The Relationship Between Aspect Ratio and Lift/Drag Ratio

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Abstract. Modern aircraft requires a reliable structural design, and the Lift/Drag ratio possesses irreplaceable features in such a design. Most of the current experiments are based on passenger aircraft models and few are conducted on the Lift/Drag ratio of gliders. The value of the Lift/Drag ratio is related to several factors. This paper discusses the relationship between aspect ratio and Lift/Drag ratio. At first, brief corresponding knowledge is provided while predicting such a relationship based on related theorems. Then, an experiment based on self-constructed aircraft is conducted to obtain practical data. Finding that as the wingspan ratio increases, so does the lift-drag ratio. The disadvantage is that the environment is subject to more unstable factors. The experiment can be more accurate if it changes the field without wind. This experiment can provide more realistic experimental data in the field of gliders. The innovative idea of this experiment can be extended to many experiments. Finally, the data are analyzed to form the result. By comparing the result and prediction, the deficiencies in this experiment are discovered in the experiment and improvements are provided. In the end, the whole process and prediction of the future development of related technologies were concluded. By exploring the Lift/Drag ratio of the glider model, the data of the Lift/Drag ratio of the glider can be perfected. The innovation of this experiment can also be applied to research in different fields.

Keywords: Glider research; Lift-Drag ratio; Aspect ratio; Angle of attack; Glider experiment.

1. Introduction

The Lift/Drag (L/D) ratio refers to the ratio of the lift generated by the wings of an aircraft to the aerodynamic drag it experiences. The L/D ratio has a significant impact on aircraft flight. Lift is the force perpendicular to the direction of aircraft motion, enabling the aircraft to overcome gravity and maintain flight. Drag, on the other hand, is the force acting in the opposite direction to the aircraft's motion, impeding its forward progress and consuming fuel. Improving the L/Dratio offers the following advantages [1]; Increased climb performance: Increasing the L/D ratio allows the aircraft to reach the desired altitude at a faster speed [2]. Improved fuel efficiency: A higher L/D ratio leads to a decrease in aerodynamic drag, resulting in reduced fuel consumption and improved fuel efficiency. 3) Extended time in the air: Increasing the L/D ratio reduces fuel consumption, thereby extending the aircraft's flying time. 4)Increased range: By improving the L/D ratio, the aircraft can fly farther with the same fuel and payload, thereby increasing its range.[3] The design of modern aircraft should consider both lift-drag ratio and velocity to find the most energy-efficient way to drive. Aircraft designers are constantly tweaking tiny details to improve flight performance. In some situations, the velocity increases sharply, but the lift-drag ratio decreases, which means that the plane is subjected to greater drag during flight. Aircraft designers are constantly balancing between lift-drag ratio and maximum velocity. Different kinds of aircraft are used in different areas of work. For example, manned aircraft’s and cargo aircraft’s design often demand a high lift-drag ratio to have less air drag during the flight process. Such demand would cause manned aircraft and cargo aircraft to have lower fuel consumption to achieve maximum profits. Warcraft need high velocity and agility, such aircraft always have higher cost and fuel consumption because of special materials and different design. In this field of exploration, aircraft designers and scientists are studying constantly. Different types of airplanes have different Lift/Drag ratios. As shown in the graph, gliders have the highest L/D ratio when the speed is between approximately 50 and 300km/h, indicating that gliders have a significant L/D ratio.

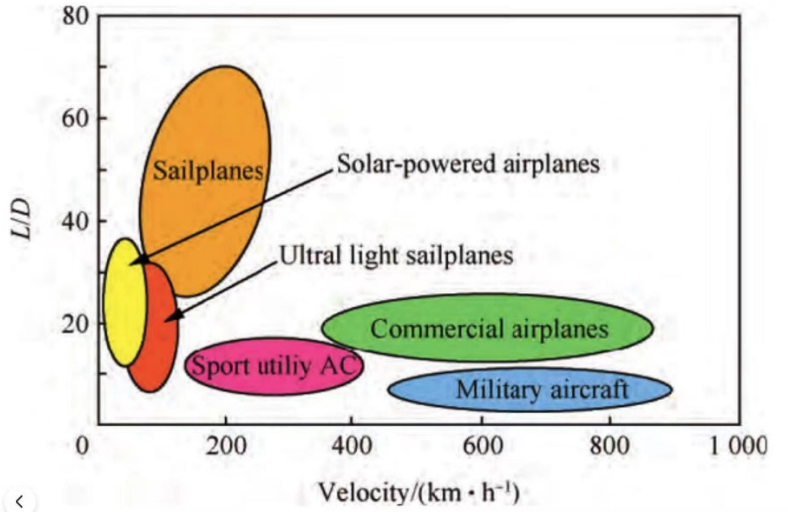


Fig. 1 Aircraft categorize.

There are several ways to enhance the L/D ratio [4]. Increasing the L/D ratio by changing the volume of the fuselage [5]. By extending a theorem to the plane surface of an aircraft wing, the optimal solution is found [6]. New technologies are used in aircraft, such as the plasma Gurney flap, which has many advantages, such as active control ability and little drag force [7]. Through the experiment in the wind tunnel, the coefficient is calculated by a mathematical method, and then corresponding improvement is made [8]. The relationship between the stability value of the roll and the Lift/Drag ratio is calculated by setting the function. Through the function calculation, the optimal value is calculated. These approaches can also be applied to improve the L/D ratio, such as improving the smoothness of the aircraft's surface to reduce frictional drag [9]. Aerodynamic optimization techniques, such as boundary layer control, can be employed to increase lift. [10] Modifying the wing's shape, such as increasing the Oswald coefficient or optimizing maximum thickness and camber, is another avenue to explore. However, these studies are based on theory but lack real flight experiments. They also ignore certain variables that affect the flight of an airplane. In conclusion, lift and drag are crucial considerations in aircraft aerodynamic design, directly impacting performance, fuel efficiency, and safety. Our research focuses on the relationship between the aspect ratio and the L/D ratio. The results were expected to demonstrate a direct correlation between an increased aspect ratio and a higher L/D ratio. To support our paper's aims to influence future improvements in aircraft wing design, leading to enhanced fuel efficiency, improved safety, and overall performance.

2. Theory and Prediction

2.1. Preknowledge of Lift and Drag

The section headings are in boldface capital and lowercase letters. Second-level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph). Lift and drag forces are key features to consider during aircraft design, and they could be calculated by the following formulas:

$$L = \frac{1}{2}\rho S_{ref} C_L V^2 \tag{1}$$

$$D = \frac{1}{2}\rho S_{ref} C_D V^2 \tag{2}$$

Where D denotes drag, L denotes lift, S denotes wing surface area.

V denotes velocity, C_L denotes lift coefficient, and C_D denotes drag coefficient.

According to the above formulas, forces are calculated using their corresponding coefficients, whose calculation and relationship are shown below:

$$C_L = C_{L0} + a\alpha \tag{3}$$

$$C_D = C_{D0} + \frac{1}{\pi are} {C_L}^2 \quad (4)$$

Where C_{D0} denotes Drag coefficient at zero lift, a denotes gradient, α denotes angle of attack, e denotes Oswald efficiency, ar denotes aspect ratio

Based on formula (1), the Lift/Drag ratio is represented by the formula below:

$$\frac{Lift}{Drag} = \frac{C_L}{C_D} \quad (5)$$

The aspect ratio is defined to be as follows:

$$ar = \frac{wing\ span}{average\ chord} \quad (6)$$

2.2. Background knowledge of hydromechanics

During the period of flying, the air above and below the wings has three kinds of energy:

kinetic energy, potential energy, and potential pressure energy. From the energy conservation law, these three kinds of energy add up to a constant. It can be written as:

$$\text{constant} = \frac{1}{2}\rho v^2 + p + \rho g h \quad (7)$$

The upper surface which curves upwards of the wing has a faster wind flow. Based on energy conservation, the kinetic energy increases as the pressure energy decreases. Such a relationship leads to the lower pressure of the upper part. Because of the pressure difference, the wing has exerted a lift perpendicular to the free-stream velocity, and the angle between the relative wind and chord is called the angle of attack.

2.3. Prediction of aspect ratio

Before introducing the corresponding experiments, it is important to provide a reasonable estimate. The Lift coefficient is calculated by the formula (2), where C_{L0} and a are defined by constants based on experience. C_L is then taken to formula (3) where the value of C_{D0} is defined as 0.02. By using formula (3), the aspect ratio can then be calculated, which could then be calculated using the Oswald efficiency calculator, 0.87.

3. Experiments

3.1. Preparation of making glider

A glider was constructed for experimental usage. Such a glider was separated into several parts. The glider's wing was curved by two mental rods to create lift which is caused by pressure difference. The length of the wing was measured at 55 cm. Three foam boards also were prepared which were used as the fuselage. A foam board was dug to create space which was used to place the battery, electric system controller, and motor connecting these three boards by glue. The empennage also took indispensable responsibility in flying. It contains an elevator, rudder, and other parts of the plane. The rudder and elevator were linked with a mental rod that controlled the movement track by the electric system controller. These designs help achieve yaw. The different parts were linked by the largest rod (length 42cm) in series. Ailerons were connected by an electric motor controller, too. The propeller driven by a motor was placed behind the wing to provide the forward thrust.

3.2. Experiment process

There are multiple approaches to improving the L/D ratio, such as enhancing the surface smoothness, optimizing aerodynamics through boundary layer control, and modifying the wing's shape. A decision was made about measuring the L/D ratio by adjusting the wing's area.

The L/D ratio is calculated by height per unit of descent divided by the maximum distance to glide forward when under no power conditions. To begin with, height changes by landing on different

stages from the same height. A slide was chosen that has many steps along the side. After a period of measuring, it found the building doorway flows a strong wind which influences the flying track. Because the point is a slide, it was hard to measure the highest point directly.

Another position was chosen that has less wind stream. Such a position can provide a more stable environment to glide. Moreover, this position was a flat countertop which measured more easily than a slide. The change in vertical height is more accurate. The position is conducive to the authenticity and accuracy of results. five steps were measured, respectively (first step 40cm, second step 33 cm, third step 30cm, fourth step 40 cm, fifth step 32 cm). The plane was thrown by a man at 170cm in height. The top point-to-bottom height was 345cm. The top point of the first stage was 305cm. The top point to the second stage was 272cm. The point to the third stage was 242 cm.

To begin with, the plane's engine must be shut down at the same horizontal position to ensure the horizontal distance measurement starts from the same point.

data was recorded without the change in wingspan of the aircraft gliding flight distance at different vertical distances. Every stage was measured 3 times. 12 sets were got of data in the end.

To research the influence of the wing's area, an external area was added (21 square centimeters). The above steps were repeated to get another 12 sets of data and draw the Lift-Drag ratio.

In the last experiment, another external wing was added (15 square centimeters) to extend the wing's area. In total, 36 sets of data were measured and prepared to draw a Lift-Drag ratio diagram to illustrate the influence of the wing's area.

4. Data analysis

After experiments, analysis took place to find out the theorems and relationships inside the phenomenon. During the whole analysis process, the theorems were discovered from processing data to suit the practical.

4.1. L/D ratio and aspect ratio

By measuring glided distance and glided height, a distance-height graph is formed where the average gliding distance at different heights for the original wingspan, wing with 3cm extra span, and wing with 6cm extra span is represented in Fig. 2 with the color's red, blue and black. Such dots are fitted into straight lines using polynomial fitting to show their variations.

Because during the flight, the angle of attack is controlled to nearly zero difference, while the gradient represents the L/D ratio, an increase in gradient could lead to the result that the L/D ratio increases with the aspect ratio.

From the gradient calculation of each three lines, it could be discovered that all gradients of the segment have increased. It means that the L/D ratio of aircraft with the same wingspan ratio approaches a constant.

It also can be observed that the gradients increase from the red segment to the black segment. So, the gradient has increased in the increase of aspect-ratio. It means that the L/D ratio has significant increases by increasing the aspect ratio.

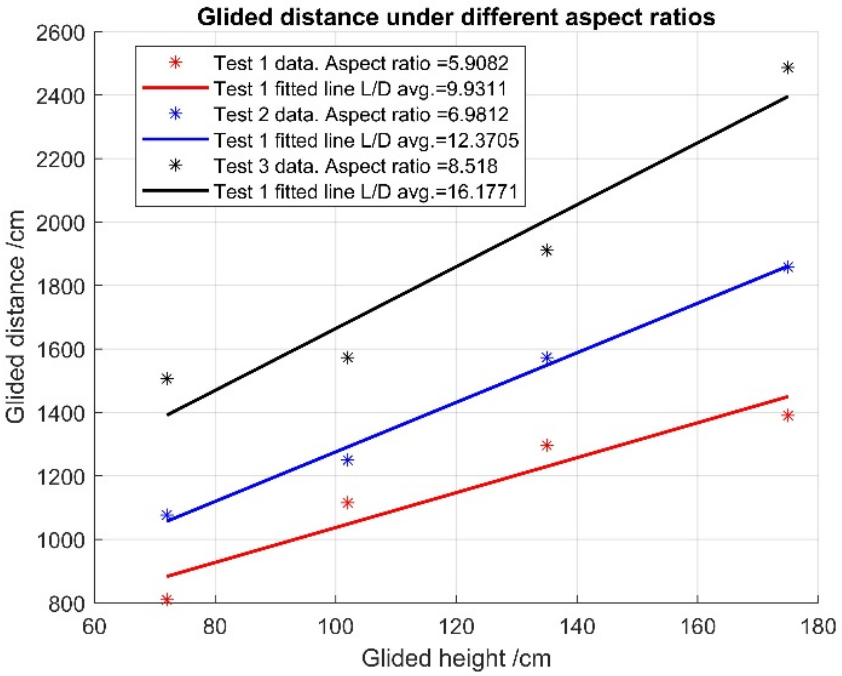


Fig. 2 The glided distance/height ratio graph

4.2. L/D ratio and angle of attack

By using formula (3) combined with related data in reality, the ideal change of the L/D ratio with the rise in aspect ratio in different aspect ratios is represented by three solid curves in Fig. 3. The data were recorded based on the experiment formed by dots in the graph. After using the polynomial fitting, the fitting curve surprisingly stuck close to the ideal curve, which proved the correctness and accuracy of the prediction.

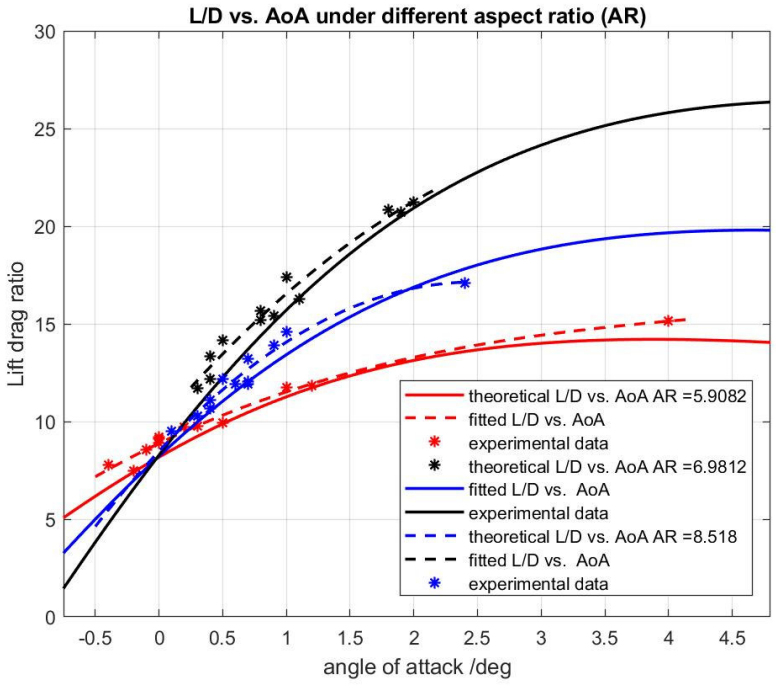


Fig. 3 The L/D ratio and angle of attack graph

Both three-line segments showed an increasing trend, and the gradient gradually becomes flat. This means that as the angle of attack increases, the L/D ratio also increases until it becomes a constant. Even the red segment shows that the gradient is going to drop at the angle of attack of 4.

It can be observed that gradients increase from red to black. This also shows that as the wingspan ratio increases, at a fixed angle of attack, the larger aspect ratio has a higher L/D ratio.

4.3. Discussion

Through personal experiments, relatively accurate manual measurements, and statistical data, the expected results have been obtained and the drawing image is also consistent with the expected results. Thanks to innovative ideas, I make the best use of local terrain. The disadvantage of inaccurate vertical height measurement is successfully avoided.

Though the above graphs are drawn with accuracy, several features still prove that the experiment is done with errors, such as the unfitted dots in Fig. 2. Several reasons and factors are likely to be the cause.

Due to the facility limitation, some unrelated factors are not controlled properly, which might influence the measurement. To measure the gliding, the aircraft turned off its power after reaching the required height. However, in outdoor testing, the wind is hard for an unpowered aircraft to overcome, which means the effect of the wind on gliding performance is unavoidable. Another influencing factor is the changing take-off position, due to place limitations, data is measured at different starting points while the measure brought the error itself at the same time. The method of camera shooting is also a problem, videos are required to be taken to measure the angle of attack during the flight, while parallax error occurred at the same time. Finally, the aircraft was not built in a directly proper way, so damages and flaws were made during the construction and experiments. Such imperfections might affect flight performance.

4.3.1 Methods improvement

During the experiment, the initial methods were discovered to be deficient. Improvements in throwing and driving aircraft were done to accurate the results.

In the beginning, the method was to launch the plane by lifting it over the head. The advantage of doing this is that the force applied to the plane during projection is greater compared to the second method, resulting in a higher initial velocity that can partially counteract air resistance and make the airplane fly more stably. The reason that this method was given up is that it couldn't show the angle at which the plane was released, making it impossible for us to effectively control the angle. Therefore, another method that decided to evolve, is the second method.

The second method involves launching the plane at the same height as the eyes. The advantage of this approach is that it solves the problem of not being able to control the release angle. However, the disadvantage is that it is very difficult to generate enough force, resulting in a low initial velocity that is insufficient for takeoff. After multiple attempts, this method also was given up.

The third method addresses the shortcomings of the previous two methods and combines the advantages of both. Firstly, the left arm is extended to the right side to align the body and the arm on the same line. Then, the arm is kept perpendicular to the forearm. The left foot is placed in front and the right foot is placed behind, with the same width as the shoulders. The forearm swings back and forth before releasing the plane. During the launch, the waist rotates to the right, propelling the arm forward. This method allows for angle control and provides enough force to achieve a sufficient initial velocity, thus enabling the plane to take off. This is the method that has been developed through countless failures and careful analysis.

When driving the aircraft outdoors, overcoming the wind is a key problem to solve. The experiment requires the aircraft to glide and land at a constant angle of attack, so the driver needs to keep pulling up using the elevator. At the same time, to keep the flight steady when facing the wind, a rudder was used to overcome the push force exerted by the wind. Another improvement on landing is to keep the gliding initial velocity constant, this was achieved by using higher power to push up to different gliding heights while keeping the power the same each time.

5. Conclusion

In this paper, the relationship between the aspect ratio and the Lift/Drag ratio of aircraft is studied using the experimental method of control variables. It is found that the Lift/Drag ratio may increase with the increase of aspect ratio in a certain range. The paper predicted and proved the relationship between aspect ratio and Lift/Drag ratio. The results showed that the Lift/Drag ratio increases with the aspect ratio. According to the whole process, an aircraft was built and tested to investigate its features. To test the required variable, efforts were made to control other related variables. The angle of attack and initial velocity were controlled, though wind and other unavoidable factors still influenced the result. In the future, an indoor testing place to avoid wind effects is planned to be chosen, multiple cameras may be set up to eliminate the parallax error. Also, different types of aircraft may be tested to discover the effect of different structures on gliding and Lift/Drag ratio, such an experiment could prove the universality of the discovered theorem. Another suitable improvement for future corresponding experiments is to increase the range of test height to handle the situation even more fully. Lastly, other factors could be introduced to discover extra related variables influencing the Lift/Drag ratio. In this experiment, the wingspan ratio is taken as the variable under the realistic environment. To explore the relationship between the lift-drag ratio. The value of the lift-drag ratio with the change of Angle is also explored, and the expected trends are accurately fitted. The most important thing in this experiment, is reasonable use of the surrounding terrain, through the height difference of the steps, to achieve accurate vertical height transformation. The stable and accurate value is also obtained by accurate and patient measurement. Nowadays, with the advancement of technology, the Lift/Drag ratio of aerial vehicles is also worth exploring. There has been a lot of exploration of how to improve the lift-drag ratio with drones. In the future, the manual measurement method may be reduced, and the integrated function calculation of the sensor software inside the drone may be used to calculate the most appropriate design method. This may further increase the accuracy of the experiment and greatly improve the performance of aircraft, achieving technological progress.

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