# Aerodynamic Characteristics Analysis of the Lift-to-Drag Ratio of Gliders and Their Wing Shape

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**Abstract.** A glider is a kind of fixed-wing aircraft that does not use any power. After takeoff, it relies on the reaction force of the air acting on its lifting surfaces for free flight. So, an experiment is designed to research some information and the relationship between gliders. The method of controlling variables is used to study the theme and compare the data from different experiments to get a result. The experimental results are consistent with the actual law. For example, although the process of making the paper glider has some problems, the behavior of the glider would not be observed, so that the gravity point may have a large difference that influences the flight. In this case, there are no checks and changes on the glider in the experiment. This is a mistake of people who do this experiment, which causes the result to become different. The theories are summaries of natural phenomena and laws. These theories need to be proved, and the experiment can verify their correctness, so experimenting is essential and meaningful. In addition, new phenomena may be found in the new study, which can lead the next and further research. In this process, it may promote the development of new technologies and skills and improve creativity.

**Keywords:** Lift-to-Drag ratio, Paper glider, Glider flight.

## 1 Introduction

Birds fly in the sky by flapping their wings and can change direction by altering the angle of their wings. In this case, the flight of birds is closely related to aircraft such as gliders, because the flight of planes is designed based on the flight of birds. The model is shown in Figure 1. Nowadays, planes are designed to become better as technology develops. So, an experiment was designed using paper airplanes to research the gliders. Although a paper airplane is simple, it involves complex aerodynamics. Through experiments, scientists can explore the force conditions, airflow distribution during flight, and the influence of different shapes and structures on flight performance, thereby providing a theoretical basis for the design of new aircraft. In this case, the gliders can be designed to become better. The most crucial factor is about lift-to-drag ratio. Some theories of the relationship between lift-to-drag ratio and their wing shape can help the gliders have better flying behaviours. In some literature reviews, they show many results. A good connection can be ensured by the forward-swept wing structure between the wing and the fuselage. The forward-swept wing structure also reasonably distributes


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the pressure that the aircraft bears, in order to improve the aerodynamic performance of the aircraft during maneuvers, especially during low-speed maneuvers. In addition, gliders with rectangular wings have better dynamic stability with higher lift force because they have a larger wet area, which offsets the roll moment. Besides, the maximum lift coefficient of flying fish is measured at α=30–35 degrees, where the airplane is observed. The lift-to-drag ratio is largest at α=–5~0 degrees, which indicates that the best gliding performance can be achieved when the airplane glides nearly parallel to the sea surface. When the lateral dihedral angle of fins reduces, the lift coefficient slightly increases [1-3]. Many papers show that they can improve the performance of different gliders through optimizing the lift-to-drag ratio that relates to the angle of pitch and the area of wings. In addition to the enlarged pectoral fins, the large pelvic fins have an important role in enhancing the lift-to-drag ratio and longitudinal static stability. The enhancement of the lift-to-drag ratio from the pelvic fin is attributed to the jet-like flow existing between the pectoral and pelvic fins. However, there are many problems in the experiments. This is because the area and the shape of the wings cannot be ensured to be the same completely because a machine cannot be utilized to control them to be accurate and precise, but they are made as similar as possible in the experiment. This may cause some problems with the analysis due to the large error. However, these data can still be compared roughly to get a result because the laws between different experiments' comparisons are similar. More precise equipment is only used to measure the conditions of a paper airplane. This article aims to find the relationship between lift-to-drag ratio and wing shape by making a paper plane do a simple experiment, which can be done at home and does not require a large space to allow the plane to fly. This provides a convenient way to do this experiment.

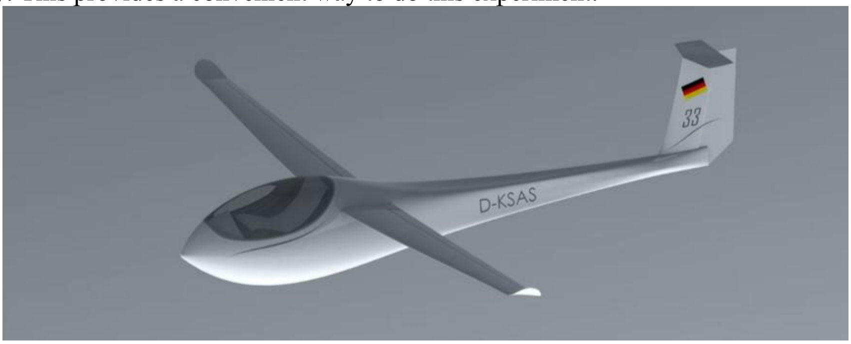


**FIGURE 1.** Glider model drawing. (Picture credit: Original)

# 2 Methodology

## 2.1 Relative Equation and Knowledge

According to aerodynamic theory, the lift L generated by the wing of a glider can be represented by the formula $L = \frac{1}{2}\rho v^2 SC$. In Formula (1), ρ is the air density, v is the flight speed of the glider, S is the wing area and C is the lift coefficient. General force analysis of gliders is shown in Figure 2.

Lift-drag ratio formula: Lift-drag ratio K = L/D = CL/CD. When the wing area changes, both lift and drag will be affected, and then the lift-drag ratio will be affected.

The definition of the density is mass per unit volume of a fluid, usually denoted by p. The density is a constant value for liquids, but it is a function of temperature, T, and pressure, p, for gases. Indeed, for a gas, p and T are related by the equation of state.

$$P = pRT \tag{1}$$

where R is a constant value of the universal gas. Its value can be found in Appendix A1 for both the English and SI systems. T, in Equation (1), is the absolute temperature measured in degrees Kelvin in the SI system and degrees Rankine in the English system [4].

The downward velocity is proportional to the change of circulation and inversely proportional to the geometry of the wing. Unfortunately, circulation is a function of the lift coefficient, and this depends on the induced angle of attack and downwash velocity. Therefore, this equation is in implicit form and must be solved numerically. Start of the calculation process is from the preparation of a geometrical model. In this case, the initial induced angle of attack distribution is estimated (set to zero or adopted from the previous solution). The total angle equals the sum of the induced angle, wing angle, and twist angle [5].

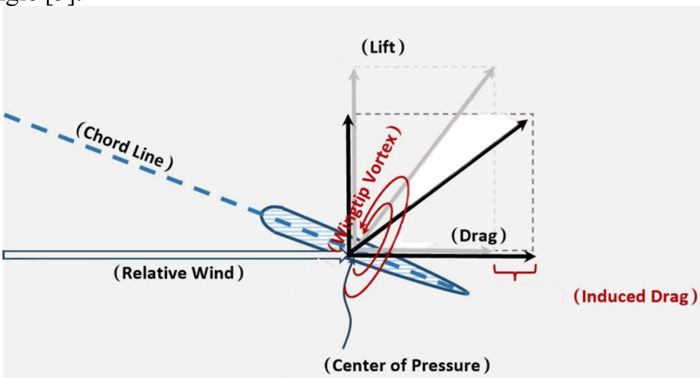


**FIGURE 2.** Forces acting on the glider. (Picture credit: Original)

## 2.2 Method

Videos are taken by a camera to track the trace of the gliding plane. Then, the videos are uploaded to the tracker to extract the data from the trace.

The ruler is used to measure the length of the wing. Then the wing area and the aspect ratio can be calculated.

Many paper planes are made, and three are finally chosen. They can glide slowly so that data can be collected from their traces.

The control variable method is used.

Three sets of experiments are conducted using the three planes. The first group is set as the control group. The second group is taken out by the plane with the same area of each wing but a different ratio from the first plane. The third group used the plane with

different areas of each wing, but the same aspect ratio as the first plane. The paper of the same size (A4) is used to make paper planes. Thus, the three planes have similar weight. Also, all videos were shot in the same environment without wind.
During the process of making planes, several groups of planes with different areas are obtained by folding the paper at different angles. Then the aspect ratios are calculated by AR equals the square of the length over the area.
And the angle of folding several times is changed to achieve different areas with the same aspect ratio.

## 3 Results and discussions

The dynamic movement of a glider uses the gravitational potential energy of the aircraft body and the kinetic energy. The gravitational potential energy is generated by the height of the aircraft's body and transforms the kinetic energy of the aircraft's body through the height difference, providing propulsion for gliding. The glider's flight process is shown in Figure 3. The lift of a glider is mainly generated by the wings and is related to factors such as the shape and area of the wings, flight speed, and angle of attack. Drag includes frictional drag, induced drag, and so on, which will affect the flight performance and speed of the glider.

The relationship between wing area and lift is very close. In other theories, under the condition that other factors remain unchanged, when the wing area S is larger, the lift L will be larger. This is because a larger wing area means that more air interacts with the wing surface, so that it can generate greater lift to support the weight of the glider.

In another similar study, flow field analysis of the vehicle in various flight states showed that the vehicle can match the corresponding shockwave angles at different inflow velocities because it can adjust the wing opening, thus a certain waverider effect is generated, and overflow is minimized from the lower surface to the upper surface. Analysis of the pressure field indicates that a higher-pressure difference between the lower and upper surfaces is maintained by wing deployment. Overall lift performance is also enhanced effectively [6]. When airplanes fly near the ground, the flyers can obtain considerable advantages in aerodynamic performance. It has been suggested that the flying fish takes advantage of the ground effect that is to increase the lift-to-drag ratio to prolong the gliding distance, especially during take-off and the end phase of the flight [7].

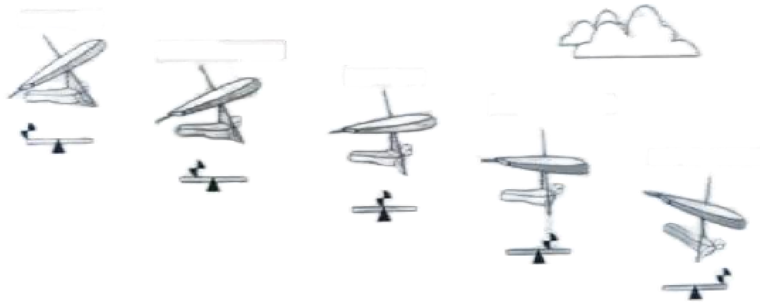

**FIGURE 3.** Glider flight process photo credit. (Picture credit: Original)

The data in Tables 1-6 is collected by trackers.
Data of the plane: weight: 0.0428N
Experiment 1: area of 163 cm^2: aspect ratio (AR): 0.08824; wing width:12 cm.

**TABLE 1** Basic data of the paper glider for experiment 1

| t | Angle theta | CL/CD | Magnitude U |
|---|---|---|---|
| 0.033S | 0.76rad | 1.16 | 655 |

**TABLE 2** Data of flight process for experiment 1(wing length=10.5cm, area=132, AR=0.8311)

| t | X | y | Angle theta | Tan theta | CL/CD | Speed Ux | Speed Uy | Magni-tude U |
|---|---|---|---|---|---|---|---|---|
| 0 | 333 | -29.5 | 0.269167493 | 0.275862069 | 3.625 | -439.3939394 | -121.2121212 | 455.806332 |
| 0.033 | 318.5 | -33.5 | 0.2153577 | 0.21875 | 4.571429 | -470.5882353 | -102.9411765 | 481.715863 |
| 0.067 | 302.5 | -37 | 0.2153577 | 0.21875 | 4.571429 | -484.8484848 | -106.0606061 | 496.313314 |
| 0.1 | 286.5 | -40.5 | -0.033320996 | -0.033333333 | -30 | -454.5454545 | 15.15151515 | 454.7979 |
| 0.133 | 271.5 | -40 | 0.35877067 | 0.375 | 2.666667 | -470.5882353 | -176.4705882 | 502.588456 |
| 0.167 | 255.5 | -46 | 0.134321442 | 0.135135135 | 7.4 | -560.6060606 | -75.75757576 | 565.701658 |
| 0.2 | 237 | -48.5 | 0.362544237 | 0.379310345 | 2.636364 | -439.3939394 | -166.6666667 | 469.941285 |
| 0.233 | 222.5 | -54 | 0.263963724 | 0.27027027 | 3.7 | -544.1176471 | -147.0588235 | 563.640232 |
| 0.267 | 204 | -59 | 0.43833656 | 0.46875 | 2.133333 | -484.8484848 | -227.2727273 | 535.472638 |
| 0.3 | 188 | -66.5 | 0.28897541 | 0.297297297 | 3.363636 | -560.6060606 | -166.6666667 | 584.856335 |
| 0.333 | 169.5 | -72 | 0.170735211 | 0.172413793 | 5.8 | -426.4705882 | -73.52941176 | 432.76291 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.367 | 155 | -74.5 | 0.397079445 | 0.419354839 | 2.384615 | -469.6969697 | -196.969697 | 509.325343 |
| 0.4 | 139.5 | -81 | 0.415492096 | 0.441176471 | 2.266667 | -515.1515152 | -227.2727273 | 563.057702 |
| 0.433 | 122.5 | -88.5 | 0.546788841 | 0.608695652 | 1.642857 | -338.2352941 | -205.8823529 | 395.96800 |
| 0467 | 111 | -95.5 | 0.260602392 | 0.266666667 | 3.75 | -454.5454545 | -121.2121212 | 470.429536 |
| 0.5 | 96 | -99.5 | 0.626742901 | 0.724137931 | 1.380952 | -439.3939394 | -318.1818182 | 542.500418 |
| 0.533 | 81.5 | -110 | 0.475695219 | 0.515151515 | 1.941176 | -485.2941176 | -250 | 545.90327 |
| 0.567 | 65 | -118.5 | 0.499346722 | 0.545454545 | 1.833333 | -500 | -272.7272727 | 569.543822 |
| 0.6 | 48.5 | -127.5 | 0.616296937 | 0.708333333 | 1.411765 | -363.6363636 | -257.5757576 | 445.619429 |
| 0.633 | 36.5 | -1.30859283 | -3.72602739 | -0.26838 | 57.66192733 | -214.84992 | | 222.453111 |

Experiment 2: area of 163cm^2; AR: 0.74133; wing width:12 cm.

**Table 3** Basic data of the paper glider for experiment 2

| t | Angle theta | CL/CD | Magnitude U |
|---|---|---|---|
| 0.033S | 0.5rad | 1.8 | 731 |

**Table 4** Data of flight process for experiment 2 (wing length 11cm)

| t | X | y | Angle theta | Tan theta | CL/CD | Speed Ux | Speed Uy | magnitude |
|---|---|---|---|---|---|---|---|---|
| 0 | 279.1 | 2.15 | 0.463949 | 0.500376 | 1.998496 | -563.636 | -282.03 | 630.2595 |
| 0.033 | 260.5 | -7.157 | 0.271277 | 0.278134 | 3.59539 | -614.706 | -170.971 | 638.0394 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.067 | 239.6 | -12.97 | 0.404596 | 0.428221 | 2.335244 | -493.939 | -211.515 | 537.3219 |
| 0.1 | 223.3 | -19.95 | 0.370202 | 0.388095 | 2.576687 | -636.364 | -246.97 | 682.6073 |
| 0.133 | 202.3 | -28.1 | 0.463648 | 0.5 | 2 | -547.059 | -273.529 | 611.6304 |
| 0.167 | 183.7 | -37.4 | 0.552504 | 0.616556 | 1.621912 | -457.576 | -282.121 | 537.5574 |
| 0.2 | 168.6 | -46.71 | 0.364507 | 0.381557 | 2.620838 | -739.394 | -282.121 | 791.3885 |
| 0.233 | 144.2 | -56.02 | 0.463157 | 0.499387 | 2.002457 | -479.412 | -239.412 | 535.8672 |
| 0.267 | 127.9 | -64.16 | 0.563384 | 0.631674 | 1.583095 | -669.697 | -423.03 | 792.1166 |
| 0.3 | 105.8 | -78.12 | 0.463266 | 0.499523 | 2.00191 | -635.152 | -317.273 | 709.9855 |
| 0.333 | 84.84 | -88.59 | 0.506247 | 0.554441 | 1.803618 | -615.882 | -341.471 | 704.2111 |
| 0.367 | 63.9 | -100.2 | 0.389368 | 0.410317 | 2.437143 | -775.455 | -318.182 | 838.1941 |
| 0.4 | 38.31 | -110.7 | 0.502893 | 0.550064 | 1.817969 | -705.152 | -387.879 | 804.791 |
| 0.433 | 15.04 | -123.5 | 0.478934 | 0.519257 | 1.925828 | -855.294 | -444.118 | 963.7264 |
| 0.467 | -14.04 | -138.6 | 0.502893 | 0.550064 | 1.817969 | -705.152 | -387.879 | 804.791 |
| 0.5 | -37.31 | -151.4 | 0.616853 | 0.709169 | 1.410101 | -846.061 | -600 | 1037.217 |
| 0.533 | -65.23 | -171.2 | 0.505881 | 0.553964 | 1.805172 | -615.882 | -341.176 | 704.0685 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.567 | -86.17 | -182.8 | 0.495627 | 0.540637 | 1.849669 | -846.364 | -457.576 | 962.1367 |
| 0.6 | -114.1 | -197.9 | 0.589471 | 0.66879 | 1.495238 | -951.515 | -636.364 | 1144.701 |
| 0.633 | -145.5 | -218.9 | 0.557632 | 0.623656 | 1.603448 | -820.588 | -511.765 | 967.0926 |
| 0.667 | -173.4 | -236.3 | 0.485363 | 0.527446 | 1.895928 | -1269.7 | -669.697 | 1435.488 |
| 0.7 | -215.3 | -258.4 | 0.697087 | 0.837321 | 1.194286 | -633.333 | -530.303 | 826.0341 |
| 0.733 | -236.2 | -275.9 | 0.60149 | 0.686327 | 1.457031 | -1097.06 | -752.941 | 1330.586 |
| 0.767 | -273.5 | -301.5 | 0.660602 | 0.77707 | 1.286885 | -951.515 | -739.394 | 1205.025 |
| 0.8 | -304.9 | -325.9 | 0.818677 | 1.068875 | 0.935563 | -381.125 | -407.375 | 557.8626 |

Experiment 3: area of 132 cm^2; AR:83113; wing width:10.5 cm.

**TABLE 5.** Basic data of the paper glider for experiment 3

| t | Angle theta | CL/CD | Magnitude U |
|---|---|---|---|
| 0.033S | 0.3 rad | 1.5 | 490 |

**TABLE 6.** Data of flight process for experiment 3 (wing length 10.5 cm, area:132, AR:0.83113)

| t | X | y | Angle theta | Tan theta | CLCD | Speed Ux | Speed Uy | Magni-tude U |
|---|---|---|---|---|---|---|---|---|
| 0.0 | 333.0 | -29.5 | 0.269167 | 0.275862 | 3.625000 | -439.394 | -121.212 | 455.8063 |
| 0.0 | 318.5 | -33.5 | 0.215358 | 0.218750 | 4.571429 | -470.588 | -102.941 | 481.7159 |
| 0.1 | 302.5 | -37.0 | 0.215358 | 0.218750 | 4.571429 | -484.848 | -106.061 | 496.3133 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.1 | 286.5 | -40.5 | -0.033321 | -0.033333 | -30.000000 | -454.545 | 15.152 | 454.7979 |
| 0.1 | 271.5 | -40.0 | 0.358771 | 0.375000 | 2.666667 | -470.588 | -176.471 | 502.5885 |
| 0.2 | 255.5 | -46.0 | 0.134321 | 0.135135 | 7.400000 | -560.606 | -75.758 | 565.7017 |
| 0.2 | 237.0 | -48.5 | 0.362544 | 0.379310 | 2.636364 | -439.394 | -166.667 | 469.9413 |
| 0.2 | 222.5 | -54.0 | 0.263964 | 0.270270 | 3.700000 | -544.118 | -147.059 | 563.6402 |
| 0.3 | 204.0 | -59.0 | 0.438337 | 0.468750 | 2.133333 | -484.848 | -227.273 | 535.4726 |
| 0.3 | 188.0 | -66.5 | 0.288975 | 0.297297 | 3.363636 | -560.606 | -166.667 | 584.8563 |
| 0.3 | 169.5 | -72.0 | 0.170735 | 0.172414 | 5.800000 | -426.471 | -73.529 | 432.7629 |
| 0.4 | 155.0 | -74.5 | 0.397079 | 0.419355 | 2.384615 | -469.697 | -196.970 | 509.3253 |
| 0.4 | 139.5 | -81.0 | 0.415492 | 0.441176 | 2.266667 | -515.152 | -227.273 | 563.0577 |
| 0.4 | 122.5 | -88.5 | 0.546789 | 0.608696 | 1.642857 | -338.235 | -205.882 | 395.9680 |
| 0.5 | 111.0 | -95.5 | 0.260602 | 0.266667 | 3.750000 | -454.545 | -121.212 | 470.4295 |
| 0.5 | 96.0 | -99.5 | 0.626743 | 0.724138 | 1.380952 | -439.394 | -318.182 | 542.5004 |
| 0.5 | 81.5 | -110.0 | 0.475695 | 0.515152 | 1.941176 | -485.294 | -250.000 | 545.9033 |
| 0.6 | 65.0 | -118.5 | 0.499347 | 0.545455 | 1.833333 | -500.000 | -272.727 | 569.5438 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0.6 | 48.5 | -127.5 | 0.616297 | 0.708333 | 1.411765 | -363.636 | -257.576 | 445.6194 |
| 0.6 | 36.5 | -136.0 | -1.308593 | -3.726027 | -0.268380 | 57.662 | -214.850 | 222.4531 |

### 3.1 Analysis

In the first and second experiments, the aspect ratio is changed, and the area of the wings remains the same. The data is shown in Tables 1, 2, 3, and 4. Comparison between Tables 2 and 4 showed that for example, in line 1, the angle theta is 0.703368 in the first experiment and 0.463949 in second experiment; CL/CD is 1.179159 in the first experiment and 1.998496 in the second experiment; the magnitude of speed is 512.5546 in the first experiment and 630.2596 in the second experiment. This means that when the aspect ratio reduces, the angle theta also reduces, CL/CD increases, and the speed increases.

In the first and third experiments, the area of the wings is changed, and the same ratio is maintained. The data is shown in Tables 1, 2, 5, and 6. But when the third experiment was done, some problems were found, which is that the aspect ratio cannot be ensured to be constant, because folding two identical paper planes is very difficult. In this case, these two datasets are compared roughly. Comparison between Tables 2 and 6 shows that for example, in line 1, the angle theta is 0.703368 in the first experiment and 0.269167493 in third experiment; CL/CD is 1.179159 in the first experiment and 3.625 in the third experiment; the magnitude of speed is 512.5546 in the first experiment and 455.806332 in the third experiment. The differences in aspect ratio between the first and second experiments are larger than first and third experiments. The angle theta in the third experiment is larger than in the second experiment, and CL/CD also increases more, which means that the area also influences the angle theta and CL/CD. So, when the area reduces, the angle theta will be reduced, and CL/CD will increase. However, the speed becomes larger. This may be because of the difference in area, and maybe other factors.

Although the result is not in line with the actual theory, this may be because the number of experiments is too small, which means that an accurate result cannot be obtained, and the error of the equipment is also very large, like using a ruler to measure the length to calculate the area.

Influence of other characters of wings' changes on the whole glider:

1) The material of wings

In an experiment, to analyze which foil produces the best results, a plane with a speed of 29 m/s, and a glide angle of -3° is used. These are the optimum speed and glide angle. In this case, gliders perform best. This means that the foil's area is the only difference in all four simulations, which influences aerodynamic performance [8-9].

The choice of composite materials for F3F gliders is of utmost critical importance. Commonly used composite materials include carbon fiber-reinforced polymers

(CFRP), glass fiber-reinforced polymers (GFRP), and aramid fiber-reinforced polymers (AFRP) [10].

CFRP offers a high strength-to-weight ratio, with a tensile strength that can reach up to 5500 MPa and a density of only about 1.6 g/cm. This makes it an ideal choice for high-performance F3F gliders, International Journal of Frontiers in Engineering Technology, as it can significantly reduce the weight of the glider while maintaining high structural strength. However, CFRP is relatively expensive, with a cost per kilogram ranging from 60 - 250, depending on the quality and type. GFRP is more cost-effective, with a cost per kilogram of around 12 - 35. But it has lower mechanical properties compared to CFRP, with a tensile strength of 120 - 550 MPa. AFRP has excellent impact resistance, with an impact strength that can be 2 - 4 times higher than that of CFRP in some cases [10].

2)The shape of wings

It is often used in areas where impact protection is required, such as the wing's leading edges and the glider's nose. In a study comparing the impact resistance of different composite materials, it was found that AFRP could withstand impacts of up to 50 J without significant damage, while CFRP could only withstand impacts of up to 20 J [10].

# 4 Conclusion

In the experiment, when the aspect ratio increases, the angle theta increases, CL/CD reduces, and the magnitude of speed probably increases. Although there are tons of errors in these experiments, a simple rule appears from the experiments. Many aspects can be improved, such as experimental apparatus, human factors, and so on. For example, the error of time measurement by people cannot disappear due to response time, and the ruler for measuring the length of a paper airplane is not precise. Besides, the time of measurements is short and not enough to get the result. Through flight experiments, the actual flight data of the glider can be collected, such as flight speed, glide ratio, and turning radius. Based on this data, the design parameters are adjusted and optimized. In this case， the flight performance of the glider can be designed to improve. During the experimental process, various issues that were not anticipated in the theoretical design stage may occur with the glider. For example, in the flight experiment, it may be found that some components of the glider experience flutter under the action of high-speed airflow. If these problems are not discovered and solved through experiments, they will seriously affect the flight safety and performance of the glider. Every experiment is a valuable accumulation of experience. By analyzing and summarizing the experimental results, scientists can understand which design schemes are successful and which need improvement. These experiences can be directly applied to subsequent glider designs, avoiding repeating past mistakes and improving the design level and efficiency. For example, in the experiment of a certain type of glider, it was found that using a certain new composite material can significantly reduce the weight while maintaining good structural strength. Then, in subsequent designs, consideration can be given to promoting the use of this material. For this experiment, the method of making paper airplanes can be improved with better factors, such as new material or a better folding method. In addition, only the data is analysed and a simple law is obtained. Deeper theories are not considered. In this way, more experiments should be done and more information should be found to get a more reasonable and reliable law.

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