective vehicle design, such as considering aspect ratio, mass, and tampering rate, which is of great value in elucidating the mechanism by which wing shape affects its aerodynamic performance and promoting the rapid design and development of high-performance gliders.

2. Method

2.1. Main Factors Influencing Glider Performance

In aeronautics, the aspect ratio of a wing is the ratio of its span to its mean chord. Thus, a long, narrow wing has a high aspect ratio, whereas a short, wide wing has a low aspect ratio [6]. The aspect ratio has a high influence on flight performance. The optimum aspect ratio for gliders should have a high lift-drag coefficient. The relationship between aspect ratio and flight performance of planes has been highly discussed. However, the effect of aspect ratio on specific aircraft such as gliders has been underestimated.

The main aerodynamic parameters of an aircraft wing are drag (C_D), lift (C_L) and pitching moment (C_M) coefficients. The other aerodynamic performance parameters can be derived from these parameters [7], such as the glide ratio, which is the ratio between lift coefficient and drag coefficients.

$$\begin{cases} C_L = \frac{2F_l}{\rho \cdot A \cdot V^2} \\ C_D = \frac{2F_D}{\rho \cdot A \cdot V^2} \\ C_M = \frac{2M}{\rho \cdot A \cdot V^2} \end{cases} \tag{1}$$

The induced drag(C_{D_i}) is the drag directly associated with the production of lift. This results from the dependency of the induced drag on the angle of attack [4]. It requires la ift coefficient to be generated. The zero-lift drag(C_{D_o}) includes all types of drag that do not depend on production of the lift. Every aerodynamic component of an aircraft (i.e., the components n direct contact with flow) generates zero-lift drag [8].

$$\begin{cases} C_D = C_{D_o} + C_{D_i} \\ C_{D_i} = \frac{C_L^2}{AR \cdot \pi \cdot e} \end{cases} \tag{2}$$

Oswald efficiency factor (e) is the value, which gives an idea about the similarity of a wing's span-wise lift distribution to the elliptical lift distribution [9]. It is mainly affected by the presence of fuselage, nacelles, and design of wing planform such as the aircraft's aspect ratio, tamper ratio, and leading-edge sweepback angle. The Oswald efficiency factor of the elliptical lift distribution is 1, which is the maximum value of this parameter. The elliptical lift distribution has an Oswald efficiency factor of 1 and generally, this is the maximum value of this parameter. drag parameter (δ) represents wing efficiency in terms of induced drag. This parameter depends on only the shape of the wing and is independent of the angle of attack and lift coefficient [7].

$$e = \frac{1}{1 \pm \delta} \tag{3}$$

$$\left(\frac{L}{D}\right)_{max} = \frac{1}{2}\sqrt{\frac{\pi e A}{C_{D_o}}} \tag{4}$$

Taper ratio is a geometry parameter which implies the ratio of root and tip chord lengths of a wing. An optimum taper ratio value for a wing, which has minimum induced drag coefficient and maximum Oswald efficiency factor values [7].

In aeronautics, the aspect ratio of a wing is the ratio of its span to its mean chord. A long, narrow wing has a high aspect ratio, whereas a short, wide wing has a low aspect ratio [6]. The key design elements that affect gliding performance are shown in Figure 1.

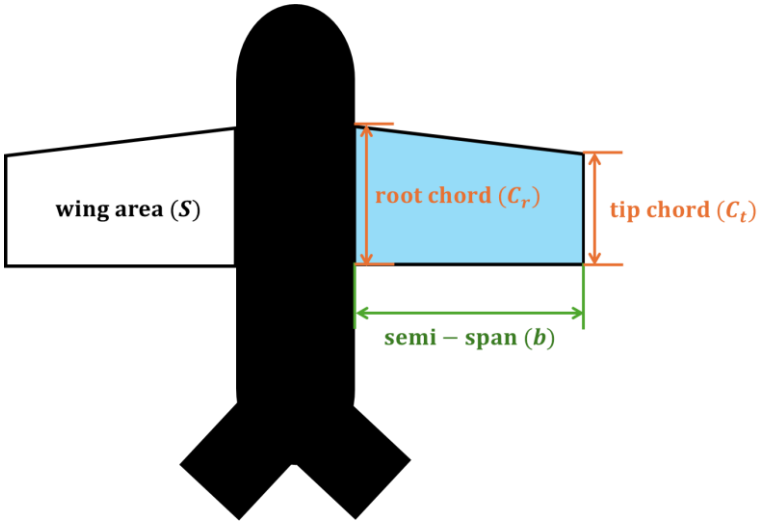


Figure 1. The key design elements that affect gliding performance

$$\text{tamper ratio} = \frac{C_t}{C_r} \tag{5}$$

$$\text{AR} = \frac{b}{c} = \frac{b^2}{S} \tag{6}$$

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2.2. Theoretical analysis

The simple force analysis diagram of a glider is shown in Figure 2.

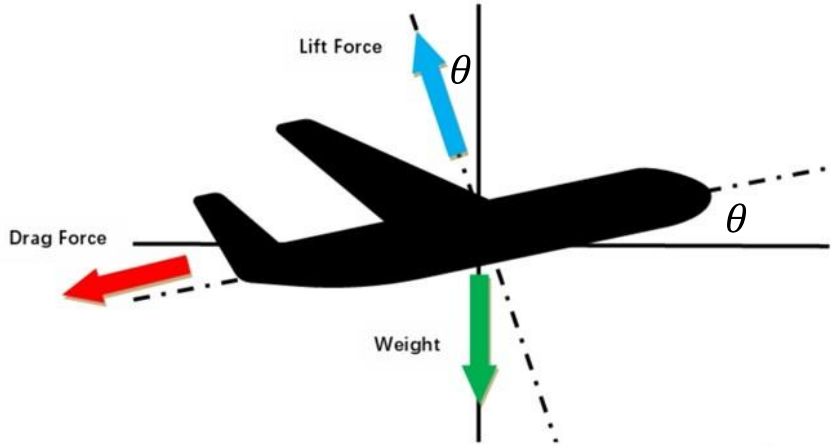


Figure 2. Simple force analysis diagram of a glider

From free body diagram, vertical and horizontal forces are balanced.
In vertical direction,

$$W = F_L cos\theta + F_D sin\theta \tag{7}$$

In horizontal direction,

$$F_L sin\theta = F_D cos\theta \tag{8}$$

By rearranging equation (7) and (8), get equation (9) and (10).

$$F_D = \frac{W\tan\theta}{\cos\theta \pm \sin\theta\tan\theta} \tag{9}$$

$$F_L = \frac{W}{cos\theta + sin\theta tan\theta} \tag{10}$$

$$\frac{F_L}{F_D} = \frac{C_L}{C_D} = \frac{1}{tan\theta} \tag{11}$$

$$R = \frac{h_1 - h_2}{tan\theta} \tag{12}$$

From (11) smaller flight angle has higher lift-drag coefficient.
By substituting (11) into (12)

$$R = \frac{L}{D}(h_1 - h_2) \tag{13}$$

Hence the range for gliding flight depends on the lift-drag coefficient and change in height. The maximum range occurs when the lift-drag coefficient is maximum.

$$C_L{}^2 = C_D \cdot \pi \cdot AR \cdot e \tag{14}$$

Then,

$$C_L \propto \sqrt{AR} \tag{15}$$

By equations (14) and (15), the square of the Lift coefficient is directly proportional to the aspect ratio, and a higher aspect ratio can produce more lift force. Therefore, the maximum range glide is flown at the minimum drag force. A higher aspect ratio wing has a lower drag and a slightly higher lift than a lower aspect ratio wing and thus a greater glide range.

2.3. Experimental design

This experiment uses identical A4 (210 mm × 297 mm) paper sheets same folding method to make the paper planes as specimens. Paper planes have a lower effect by weight and cost, with a similar Reynolds number as Micro Air Vehicles which can successfully demonstrate the significance of lift and drag force on different airplanes [10].

By changing the length of the span by 3cm in each group, the aspect ratio performs as an individual variable. The shape of the wing isn't a right rectangle. Therefore, the change in wing area is prioritized as a measure of aspect ratio.

From the lift equation,

$$L = \frac{1}{2}\rho v^2 S_{\text{ref}} C_L \tag{16}$$

Where L denotes lift force. V defines the velocity of aircraft expressed in m/s. ρ is the air density, affected by altitude. S_{ref} is the reference area or the wing area of an aircraft measured in square mmeters C_L is the coefficient of lift, depending on the angle of attack and the type of aerofoil.

The equation implies that a larger wing area can generate more lift force, and hence would have better gliding performance, therefore it can be assumed that the wide airplane that has no cutting would have the highest lift-drag coefficient.

The wide plane has an aspect ratio of 14.8, the middle plane has an aspect ratio of 12.7 and the narrow plane has an aspect ratio of 11.2. Another attempt to get more accurate results also contains practice giving the plane similar initiate velocity. In airless chamber experiments, the effects of air resistance and small changes in mass can be ignored.

Videos for all three prototypes are put into the tracker for the analysis of the locomotion of the plane. The reference length was set as the length of the plane, which implies the standard length of A4 paper(279mm), and the origin point of the X and Y axis was set to the initiate position of the plane's front point. With the track of the front point of the plane, the locomotion and descent angle can be derived and used for further calculation.

3. Results and Discussion

Graphical Representation: The experimental data was meticulously represented through graphical plots, with angles plotted on the x-axis and corresponding vertical and horizontal measurements on the y-axis (refer to Figure 5). This graphical representation served to elucidate trends in applied angles and the resulting changes in the lift-to-drag ratio (C_L/C_D) on the y-axis, providing valuable insights into the distance required for the paper planes to attain a stable flying phase (Figure 3).

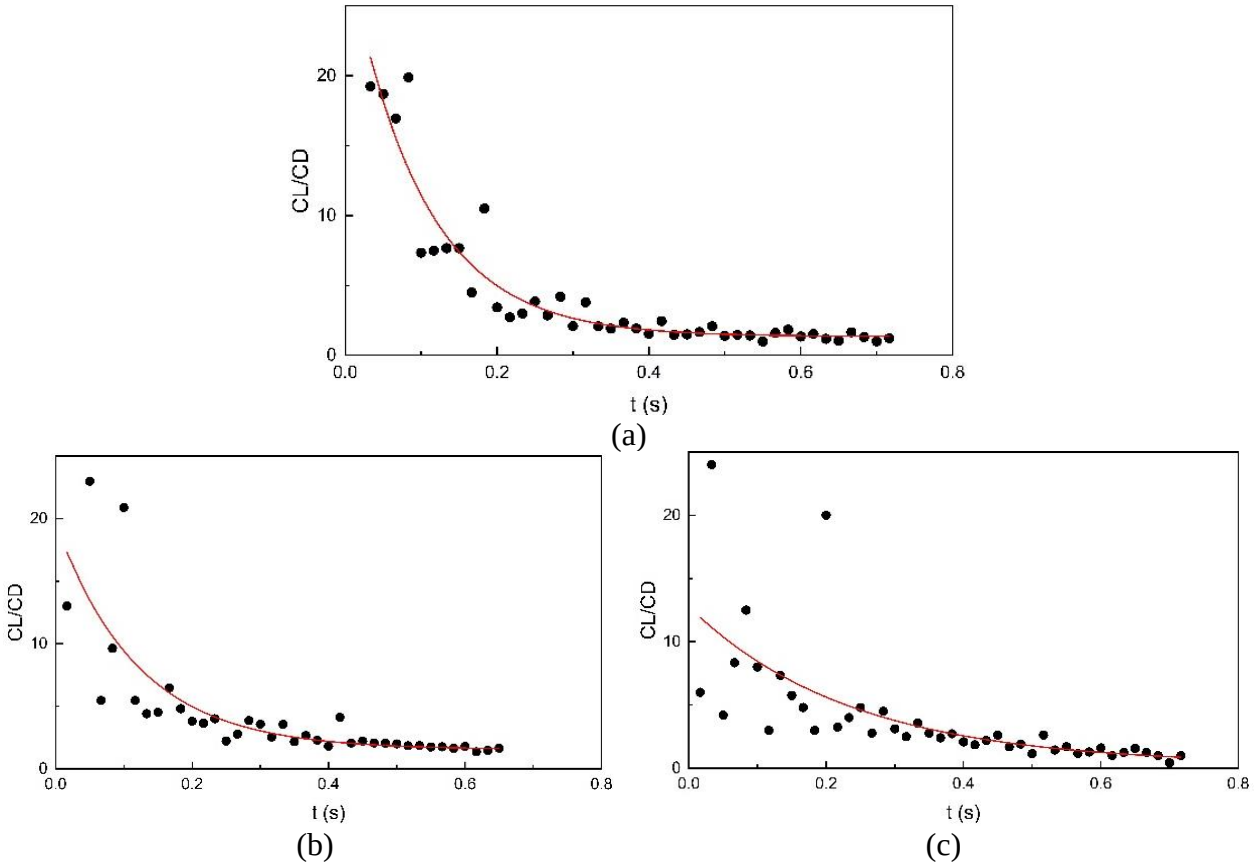


Figure 3. Lift drag coefficient as a function of time. (a) Wide; (b) Middle; (c) Narrow

Table 1. Mean theta and mean lift-to-drag ratio of three wing shapes

Wing shape	Wide	Middle	Narrow
Aspect ratio	14.8	12.7	11.2
Mean θ	22.89	19.38	23.55
Mean $\frac{C_L}{C_D}$	3.95	8.64	4.05

1). Comparison of Mean Glide Angles (Table 1): Figure 4 illustrates that the paper plane with a middle aspect ratio (AR) exhibited the smallest mean gliding angle (-19 degrees) in comparison to the high aspect ratio (-22 degrees) and small aspect ratio (-23 degrees) planes. This observation underscores the influence of aspect ratio on the gliding behavior of the paper planes, highlighting the significance of wing geometry.

2). Analysis of X-Y Relationship Diagram (Figure 5): The X-Y relationship diagrams in Figure 5 provide a detailed depiction of the decline in angle as the paper planes cover longer horizontal distances. Remarkably, the trendline analysis in Excel reveals that the middle aspect ratio paper plane exhibits the most consistent and smooth gliding angle. This deviation from theoretical expectations prompts a deeper investigation into the aerodynamic intricacies governing gliding behavior.

3). Horizontal Displacement and Steady C_L/C_D Phase (Figures 3): Examining Figures 3(a)-(c), it becomes evident that the paper plane with a middle aspect ratio covers the longest horizontal displacement before reaching a steady C_L/C_D phase (stable phase). This noteworthy observation implies superior airborne endurance and a prolonged ability to maintain optimal lift-to-drag conditions, setting the middle aspect ratio apart from its counterparts.

4). Gradient Analysis of C_L/C_D (Figure 3): Analyzing the gradients in Figure 3 reveals dynamic patterns. The gradients exhibit rapid initial descent, followed by a gradual smoothing, though not reaching absolute zero. This behavior signifies the transitional phases in the gliding process, suggesting complex aerodynamic interactions during the early stages that gradually stabilize as the paper planes traverse the horizontal distance.

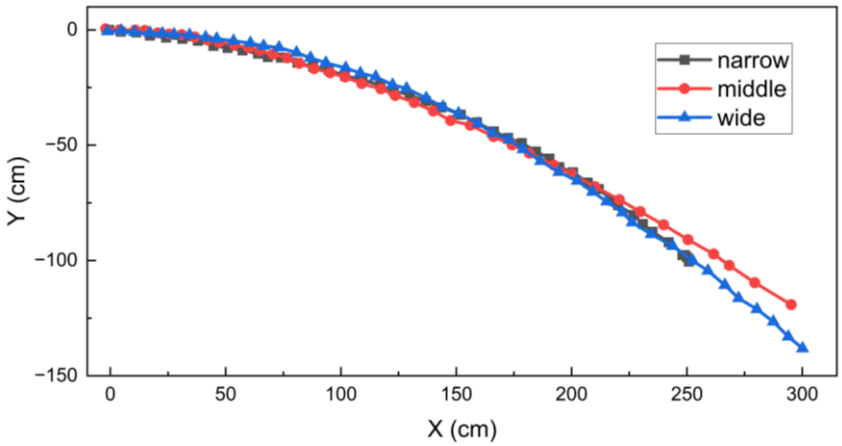


Figure 4. Flight trajectory of glider

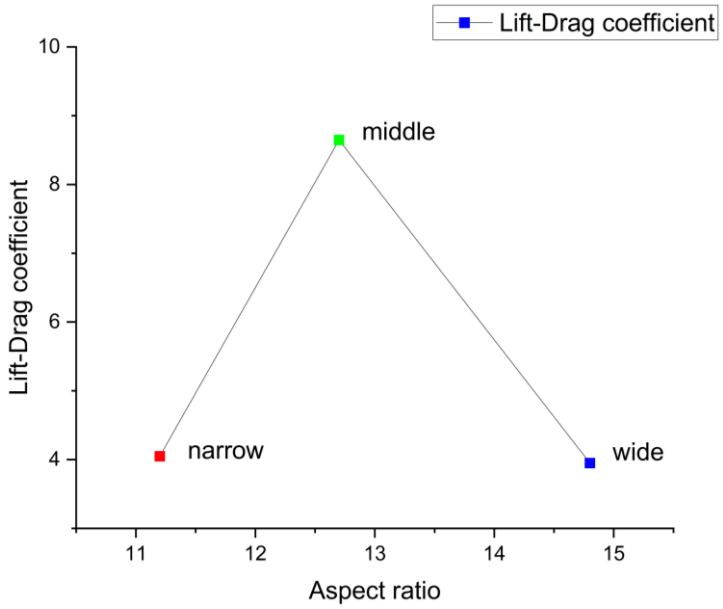


Figure 5. The relationship of lift-drag coefficient to aspect ratio (Mean tanθ)

By data analysis, the average lift-drag coefficient increases from 4.05 to 8.64 (corr. to 2 dec.) with a plane with an aspect ratio of 11.2 to plane with aspect ratio 12.7 as discussed in theoretical analysis for aspect ratio being the directly proportional square of lift coefficient.

However, further increasing the aspect ratio to 14.8 shows a decrease in the average lift-drag coefficient to 3.95 (corr. to. 2 dec.). This may be due to the following reasons:

1) Weight

The wide plane with a high aspect ratio has no cutting done and higher mass hence will be affected more by weight than the middle and narrow airplane with cutting on the wing area. There will be more force acting vertically downwards which causes the lift force and lift-drag coefficient to obtain a smaller value.

2) Initial angle and velocity

Human variations may affect the initial angle and velocity slightly. Throwing the paper plane by hand introduces variability in the initial conditions. Different individuals might throw the plane with varying force, angle, and release times, affecting the experiment's consistency.

3) Non-ideal air condition

Throwing the paper plane by hand introduces variability in the initial conditions. Different individuals might throw the plane with varying force, angle, and release times, affecting the experiment's consistency. The presence of air currents or drafts in the experimental area can influence the paper plane's flight. These unpredictable air movements can lead to variations in glide angles that are not related to the aspect ratio.

4. Conclusion

Through theoretical analysis and experiments, it has been verified that gliders with higher aspect ratios have better flight performance, as they can generate greater lift and higher lift drag coefficients. However, the experiment ignored the small influence of mass as a control variable and airflow, which resulted in default values for the results. The idea of increasing the lift and drag coefficient while reducing mass to reduce the weight effect to a certain extent, allowing the airflow to generate appropriate lift, can be applied to the design of gliders, and improving the efficiency of various aircraft. This preliminary experiment still has many improvements, such as conducting wind tunnel experiments on standard glider models using different airflow. In future research, there is still much effort and progress in the development of deeper knowledge in aircraft exterior design.

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