

Aerodynamic Characterization of Glider Lift-to-drag Ratio and its Wing Shape

Yunhao Liang *

Olive Tree International Academy, Beijing Foreign Studies University, Hangzhou, 311100, China

* Corresponding author: liangyunhao108@Gmail.com

Abstract. As a type of fixed-wing aircraft without power devices, gliders have important value in aviation measurement, cargo transportation, and other scenarios. This article studies the application of aerodynamics and fluid dynamics in gliders, but the wing shape of a glider is not sufficient to provide sufficient aerodynamic characteristics for the glider. Therefore, based on the basic theory of aerodynamics, this article studies the relationship between the lift-to-drag ratio of a glider and the aerodynamic characteristics of its wing shape in the aviation field, and changing the shape of the wings to alter the difference in air pressure between the upper and lower air during the glider's flight. Furthermore, the force exerted on the glider during flight is altered to maintain its altitude and flight time. Different airfoils to find out which one can make the glider fly farther, safer, and at higher altitudes were tested. Finally, based on this study, the conclusion drawn is that the double convex wing shape can provide higher overall efficiency and stability for gliders during flight, despite its high cost. This study provides important references for the study of aerodynamic efficiency and stability of gliders.

Keywords: Aerodynamics, Glider, Wing shape, Factor analysis, Performance evaluation.

1. Introduction

Gliders are aircraft capable of flying through the atmosphere, usually without the use of an engine [1]. They maintain flight by utilizing updrafts and thermals in the atmosphere. Gliders have many real-life applications in the background. Gliders are important in scientific research. Scientists use gliders to study the laws of motion of the atmosphere and air currents, as well as the flight patterns of birds and insects [2]. These studies help to deepen the understanding of the atmospheric environment and the flight capabilities of living things and provide an important reference for the development of aerospace technology [3]. In addition, gliders are also used in the military field. The military can use gliders for reconnaissance and surveillance missions, as well as for special operations [4]. Since gliders usually do not require an engine, they have a low acoustic and infrared signature when performing covert missions, which helps to avoid detection by the enemy. Even though modern gliders have been improved, glider safety accidents are still occurring. Yang et al. [5] carried out a study on airflow and gliders and found that the airflow direction and air temperature affect the gliders, however, the current study did not elucidate the impact of the glider's design on the flight, which affects the glider's design and application, and this thesis is based on the theoretical analysis of the research on the impact of glider design on flight. This thesis is based on the theoretical analysis method to research the effect of glider design on flight, aiming to elucidate the principle of glider flight and solve the problem of unstable flight and insufficient lift, which has the important value and significance of improving the flight efficiency of gliders.

2. Principles of Glider Flight

According to aerodynamic principles, when a glider is in flight, the airflow generates friction and vertically upward lift forces on the surfaces of the wing and tail of the loaded glider, and these forces are critical to keeping the aircraft in the air [6]. In the analysis of aircraft lift, most of the lift is generated by the wings, while the rest of the aircraft usually generates very little lift and does not act as a major source of aircraft lift [7]. Therefore, in this case, Bernoulli's law can be used for calculation.

According to Bernoulli's law, the pressure at the interface of a fluid in contact with an object decreases when the velocity of the fluid increases and increases when the velocity of the fluid decreases. During the low-speed advancement of an aircraft wing, the airflow between the upper and lower surfaces of the wing meets at its trailing edge showing a faster airflow on the upper surface and a slower airflow on the lower surface [8]. The difference in flow rates results in different pressures on the upper and lower surfaces, with slower airflow on the lower surface, so that the pressure on the lower surface of the wing is higher than that on the upper surface, resulting in upward pressure, i.e. lift. This pressure difference results in a vertically upward force of air on the wing, enabling the airplane to remain airborne. The force analysis of the aircraft is shown in Figure 1.

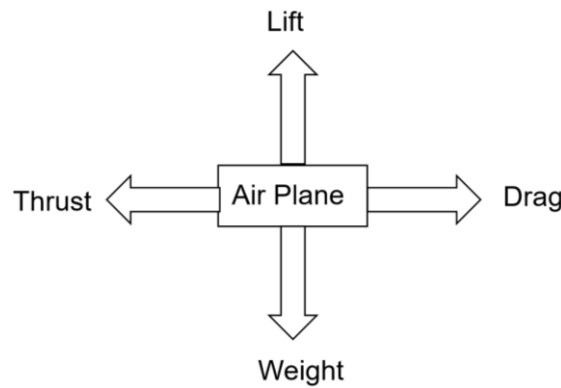


Figure 1. Force diagram of a glider in flight

2.1. Lift

A glider flying requires sufficient lift to maintain flight, which is generated primarily by using the difference in pressure between the upper and lower surfaces of an object as it moves [9]. The greater the difference in pressure between the upper and lower surfaces, the greater the lift generated. In glider flight, low pressure is generated on the upper surface of the wing, and high pressure is generated on the lower surface because air flows faster from the upper surface of the wing and slower from the lower surface. This creates an upward lift in the wing. The lift required for a glider can be calculated using equation (1):

$$L = \frac{1}{2} \rho V^2 S C_L \quad (1)$$

Where L denotes lift, ρ denotes air density, V denotes the relative speed of the aircraft to the airflow, S denotes wing surface area, C_L denotes wing lift coefficient.

It is important to note that gliders need a balance between lift and drag to maintain a stable flight speed in the absence of engine thrust. By optimizing the design of the wing and the way it flies, the lift of the glider can be maximized to extend the stalling time and flight distance. The pressure difference during glider flight is shown in Figure 2.

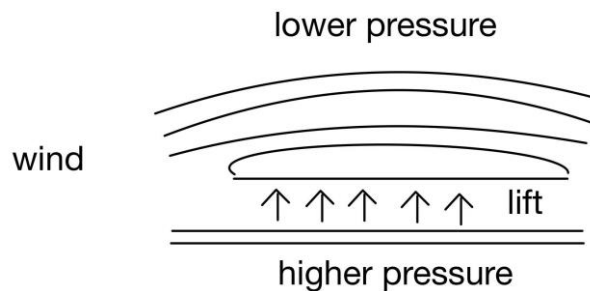


Figure 2. Pressure difference analysis during glider flight.

2.2. Increased Lift

The effect of the wing on the amount of lift produced varies from wing to wing, and the amount of lift produced will vary from wing to wing. The following are some of how lift can be adjusted by changing the wing:

Increasing the wing area: Increasing the surface area of the wing increases the pressure difference between the upper and lower surfaces of the wing, thus increasing the amount of lift produced. Therefore, selecting a larger wing area will increase the lift.

Increasing the airflow velocity: A prerequisite for a wing to produce lift is the need for a constant flow of air through it. If the velocity of the airflow over the wing is increased, the aerodynamic forces acting on the wing will also increase, resulting in greater lift. The speed of the airflow can be increased to increase lift by, for example, the use of a rocket boost.

Adjusting the airfoil shape: The density of air is related to the pressure, and the pressure increases as the density increases. Choosing a plano-convex airfoil and making its convex surfaces slightly more convex will increase the density of the airflow over the wing, thus increasing the pressure difference between the upper and lower surfaces of the wing, and thus increasing lift. As the glider falls slowly from a high altitude, the airflow is denser and lower down and can extend the glide time.

2.3. Drag

When an object moves through the air, it is subject to two primary aerodynamic forces: lift and drag. Drag is the resistance to the movement of an object through the air. It consists of two main components: frictional resistance and pressure resistance. Frictional drag is caused by the viscosity of the air and is influenced by the smoothness of the object's surface and the flow conditions on the surface. On the other hand, pressure drag arises from the pressure difference between the front and back of the object and is related to the shape of the object.

The smoothness of an object's surface directly affects the airflow over it. Reducing drag therefore consists primarily of making the surface as smooth as possible to minimize any obstructions that may impede the passage of airflow over the surface, such as the various protrusions on the wings. The shape of the object also plays a crucial role in determining pressure drag, with streamlined shapes resulting in lower pressure drag due to being smoother.

The formula is:

$$D = \frac{1}{2} \rho V^2 S C_D \quad (2)$$

Where D denotes drag, ρ denotes air density, V denotes the relative speed of the aircraft to the airflow, S denotes wing surface area, C_D denotes wing drag coefficient.

In addition to frictional, differential, and induced drag on an aircraft, there is also a type of "interference drag", which is the additional drag caused by different parts of an aircraft (e.g., wing, fuselage, and tail surfaces) interfering with each other when they are placed individually in the airflow. Interference Drag. This interference drag is not just the sum of the drag generated by the individual components but is usually less than the total drag generated when these components are assembled into a coherent whole. The interaction between these components in the airflow results in the creation of interference drag, which contributes to the overall drag experienced by the aircraft as it moves through the air.

3. Effect of Glider Airfoil Shape on Flight and Optimisation Design

3.1. Wing Design

Wings play a vital role in gliders. The wing of a glider usually consists of two parts: the main wing and the side wings. The main wing maintains the glider's attitude in the air by aerodynamically

generating lift to overcome the glider's gravity while the glider is in flight. The side wings are used to adjust the left and right tilt of the glider to restore and maintain the horizontal state of the wing.

3.2. Influence of Airfoil Shape

The lift of a wing comes from the difference in pressure between the airflow acting on its upper and lower surfaces. When the airflow passes over the wing, due to the wing's airfoil design, the airflow velocity increases on the upper surface and decreases on the lower surface, resulting in low pressure on the upper surface and high pressure on the lower surface, thus generating lift [10]. The profile shape of the wing, known as the airfoil shape, has a great influence on the amount of pressure difference between the upper and lower surfaces of the airflow and its drag. This effect is the aerodynamic performance of the airfoil. Therefore, the aerodynamic performance of an airfoil has a significant impact on the performance of an aircraft. The specific airfoil of an aircraft is shown in Figure 3.

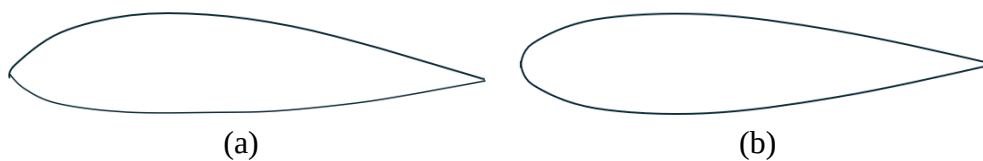


Figure 3. Glider wing profile. (a) Biconvex wing profile; (b) Plano-convex wing profile

A plano-convex airfoil is an aircraft wing design with a flat upper surface and a raised lower surface. This airfoil is designed to take advantage of the difference in air pressure between the upper and lower surfaces to generate lift while minimizing drag. The plano-convex airfoil is widely used in aeronautical engineering because of its ability to provide good lift and low drag, thereby improving aircraft performance and fuel efficiency.

A biconvex airfoil is a design of an aircraft wing that has a curved upper surface and a curved lower surface of the airfoil. As air flows over the curved upper surface of the airfoil, it increases in velocity compared to the air flowing underneath the wing. According to Bernoulli's principle, this difference in airflow velocity results in a lower pressure on the upper surface than on the lower surface, resulting in lift. The specific curvature and dimensions of the biconvex airfoil have been carefully designed to optimize lift generation while minimizing drag, ultimately contributing to the overall efficiency and stability of the aircraft during flight.

The wings of an aircraft can also be classified according to the shape of the plane viewed from the top: flat, swept-back, and swept-forward which is shown in Figure 4.

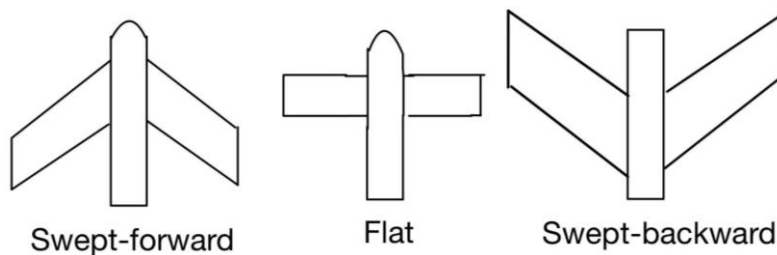


Figure 4. The shape of the plane

A flat wing is a wing with no significant swept-back angle and has a rectangular, trapezoidal, or semi-elliptical planform shape. Simple structure, easy to manufacture, higher lift efficiency, and higher drag is the current mainstream wing type.

A swept-back wing is a wing in which both the leading and trailing edges are swept back. It can reduce the drag of the aircraft when flying and is more suitable for high-speed flight. Variable swept-back wings were subsequently developed, which means that the swept-back angle of the wing can be changed during the flight of the aircraft. It has high flexibility and can be suitable for low-speed flight and high-speed flight, but has a complicated structure, many restrictions, and a high failure rate.

The forward-swept wing is the opposite of the back-swept wing, the shape of the forward-swept wing is characterized by the fact that both its leading and trailing edges are swept forward, i.e., the swept angle is acute. Characterized by good low-speed performance, high available lift, and high aerodynamic efficiency of the wing, the disadvantage is that the wing is easy to bend and deform [11].

3.3. Discussion

The design of the plano-convex airfoil enables the aircraft to remain stable at different speeds and altitudes, so the plano-convex airfoil is safer and has higher lift and lower drag, and because the plano-convex airfoil is the most convenient of all airfoils to be produced in large quantities. Therefore, it is widely used in some low-speed aircraft which do not have high requirements.

Biconvex airfoils have a wide range of applications in aviation. Biconvex airfoils are designed to improve flight performance by increasing lift and reducing drag. Moreover, the aerodynamic performance of the biconvex wing type is superior and can be applied from low speed to subsonic speed up to supersonic speed. At the same time, biconvex wings are easy to machine, and have good structural characteristics, and the addition of rudders and other aids to the wing can significantly improve performance.

The internal structure of the flat wing is relatively simple, easy to install, and suitable for low-speed flight and due to the large aspect ratio of the flat wing, the relative thickness is also larger, which makes the aircraft obtain a larger lift at lower speeds, and the wing shape of the flat wing has been optimized, so that the drag during flight is relatively low, which makes the aircraft more efficient during flight. However, it is not suitable for high subsonic flights: as the flight speed increases to high subsonic speeds, the leading edge of the flat wing generates excursions earlier, leading to an increase in drag.

Swept-back wings can delay surge generation, primarily because they reduce the effective velocity over the wing and because they increase the critical Mach number by keeping the velocity component of the airflow perpendicular to the leading edge of the wing lower than the speed of flight, delaying the generation of surges and helping to attenuate surge intensity and reduce drag. However, to support a variable wing swept-back angle, the wing must consist of a variable mechanism, which increases the complexity of the mechanism and the number of parts, as well as increasing the weight of the airframe, decreasing reliability, and increasing production complexity and maintenance costs.

The forward-swept wing structure can ensure a good connection between the wing and the fuselage, and reasonably distribute the pressure borne by the aircraft, to improve the aerodynamic performance of the aircraft during maneuvers, especially during low-speed maneuvers. In addition, under subsonic flight conditions, the forward swept wing technology can significantly improve the maneuverability of the aircraft, especially when flying in elevation [12]. Compared with a rear-swept-wing aircraft with the same wing area, a forward-swept-wing aircraft has greater lift and payload, which can reduce the wing size, lower the head-on drag, and reduce the structural weight, thus increasing the subsonic range, improving the low-speed maneuvering performance, and shortening the take-off and landing taxiing distance. However, forward-swept wing aircraft also have some disadvantages: forward-swept wing aircraft on the aircraft material requirements are very harsh, even if the use of lightweight high-strength materials, will lead to the wing because of the lack of torsional stiffness and breakage.

4. Conclusion

This article adopts the idea of changing the wing shape to study the influence of gliding wing shape on the stability of gliders. The conclusion drawn from studying the resistance and lift provided by different airfoils is that the use of forward-swept biconvex airfoils can provide gliders with higher overall efficiency and wing stability during flight compared to flat-convex airfoils. However, due to manufacturing difficulties, the implementation of forward-swept biconvex airfoils in curved surface production is more difficult and expensive to fabricate. In addition, long-term use can easily lead to bending, deformation, and even fracture of the forward-swept wing shape. Material technology is

expected to improve the performance of gliders in the future. In future research, materials and manufacturing processes will be focused on exploring advanced wing design and manufacturing methods with high strength and low cost.

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