

Exploring the Influence of Wing Shape on the Aerodynamics of Gliders

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Abstract. The lift-to-drag ratio and the aerodynamic characteristics of the wing shape play an important role in the performance of the glider. Lift-drag ratio, as a key index of aircraft performance evaluation, is directly related to aircraft glide performance, fuel efficiency, and flight range. The selection and optimization of wing shape is also considered to be one of the main factors affecting the performance of gliders. However, despite the extensive research in the field of glider design, there are still some gaps in the understanding of the relationship between lift-drag ratio and wing shape. The traditional research is carried out in a specific situation, and the aerodynamic characteristics of different wing shapes are relatively short of systematic comparison and in-depth theoretical analysis. Therefore, this research focuses on the design and performance optimization of gliders, focusing on the lift-drag ratio and aerodynamic characteristics of wing shape. The tracker is used to collect the data of glider models with different wing shapes in the air, compare the performance of various shapes, discuss their advantages and disadvantages, and make a comprehensive analysis. Important findings from this study not only provide practical guidance for glider design but also provide insight into the relationship between lift-drag ratio and wing shape research, this research encourages further exploration and expansion of this area to advance the development of glider technology. This research provides useful references for scientists, engineers, and designers in the field of aviation, leading to more advanced and efficient glider design and manufacture.

Keywords: Lift-drag ratio, Mean angle, Aspect ratio.

1. Introduction

In aviation, optimizing glider design and performance is crucial, with lift-drag ratio and wing shape playing key roles. Researchers like Chen et al [1] propose innovative methods, such as Gaussian process regression and mixed feature mining, to evaluate airfoil lift-drag ratios under turbulent conditions. Understanding and optimizing these factors are essential for improving glider performance.

At present, the glider is also faced with stability, over-dependence on environmental conditions, and multi-dimensional and multi-modal optimization design problems on the impact of the glider's empty time. Wang and Xu [2] used a combination of multi-island genetic algorithm (MIGA) and simulated annealing (SA) to numerically optimize the aerodynamic performance of a supersonic airfoil, and greatly extend the flight distance of the glider by finding the best geometry. To make the vehicle more stable, Bras, Warwick, and Suleman [3] focused on the development of flexible wing UAVs to solve the aeroelastic phenomenon in the design of modern high aspect ratio wing aircraft, so that the aircraft can fly stably in more complex environments.

At this stage, choosing a suitable lightweight power system with the glider can effectively extend the endurance of the glider and provide a certain degree of stability against wind resistance. The Solid Oxide Fuel Cell-Gas Turbine [4] hybrid system can not only provide better power but also reduce CO₂ emissions by using more environmentally friendly liquid fuel, which is a good power system choice for gliders. Not only that, wave gliders [5] can use wave energy drive and solar power to provide power, in today's more low-carbon emissions, these research trends are the future.

Establishing a scale-down model to analyze the physical characteristics of gliders can greatly reduce the economic cost of the experiment. Peng et al. [6] established a new model in which a Y-

shaped flow channel is opened inside the airfoil to generate lift and drag to drive itself at different wind speeds and angles. This new power-driven glider model gives us a glimpse of the endless possibilities for future glider development.

In this context, this article focuses the research on experimental design and data analysis to fully understand the performance of different wing shapes in glider aerodynamic characteristics. The purpose of this study is to investigate the effects of lift-drag ratio and wing shape on glider performance, and systematically explore the aerodynamic characteristics of different wing shapes through the collection and analysis of experimental data. Through an in-depth analysis of the theoretical basis of the lift-drag ratio, this research reveals its key role in glider design and provides substantive guidance for glider performance optimization combined with practical data analysis. Through the in-depth analysis of this study, this research hopes to provide practical guidance for future glider design and performance optimization and provide a useful reference for scientists and engineers in the field of aviation to promote the further development of the field.

2. Method

2.1. Overview of glider types

The variations in wing shapes among glider types of primarily stem from differences in wingspan, wing area, airfoil design, and aspect ratio.

Wingspan: High-performance gliders are characterized by elongated wingspans, which contribute to improved aerodynamic efficiency by reducing induced drag and increasing span efficiency. In contrast, competition gliders may exhibit even larger wingspans to optimize lift generation and overall performance.

Wing Area: The wing area of high-performance gliders tends to be relatively smaller compared to other types, which enhances their glide ratio by reducing drag while maintaining sufficient lift. Conversely, competition gliders often feature larger wing areas to maximize lift production and increase overall speed during competitive events.

Airfoil Design: High-performance gliders typically employ airfoils optimized for high lift-to-drag ratios at various speeds, allowing for efficient energy conservation during long-distance flights. Competition gliders may utilize airfoils tailored for specific performance requirements, such as enhanced lift at high speeds or improved maneuverability during racing scenarios.

Aspect Ratio: The aspect ratio, defined as the ratio of wingspan to mean aerodynamic chord, plays a crucial role in determining the efficiency and performance characteristics of glider wings. High-performance gliders typically exhibit higher aspect ratios, contributing to reduced induced drag and improved glide performance. Competition gliders may also feature elevated aspect ratios to capitalize on enhanced lift production and speed capabilities during competitive maneuvers.

These nuanced differences in wing characteristics underscore the specialized design considerations tailored to the performance objectives of each glider type, emphasizing the intricacies of aerodynamic optimization in the realm of glider engineering.

2.2. Physical analysis

Generally, Euler's finite volume method (FVM) [7] is a commonly used numerical method for solving fluid dynamics equations such as Euler's equations. In aircraft design and engineering, FVM is widely used to solve aerodynamic problems, including airflow around, aerodynamic calculation, etc. However, the model considered in this paper is relatively simple, so two-dimensional force analysis is adopted for analysis. Gliding is light without the use of thrust. A glider lying in equilibrium slowly sinks to the ground, with its glide angle determined by a balance between the vehicle mass, gravity, and the lift and drag forces experienced by the glider. Consider the free-body diagram shown below. The glider descends at an angle θ . The drag force acts in the direction of motion, while the lift force acts in the direction perpendicular to the glider motion. The weight of the glider acts vertically.

Projecting FD and FL onto the horizontal and vertical is shown in Figure 1.

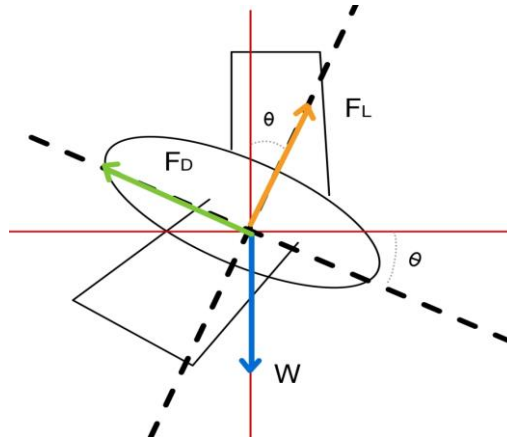


Figure 1. Glider force analysis diagram

Vertica:

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

Horizontally:

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

From the horizontal equation

$$\frac{F_L}{F_D} = \frac{C_L}{C_D} = \frac{1}{\tan \theta} \quad (3)$$

Therefore, if θ can be measured, the C_L / C_D ratio can be inferred, and the mean angle of the paper plane can be measured in this experiment.

When the weight W is known, the drag and lift forces can be determined explicitly.

$$F_D = \frac{W \tan \theta}{\csc \theta + \sin \theta \tan \theta} \quad (4)$$

$$F_L = \frac{W}{\cos \theta + \sin \theta \tan \theta} \quad (5)$$

The values of and depend on many factors, including the shape and size of the wing. The area of the wing is given by:

$$S = b \times c \quad (6)$$

Where b is the wing length and c is the chord, see Figure 2. The wing aspect ratio is given by.

$$AR = \frac{b}{c} = \frac{b^2}{S} \quad (7)$$

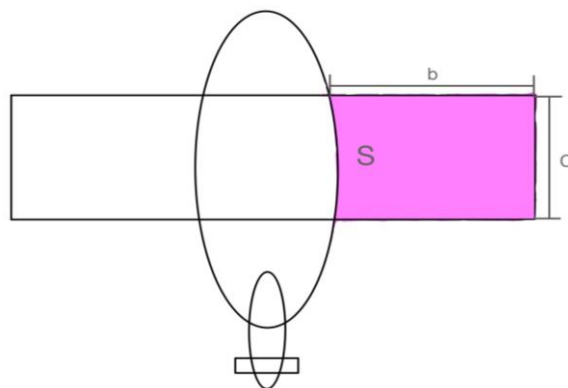


Figure 2. Top view of a model glider wing

2.3. Wing design

A stringent selection protocol was employed to curate a subset of five videos from the recorded footage, meticulously scrutinized to meet the predefined criteria, thus ensuring the integrity and reliability of subsequent data analysis endeavors. This rigorous approach aimed to maintain consistency and accuracy in the selection process, thereby enhancing the credibility of the experimental results.

The experimental setup utilized an iPhone 15 Pro Max as the recording device, capturing footage at a frame rate of 60 frames per second. Each video was meticulously recorded in a controlled basement environment, isolated from external airflow perturbations.

To ensure uniformity and precision in data acquisition, rigorous measures were enacted to minimize extraneous factors such as wind disturbances. Horizontal launches were executed with meticulous attention to consistent aircraft height and initial velocity, although constrained by limitations in manpower.

The paper airplanes, meticulously fashioned from A4 paper with a density of 70 g/m^2 , adhered strictly to the designated specifications without the inclusion of supplementary materials. Each paper airplane measured $210 \times 297 \text{ mm}$ and weighed precisely 4.3659 grams.

By meticulously documenting the experimental setup, including the recording device, paper airplane specifications, and recording environment, transparency and reproducibility were prioritized, laying the foundation for robust data analysis and interpretation.

2.4. Group Experiments

Group1:

This group is made from a full sheet of A4 paper (specifications as previously described). The total wings area is 120.995 cm^2 and the weight is 4.3659 g.

The top view of the group1 glider wing is shown in Figure 3.

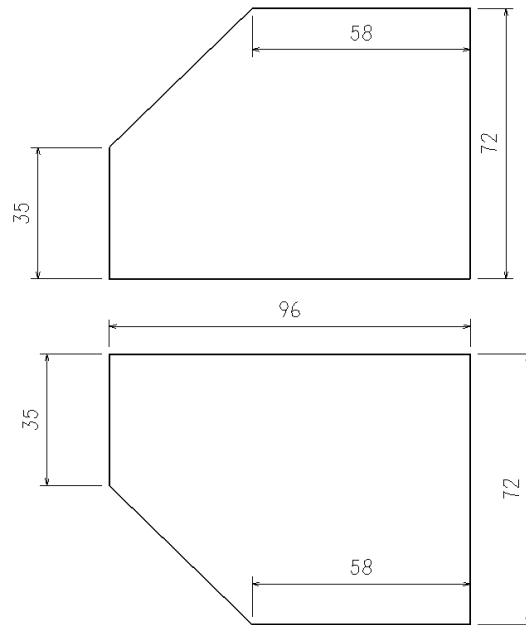


Figure 3. Top view of the group1 glider wing

Group2:

This group is obtained by cutting off part of the wing from Group 1, with a slight reduction in weight and a reduction in wing area, together with a change in A/R. The total wings area is 100.595 cm² and the weight is 4.06 g.

The top view of the group 2 glider wing is shown in Figure 4.

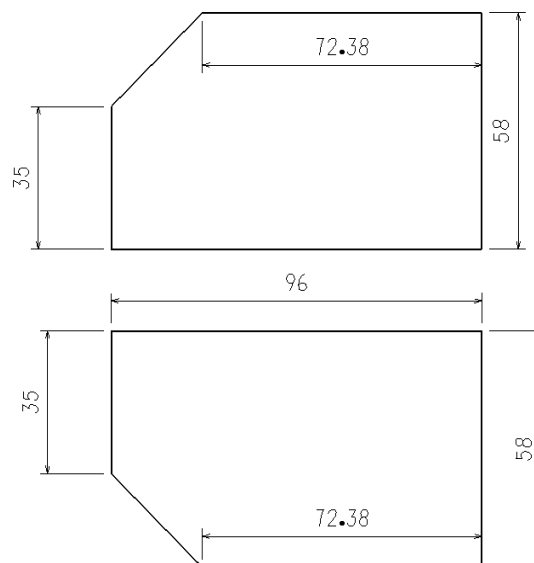


Figure 4. Top view of the group 2 glider wing

Group3:

This group is a completely new model with the same weight as Group 1 but with a completely changed wing structure and area. The total wings area is 152.5cm² and the weight is 4.3659 g.

The top view of the group 3 glider wing is shown in Figure 5.

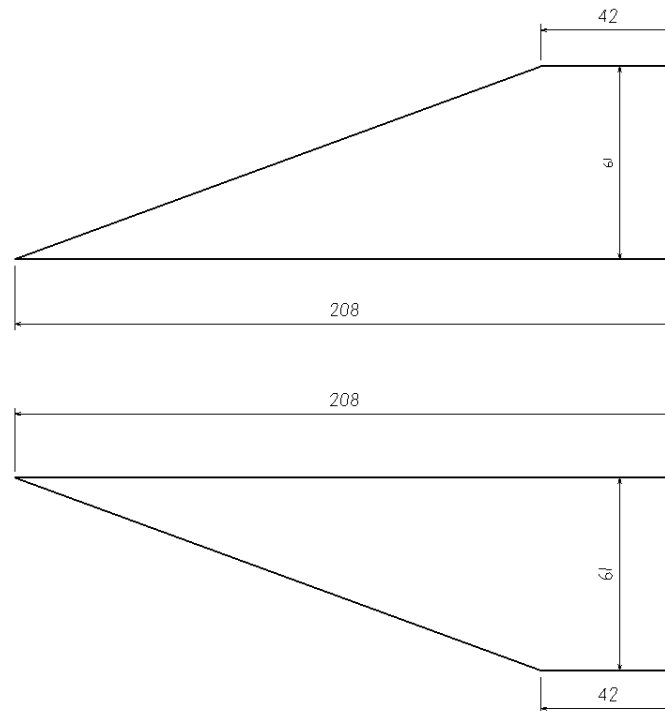


Figure 5. Top view of the group 3 glider wing

2.5. Tracking and analysing procedure

The tracking and analysis process begins with the utilization of the "Tracker" software, renowned for its precision in tracing aircraft trajectories. Calibration tools are promptly deployed to establish measurement scales, referencing a fixed length within the video background, typically a door frame, ensuring accurate measurements. A Cartesian coordinate system is swiftly established with the groundwork laid, positioning the aircraft's takeoff in horizontal flight as the origin point. Employing the intuitive "trajectory" tool, the frontal aspect of the aircraft is swiftly designated as the reference point. Frame by frame, meticulous annotations are swiftly made to record the trajectory, ensuring no detail is overlooked. This meticulous data collection facilitates comprehensive analysis, enabling insights into crucial aerodynamic characteristics essential for optimizing glider performance.

3. Results and Discussion

The "Tracker" software imported the horizontal and vertical coordinate data obtained from the tracking and analysis of the glider models in the three sets of videos into Excel tables to obtain three different sets of trajectory equations. From the first group to the third group are shown in Figures 6-8.

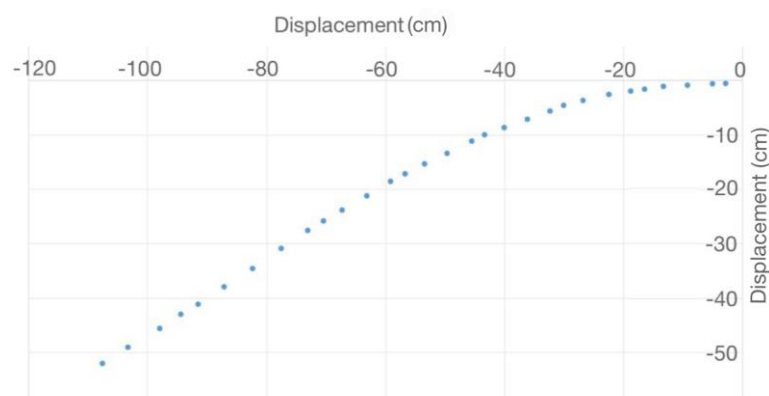


Figure 6. Trajectory image (Group 1: $Y = -0.0038X^2 + 0.0996X^1 + 0.7558$)

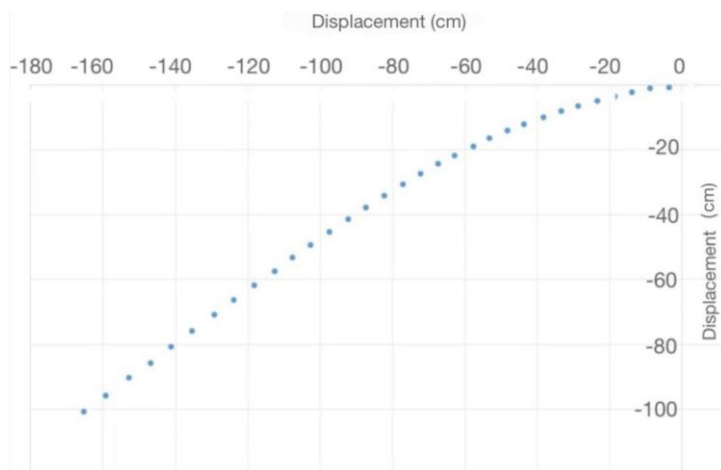


Figure 7. Trajectory image (Group 2: $Y = -0.0024X^2 + 0.2391X^1 + 1.6071$)

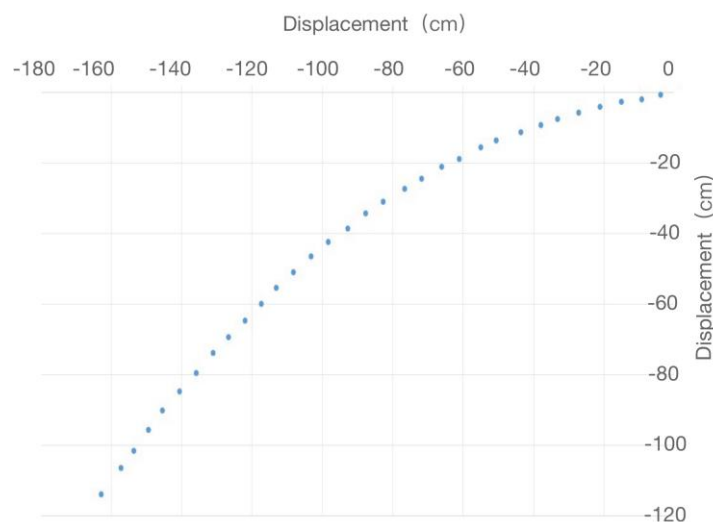


Figure 8. Trajectory image (Group 3: $Y = -0.0024X^2 + 0.0287X^1 - 1.4412$)

Through calculation, the average AR and mean angles of the glider models of the three groups of experiments are obtained, which are respectively:

Group 1: AR=1.4928, angle 24.047°

Group 2: AR=1.8938, angle 29.670°

Group 3: AR=2.0164, angle 33.801°

The mean glide angle as a function of the wing aspect ratio is shown in Figure 9.

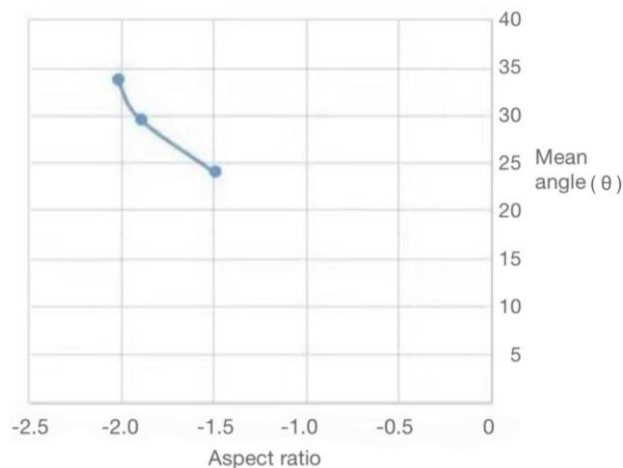


Figure 9. Function diagram of Aspect and Mean angle

3.1. Discussion

Through meticulous analysis of the experimental data, several key conclusions have been drawn regarding the relationship between aspect ratio and lift-drag ratio in glider aerodynamics. Firstly, it is evident that there exists a direct correlation between the aspect ratio and the angle of attack (θ), whereby higher aspect ratios correspond to greater angles of attack, and vice versa. This relationship underscores the fundamental influence of aspect ratio on the aerodynamic behavior of gliders.

Moreover, the experimental findings affirm that a larger aspect ratio typically reduces drag experienced by the glider, thereby facilitating more efficient gliding at a given glide angle. This observation underscores the critical role of aspect ratio in optimizing glider performance, particularly in terms of minimizing drag and maximizing glide efficiency.

Furthermore, the analysis reveals a compelling relationship between aspect ratio and lift-drag ratio, wherein higher aspect ratios are associated with greater lift-drag ratios, and conversely, lower aspect ratios correspond to diminished lift-drag ratios. This phenomenon can be attributed to the structural characteristics of wings with larger aspect ratios, which feature elongated and narrower profiles that effectively reduce drag by minimizing cross-sectional area.

In summary, the experimental data unequivocally demonstrate the significance of aspect ratio in influencing both drag reduction and lift-drag ratio enhancement in glider aerodynamics. By maximizing the aspect ratio, glider designers can effectively optimize performance parameters, thereby enhancing overall efficiency and flight dynamics.

3.2. Replenishment

In addition to the aspect ratio, the lift-drag ratio of gliders is subject to the influence of several other pertinent factors, each warranting careful consideration in aerodynamic analysis and design optimization:

1. Aircraft Quality: The weight and structural integrity of the aircraft exert a direct impact on the lift-drag ratio. Lighter aircraft typically exhibit superior lift-drag ratios due to reduced inertia and aerodynamic drag, enabling more efficient flight performance.

2. Air Temperature and Pressure: Ethan D. Terence R. Thompson and Radley M. Horton [8] found that as temperatures rise, aircraft generate less lift at a given airspeed, which can lead to reduced takeoff stability or more energy consumption. Variations in air temperature and pressure significantly affect air density, thereby influencing lift generation and aerodynamic resistance. Consequently, fluctuations in atmospheric conditions may result in corresponding variations in the lift-drag ratio of gliders.

3. Speed: At first, in the simulation of aircraft exhaust jet dynamics in computational fluid dynamics (CFD), it is necessary to consider the uncertainty [9]. Secondly, flight velocity plays a pivotal role in shaping the lift-drag characteristics of gliders. Variations in speed directly influence aerodynamic forces and power requirements, consequently impacting the lift-drag ratio across different flight regimes.

Furthermore, Y.D. Dwivedi, Abdul Wahab, et al [10] found that the roughness of the wing surface also affects the lift, drag and stall performance of the aircraft. Additional factors such as wing geometry, surface roughness, and aerodynamic configurations can also exert considerable influence on the lift-drag ratio, necessitating a comprehensive understanding of the complex interplay between various aerodynamic parameters.

In conclusion, the lift-drag ratio of gliders represents a multifaceted phenomenon influenced by a myriad of factors, each contributing to the overall aerodynamic performance and efficiency of the aircraft. By elucidating these factors and their respective effects, researchers and designers can advance the optimization of glider design to achieve enhanced performance and operational capabilities in diverse flight conditions.

4. Conclusion

This study investigated the relationship between the lift-drag ratio, angle of attack, aspect ratio, and wing characteristics of gliders through a series of experiments. Three glider models were constructed, each featuring distinct wing designs. Using Tracker software, this research tracked the glide motion of these models in recorded videos to obtain experimental data.

Findings revealed several key insights into the aerodynamic performance of gliders. Firstly, there is a clear correlation between the lift-drag ratio and the aspect ratio of the wings. Gliders with higher aspect ratios demonstrated superior lift-drag ratios, indicating enhanced aerodynamic efficiency. Additionally, this research found that variations in the angle of attack significantly influenced the lift-drag ratio, with optimal angles resulting in maximal performance.

Furthermore, the analysis highlighted the importance of wing design in determining glider performance. By comparing the aerodynamic characteristics of different wing shapes, the impact of wing geometry on lift generation and drag reduction was elucidated. This underscores the significance of optimizing wing design to achieve desired performance outcomes.

The study also has problems and areas for improvement:

Experimental Design and Methodology: This study explored glider aerodynamics using a simple experiment but lacked detailed explanations of construction and procedures. Future studies should improve experimental design for better reproducibility.

Data Analysis: While this research used Tracker software for data collection, the analysis methodology is not clearly described. Future studies should employ comprehensive analysis techniques to enhance credibility.

Interpretation of Results: This study's findings offered insights into glider aerodynamics but could benefit from a deeper analysis of underlying principles for a more comprehensive understanding.

Future Research Directions: Although this paper expressed aspirations for future research endeavors, such as expanding the scope of experiments and considering additional factors influencing glider performance, the discussion on future research directions was not sufficiently detailed. Providing specific recommendations and proposals for future studies would guide further advancements in this field and contribute to ongoing research efforts.

Overall, this research contributes valuable insights into the fundamental principles governing glider aerodynamics. By systematically exploring the relationships between lift-drag ratio, angle of attack, aspect ratio, and wing characteristics, this paper has deepened the understanding of glider performance optimization. These findings have implications for the design and development of more efficient and capable gliders in the future, with potential applications in aviation and beyond.

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