

Design of Glider Wing Shape and Research on its Aerodynamic Characteristics

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Abstract. The glider is a type of aircraft without a power device, which relies on airflow to obtain forward power and has important application value in environmental detection, rescue, and other scenarios. The wing shape of a glider is one of the biggest factors affecting its gliding performance. However, the quantitative mechanism by which specific airfoil parameters affect gliding performance is still unclear. This paper dives into the field of aerodynamics and analyzes which airfoil performs the best in realistic situations. Unlike traditional methods in which the only way to analyze such a foil is through rigorous testing in a wind tube, this paper uses two ways, both through simulation and idealized calculation to determine the best airfoil. The results demonstrate that the lift-to-drag ratio characteristics of NACA 4424 and NACA 4415 are better than those of NACA 64A210 and NACA 2412, but there is a certain difference between the simulation results and theoretical results, which may be related to the accumulated errors in the simulation and data processing processes. This study helps to enhance the understanding of the impact of different airfoil parameters on their aerodynamic performance, providing a reference for the optimization design of airfoils.

Keywords: Aspect ratio, Reynolds number, Ground roll, Leading-edge vortices.

1. Introduction

A glider is a plane that glides without any form of propulsion [1] The Wright brothers developed the first form of the glider in 1903 [2]. Unlike powered planes, the only forces on a glider are lift, drag, and weight. This environmentally friendly plane has two fatal flaws. First is that without propulsion it cannot get into the air by itself [3]. What it does have though, is the ability to glide down slowly [4]. To solve this, it has to be towed by another plane or launched from a catapult [5]. The other problem was that since the glider could not self-propel, therefore, it had to rely on environmental factors such as pressure, temperature, and wind to help it achieve its desired performance. This means that its performance relies heavily on the day's performance, with higher pressure resulting in a high density, leading to a low-density altitude improving climb performance. Similarly, a headwind results in a short ground roll, and lower speed (where the glider would be slower than the reported speed) [6]. Moreover, studies show that leading-edge vortices may form which would allow the glider to glide further.

Indeed, since gliders have a unique design in that it has a high aspect ratio, some of the wings are used on regular aircraft [7]. Besides, a different flap design from ordinary flaps is used, these flaps are low drag and are designed for both fast and slow flight. Therefore, only a small portion of the vast number of airfoils can be used. This means not the task of evaluating which foil performs the best would be relatively easy as there are only a few foils that can be used on a glider.

2. Glider Wing Shapes

For gliders to glide long distances, engineers have to design a glider with a high lift-to-drag ratio. Besides several environmental phenomena that aid gliders in gaining altitude, and therefore distance, gliders have to rely on their unique low-drag wing shape to glide smoothly. Hence, designing a good wing would be necessary in determining the performance of a glider.

2.1. Equations

To determine the most suitable wing design, one of the best ways is to determine each wing's lift-to-drag ratio about its aspect ratio. For a glider to glide farther, its aspect ratio must be big, this means that its lift must be high, and its drag also has to be low. To find out which airfoil best suits this requirement, a simulation of the glider's wing can be conducted through a simulator to simulate how the wing would behave in real-world scenarios [8]. In a realistic scenario, the design must be put into virtual and artificial reality to determine the glider's real performance, but in this case, a simulation would be enough [9]. Following the traditional way of glider development, the wings and fuselage would be calculated separately, but in this paper, the only thing measured would be the wing.

The glider wing's drag force can be determined by the following:

$$F_d = C_d \rho v^2 A \quad (1)$$

where C_d is the drag coefficient, which can be determined through the Reynolds number, and ρ is the air density, with a value of 1.293 kg/m^3 . A is the area of the wing, and v is the speed of the glider.

Then, the lift force can be determined using the equation:

$$F_l = C_l \rho v^2 A \quad (2)$$

Similar to before, ρ , is density of air would be 1.293 kg/m^3 , A , is the area of the wing, and v is the speed of the glider. However, this time, F_l , is the lift force, and C_l , is the lift coefficient.

Therefore, assuming that the drag-to-lift ratio would be:

$$\frac{F_l}{F_d} = \frac{\left(\frac{1}{2}\right) C_l \rho v^2 A}{\left(\frac{1}{2}\right) C_d \rho v^2 A} = \frac{C_l}{C_d} \quad (3)$$

The flight path of the glider can be expressed as [10]:

$$\tan(a) = \frac{h}{d} \quad (4)$$

$\tan(a)$ can also be associated with drag and lift in that

$$\frac{1}{\tan(a)} = \frac{F_l}{F_d} = \frac{C_l}{C_d} \quad (5)$$

Thus, when both equations are combined, the resulting equation would be,

$$\frac{F_l}{F_d} = \frac{d}{h} = \frac{C_l}{C_d} \quad (6)$$

This equation can be used to calculate the most suitable airfoil that would be able to achieve the longest distance.

2.2. Simulation Process

Simulations can also be used in addition to calculations. This can be accomplished by putting several different airfoils into said simulation to mimic their real-life behaviors. This would allow accurate data to be acquired. The following airfoils would be tested NACA 4424 (Figure 1), NACA 4415 (Figure 2), NACA 64A210 (Figure 3), and NACA 2412 (Figure 4).

These simulations can provide a more in-depth analysis of these foils where calculations based on assumptions are only hypothetical. Moreover, it can also provide a better understanding of the flow around the foil which the data-based calculations did not take into account.

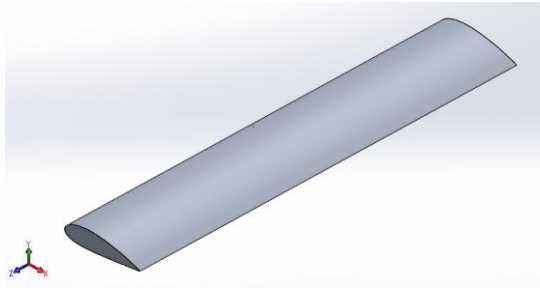


Figure 1. NACA 4424 airfoil modeling

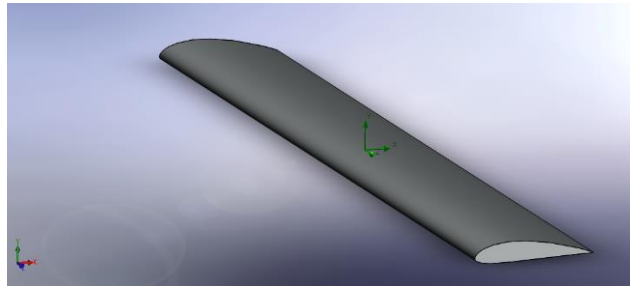


Figure 2. NACA 4415, courtesy of AZ Bravo



Figure 3. NACA 64A210, courtesy of Neelay Deshmukh

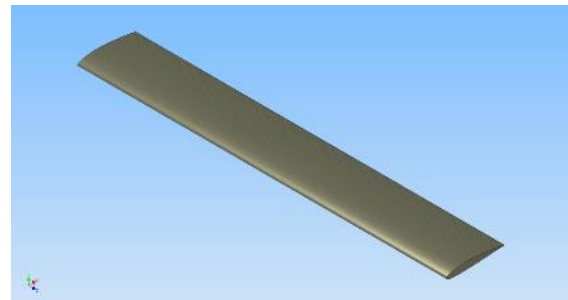


Figure 4. NACA 2412, courtesy of Ojeda Moncayo, Luis A.

To analyze which foil produces the best results, a speed of 105 kph, or 57kts or 29m/s, and a glide angle of -3° is used. These are the optimum speed and glide angle or angle of attack in which a glider performs best. This means that the only difference in all four simulations would be the foil's area and hence, aerodynamic performance. The basic parameters of the four types of airfoils are shown in Table 1.

Table 1. Basic parameters of four types of airfoils

Foil	Area	Chord Width
NACA 4424	5.3279m ²	0.242m
NACA 4415	5.1651m ²	0.155m
NACA 64A210	6.0725m ²	0.1m
NACA 2412	3.9m ²	0.06m

To find the drag coefficient of each foil, the Reynolds number must first be calculated using the equation:

$$Re = \frac{\rho vl}{\mu} = \frac{vl}{\nu} \quad (6)$$

Where the viscosity of air at room temperature is 1.52, and ν is the kinematic viscosity of the fluid.

By plugging in all the available data, the resulting Reynolds number are as follows; 474189 for NACA 4424, 303716 for NACA 4415, 195946 for NACA 64A210, and 117568 for NACA 2412.

After finding the Reynolds number, the drag coefficient would be easy to find, as it is only necessary to use a graph to find their relation seen in Figure 5.

This graph shows that the drag coefficient of NACA 4424 is 0.227, 0.420 for NACA 4415, 0.547 for NACA 64A210, and 0.616 for NACA 2412.

Figure 5 demonstrates that when the angle of attack is -3 degrees, the lift coefficient for NACA 4424 is about 0.1, for NACA 4415 it's about 0.25, for NACA 64A210 it's 0, and for NACA 2412 it's also 0.

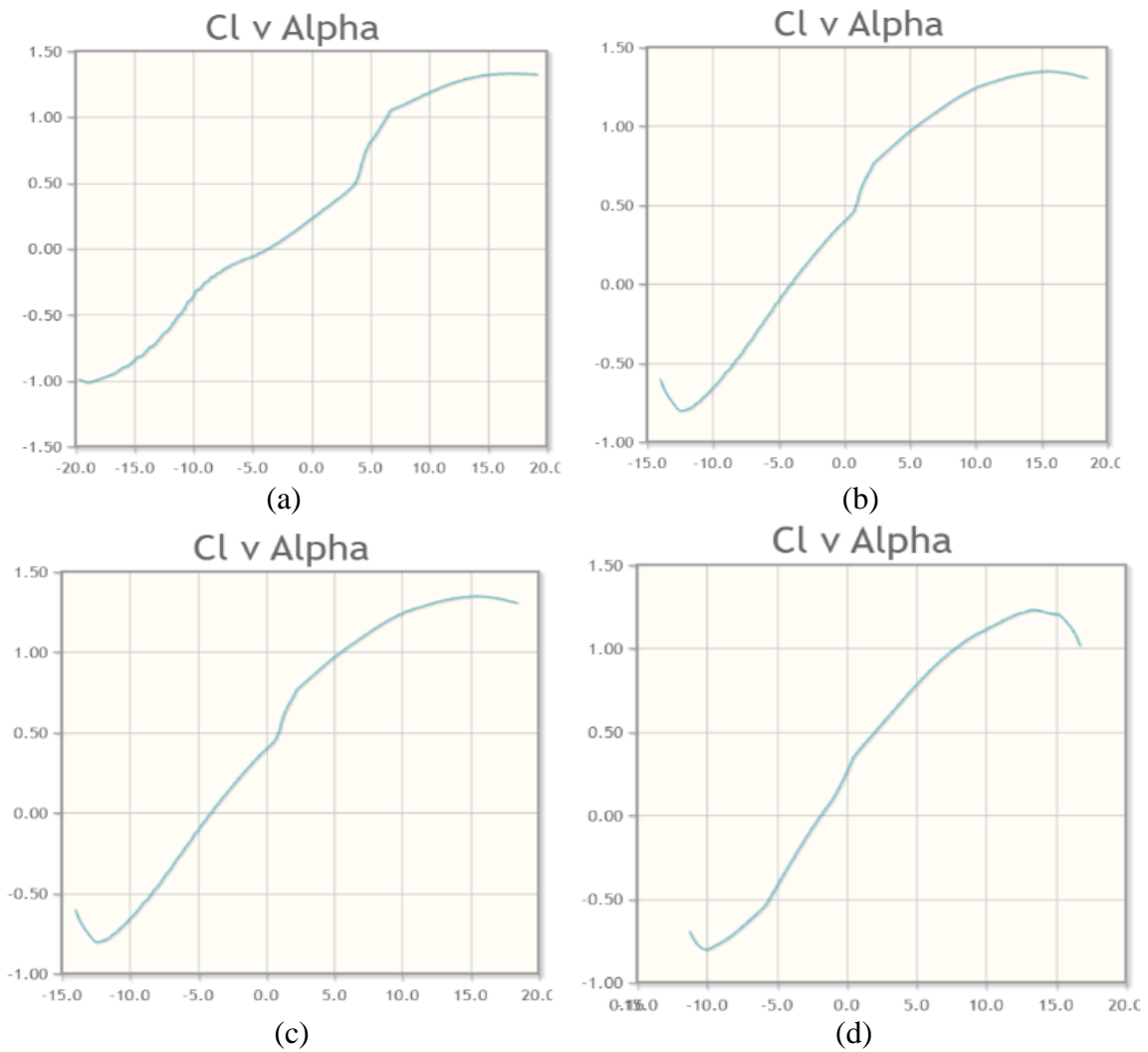


Figure 5. The relationship between lift coefficient, drag coefficient, and angle of attack for four types of airfoils. (a) NACA 4424, courtesy of Airfoil tools; (b) NACA 4415, courtesy of Airfoil tools; (c) NACA 64A210, courtesy of Airfoil tools; (d) NACA 2412, courtesy of Airfoil tools

2.3. Simulation Results

Likewise, the simulation produces a similar result. As given by Bernoulli's equation, when the pressure is high, the velocity is low. This causes the occurrence of lift. Figure 6 shows the pressure-velocity graph of all the airfoils.

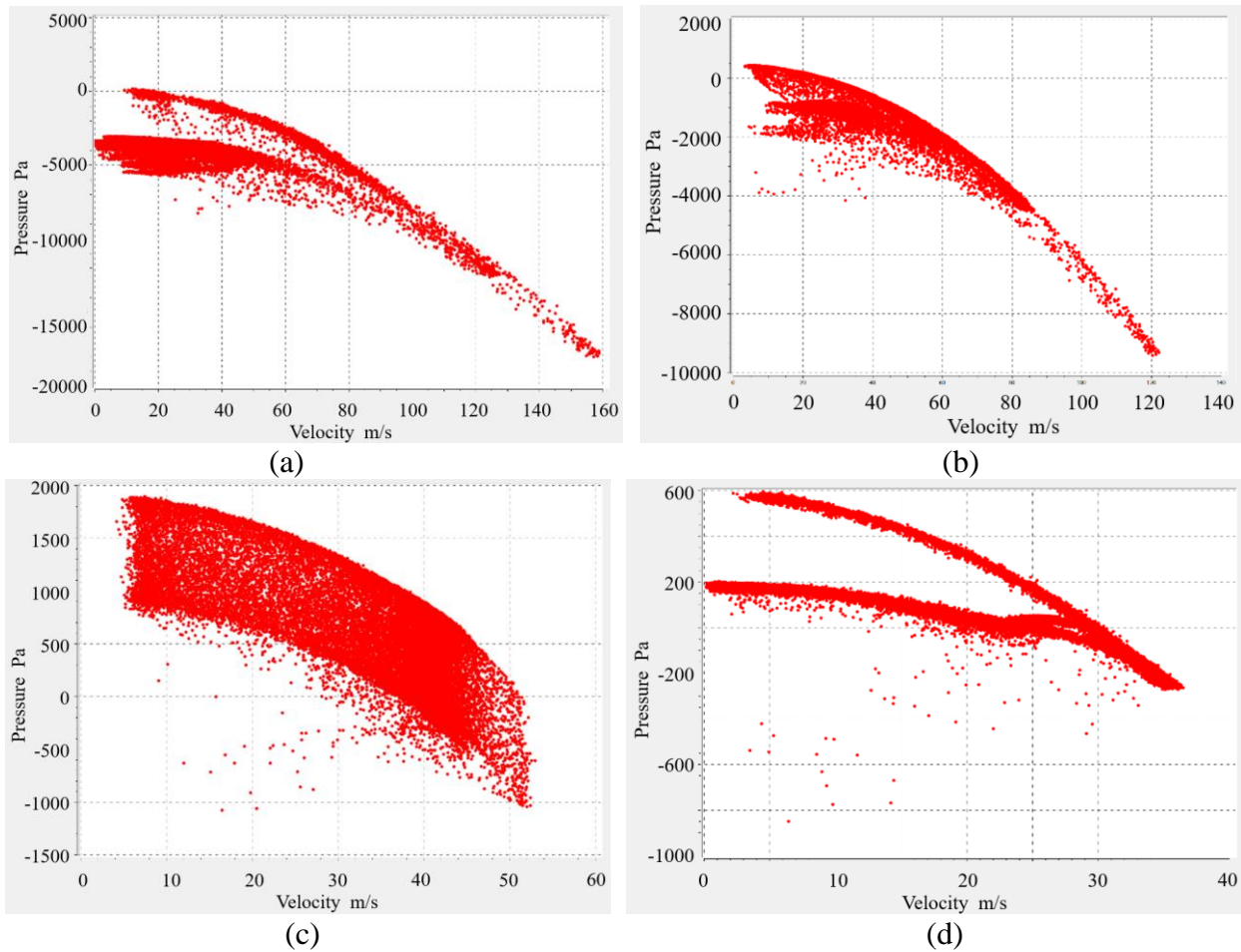


Figure 6. The pressure-velocity graph of four airfoils (a) NACA 4424; (b) NACA 4415; (c) NACA 64A210; (d) NACA 2412

Figure 6 shows the pressure difference between the gliders. From Figure 6, it can be determined that all foils except for NACA 64A210, whose lower wing pressure is significantly larger than the upper wing foil. For NACA 64A210, its lower wing pressure is slightly higher than its upper foils.

Table 2 shows the results of surface pressure at average airflow velocity.

Table 2. The results of surface pressure at average airflow velocity

	Pressure (Pa)	Velocity(m/s)
NACA 4424	401	29
NACA 4415	188	29
NACA 64A210	156	29
NACA 2412	52	29

2.4. Discussion

From this, the lift-to-drag ratio can be deduced. This, therefore, can be used to determine which airfoil performs the best when the glider is cursing at 57 knots with an angle of attack of -3 degrees.

The lift-to-drag ratio of NACA 4424 is ~0.44, the lift-to-drag ratio NACA 4415 is ~0.59, the lift-to-drag ratio of NACA 64A210 is ~0.54, and the lift-to-drag ratio of NACA 2412 is ~0.16.

By calculating this ratio, the distance that each wing can travel, and a constant height can be calculated by applying the equation:

$$\frac{F_l}{F_d} = \frac{d}{h} = \frac{C_L}{C_d} \quad (7)$$

This equation reveals that C_l is directly proportional to d meaning that when C_l increases, d increases. However, since C_d is nonconstant, this equation becomes more complex. This means that since h is constant, the aspects affecting d would be C_l and C_d .

Therefore, by calculating the lift-to-drag ratio, it is discovered that the best airfoil would be NACA 4415 as it provides the longest distance traveled at the same height. While other foils like NACA 4412 performed quite well, it did not come as close as the distance traveled by NACA 4415.

As seen in Figure 6, all airfoils behave relatively the same. This means that when Bernoulli's equation is applied, the lift force can be determined. And since the drag force is already found, the true behavior of said foil can be found.

The following equation can be applied:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho gh_2 = P_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2 \quad (8)$$

Since the height difference between the upper and lower foil is insignificant, it can be canceled. Turning the equation into:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2 \quad (9)$$

Since lift force can equal

$$F = \Delta P \cdot A \quad (10)$$

Where ΔP is $P_2 - P_1$ the lift force can be found by plugging the now modified Bernoulli's equation into the equation above.

Thus, by applying the information gathered during the simulation, the lift force of the foils can be determined. The resulting lift force of the foils is shown in Table 3.

Table 3. The resulting lift force of the four foils

Wing profile	Parameters
NACA 4424	2136.48N
NACA 4415	971N
NACA 64A210	947.31N
NACA 2412	202.8N

Thus, by using the lift force equation shown above, the real lift coefficient can be derived. This would provide the realistic behavior of all the foils.

The lift coefficient of NACA 4424 is 0.77, for NACA 4414 is 0.39, NACA 64A210 is 0.3, NACA 2412 is 0.1. Then by applying the same equation:

$$\frac{F_l}{F_d} = \frac{d}{h} = \frac{C_l}{C_d} \quad (11)$$

This means that NACA 4424's lift-to-drag ratio is ~3.39, NACA 4415's lift-to-drag ratio is ~0.93, NACA 64A210's lift-to-drag ratio is ~0.55, and NACA 2412's lift-to-drag ratio is ~0.16. As stated above, the distance traveled depends only on the lift-drag ratio.

However, this data shows that the previously calculated data was incorrect in that it depicted that NACA 4415 can travel the longest. In contrast, in this simulation, the data showed the NACA 4424 can travel the farthest as it has the largest lift-drag ratio. Although this conflicts with the previous analysis, it proves that when conducting such experiments, a sufficient real-life test can be the only valid way to deduct which foil performs the best.

Both simulation and theoretical calculation results indicate that the lift-to-drag ratio characteristics of NACA 4424 and NACA 4415 are superior to those of NACA 64A210 and NACA 2412. However,

this data shows that the previously calculated data was incorrect in that it depicted that NACA 4415 can travel the longest. In contrast, in the simulation, the data showed the NACA 4424 can travel the farthest as it has the largest lift-to-drag ratio. Although this conflicts with the previous analysis, it proves that when conducting such experiments, a sufficient real-life test can be the only valid way to deduct which foil performs the best.

3. Conclusion

This article uses two methods, computational fluid dynamics simulation, and mathematical analysis, to determine the aerodynamic performance of different airfoils. Both methods show that the lift-to-drag ratio characteristics of NACA 4424 and NACA 4415 are better than those of NACA 64A210 and NACA 2412. However, in terms of specific numerical values, there is a gap between the results of the two methods, which leads to the inability to solve the final performance of the wing through calculation. The analysis of the results indicates that this deviation may be related to the cumulative errors in the simulation and data processing processes. While conducting repeated experiments, there are significant differences between many data points, which can result in significant dispersion of the collected data, making it difficult to obtain accurate data. This means that the provided data does indeed contain fatal factors, but it is not yet lethal enough to spread widely, resulting in inaccurate data. In future research, wind tunnel experiments based on standard aircraft models are necessary. Only through real experimental data verification can the simulation model be reasonably modified to ensure the accuracy of future wing optimization design.

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