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The Glider Experiment: Exploring the Relationhip Between Aspect Ratio and Flight

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Abstract. This paper summarizes the findings of an experiment where different shaped wings of a glider are utilized to test the effects of the shape of the airfoil and the aspect ratio of the wing. After running multiple tests, it can be shown that while an increase in the aspect ratio of the wing also causes an increase in flight time, it also caused a decrease in the total amount of distance airborne. As the article will prove, the lower aspect ratio causes more speed, but makes the plane stay on the ground longer, while there is more lift with a higher aspect ratio, therefore the plane can stay airborne longer. This paper will also apply this to our world, discussing why planes have flaps, and why gliders have really high aspect ratios. This paper will examine the fundamentals of why planes fly, before diving deeper into aspect ratios and how it affects gliders.

Keywords: Aspect ratio, Lift-to-drag coefficient, flaps, flight trajectory

1. Introduction

At the recent Dubai Airshow, planes of various sizes, uses, and capacities were put on display at Al Maktoum Airport in Dubai. From the A380, the biggest plane in the world, to the light fighter jets of NATO and India, each plane is designed to serve its purpose as well as possible. If one observes every plane that passes by in the demonstration flights, one question might arise: why are there so many different types of wings. From the thick, wide, delta wings of the Dassault Mirage to the long, almost stick-like wing profile of the Dash-8 and gliders, what are the differences in these wing designs, and what makes them suitable for their respective aircrafts? This paper examines the logic behind the design of aircraft wings, from their angle of attack, to the position on the monocoque, and to the aspect ratio. They will be examined, one by one, to determine their effects on aircraft. It will also continue on to talk about the use of flaps and strats and how it affects lift and drag on the wing. This paper will first go through the theories behind lift, and then the parts of the wing that contributes to this, and finally talk about what changes in aspect ratio and other factors affect the behaviour of an airfoil. First and foremost, the deciding factor of a plane's airworthiness is its ability to produce lift. Lift is the force that makes a plane fly. It is generated by an airfoil, and therefore, this is why most aircrafts have wings [1]. The wings of an airplane are often complex structures, with multiple different components. From the airfoil itself, to the strats at the front, flaps at the back, spoilers on top, fuel tanks in the interior, and winglets at the edge of the wing, each is designed so the aircraft as a whole can perform well. This is why the wing is often one of the most complex

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systems on a commercial jet, as it is responsible not only for generating lift and related purposes, but also to store fuel, pump air into the cabin, reguide lighting, and in some emergency cases, dump fuel so the plane is able to land. These systems often mean that the design of the wing is crucial, and in case of a failure, the effects could be catastrophic. Then, the paper will focus on gliders, as they are simple structures without the need for any of these complex systems, instead only providing a clean airfoil for researchers to analyze. With this base, it will be easier to discuss aspect ratio, which is a deciding factor in wings and also determines the shape of the wing as mentioned before. These factors combined makes gliders' wings one of the miracles of engineering, as they allow these light planes to glide for miles unpowered, only using its existing velocity coupled with its high aspect ratio wing to generate lift and keep the plane airborne. Now, readers will be provided with some background knowledge regarding flight.

2. Factors deciding lift

2.1. Lift to drag ratio

Lift is a force that, put simply, allows an object to "float" in air. It is usually caused by the behaviour of air flowing around an airfoil. In accordance with Bernouilli's Principle, an airfoil causes air to flow faster on the top of the airfoil, which causes lower pressure on the top of the wing [2]. This causes the object to float in the air, and is what airplanes nowadays utilize to fly in the air.

Lift-to-drag ratio is the decription of how aerodynamic the wing is [3]. It is the ratio of the lift produced by the wing, which causes the plane to fly, to the drag of the wing, which slows the plane down and can cause it to stall. A higher LDR means the aircraft generates a lot of lift, making it more efficient and able to fly farther with the same amount of energy. Conversely, a lower LDR means that the aircraft experiences more drag relative to its lift, reducing its efficiency and requiring more power to stay in the air.

2.1.1. A look back: the history of aviation in lift-to-drag ratio

Commercial aviation has always been on demand. Therefore, fuel efficiency is important in the industry. LDR is directly related to this factor. From the first plane in the world, the Wright Brothers's plane, with a LDR of 8.3, according to the LDR ratio calculator from fxsolver.com. As the jet age dawns, the Boeing 747, perhaps the most iconic jet in history, makes its first flight, sporting a wing with an LDR of over 15, with the number rising to 15.5 in the -400 variant. More modern commercial jets such as the 777-200, which made its first flight in the 1990s, has a wing with an LDR of over 19. Finally, the A380, debuting in the early 2000s, can reach an LDR of 20 at cruising speed. As mentioned before, the larger the ratio is, the more fuel efficient the plane is if all other factors stay constant, and also the faster the plane flies. This is why gliders usually have a much higher LDR compared to modern commercial aviation, with some rising even to 40, such as in the case of high performance sailplanes, capping off at a lift-to-drag ratio of almost 60.

2.1.2. Why planes choose different lift-to-drag ratios

When engineers design a plane, they are always looking for the optimal way to make the plane fly. This means that the plane needs to be as durable, efficient, and versatile as possible. To achieve this, their are a couple of things engineers can tweak and revolutionize to serve their purposes, most notably the wing. The two most radical wing designs, are unsurprisingly, fighters and gliders. Fighters maximize speed and agility. They have powerful engines to push them forward, so they

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don't need that much lift. As a result, they often have small wings that are maximized for aerodynamic efficiency, whilst not producing that much lift, still make the jet go really fast as it is aerodynamic. Gliders, on the other hand, are on the other hand of the spectrum, since they have no source of power themselves. As a result, their wings are designed for the maximum amount of air time possible, thus the staggeringly high lift-to-drag ratio. If one takes a look at a glider's wings, they would see clearly how it is long, narrow, and often disproportionately larger than the monocoque itself. This is because the glider, as mentioned before, is an unpowered aircraft, only able to convert its potential energy into kinetic energy. Ergo, the design of a glider is often the opposite of that of a fighter jet, where gliders have a thin wing to minimize drag, and its huge wings in relation to its body provide maximum lift for staying airborne as long as possible.

2.2. The wing

2.2.1. The basic part: the airfoil

Wings are the main structure that allow an aircraft to fly. They are composed of multiple parts to maximize the amount of lift a plane generates. Most of this comes from the main part of a wing itself, which is shaped like an airfoil. This creates lift as air flows faster above the wing than above it, creating lower pressure zones above the wing and thus generating lift [4]. This is the design that virtually all aircraft today follow. However, a fixed piece of an airfoil isn't versatile. Take the example of an commercial airplane. It will require different amounts of lift and drag during takeoff, landing, and cruising, and thus, as past aviation engineers quickly found out, it is crucial to add some movable parts to the wing to boost its performance.

2.2.2. Spoilers, strats, flaps

In addition to the airfoil, engineers quickly added flaps and strats, able to be deployed during landing and takeoff. They increase drag while at the same time decreasing the aspect ratio of the wing, making the plane stay airborne at a slower speed [5]. Spoilers, on the other hand, are a lot like airbrakes. When the plane is in desperate need of bleeding speed, spoilers can be deployed to drastically increase air resistance to slow the plane down, usually during landing stages. These complex parts of the wing complements the airfoil and ensures maximum efficiency in every stage of a flight, there is always a correct shape of the wing to use to maximize performance. These devices, developed in the 1910s-1920s, massively boosted the performance and safety of an aircraft, as it is now able to land at lower speeds and decelerate easily, vastly helping improve the safety of the pilot and the people on the ground.

2.2.3. Winglets: increasing efficiency

Most commercial planes today incorporate some form of winglets at the end of their wing. From the basic wing guards of the airbus A320 and A380, to the sharklets of the A350 and 737s, and the raked wingtips of the 777s and 787, there are more to these devices than aesthetics.

Wingtips of the planes are a relatively late invention relative to the history of aviation, with the first ones only starting to be widely used in the 1970s and the 1980s with them being incorporated into the later variants of the Boeing 747 and the A300s. Since then, every new jet by Boeing and Airbus features some sort of wingtip device. This is because when airplanes pass through air, they generate huge wingtip vortices, which causes drag and turbulence, affecting fuel efficiency and lift.

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By adding these wingtips, engineers minimize these vortices and make the plane more flyable at low speeds and fuel efficient at high speeds [6].

2.3. Aspect ratio

Aspect ratio is simply the ratio of the wing's length to its width [7]. This is one of the deciding factors as to which type of purpose the plane serves. Unsurprisingly, fighter jets and gliders are on the ends of the spectrum, with many fighter jets having delta wings or a narrow wingspan. On the other hand, a glider often has long, narrow wings. Fighter jets need to be fast and agile, and their powerful afterburners can generate enough power to propel them forward, thus they can use a smaller and wider wing. Glider, on the other hand, have no power, thus long narrow wings sacrifice agility and speed for a longer air time by generating more lift [8].

2.3.1. Figures and calculations

To prove this effect of aspect ratio on a glider, an experiment is conducted where a model airplane is dropped from a fixed height of two meters. In each experiment, the height and the main body of the glider stays the same, while the wing changes. The three variants of the wings are shown below:

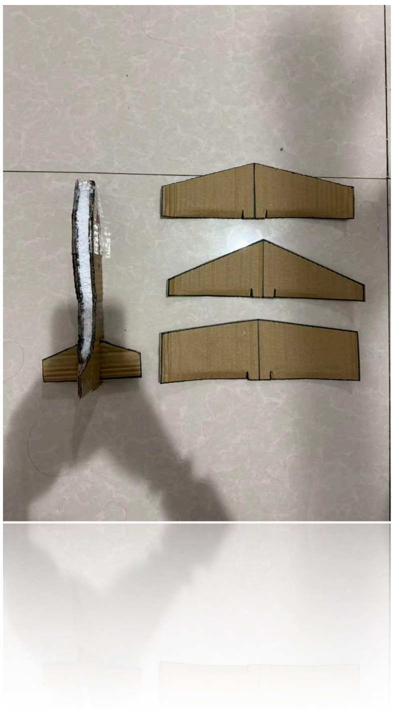

Figure 1. The different wings of the glider

The respective aspect ratios of the three wings, as shown in Figure 1, are: 1.8, 2.1, and 2.6

After conducting each test five times, and putting all the data in Tracker, there are two graphs that one can use to analyze information:

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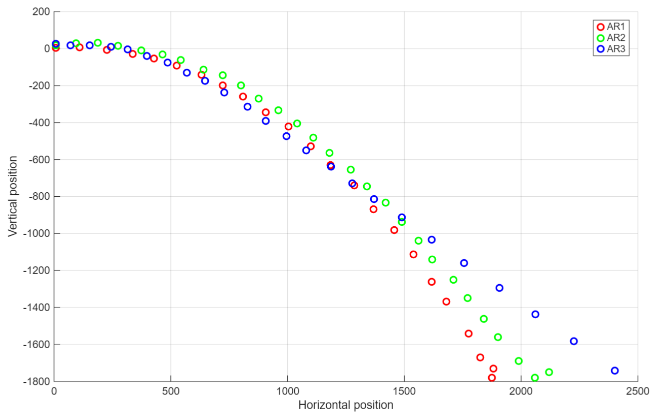

Figure 2. The flight trajectory of the three variant wings

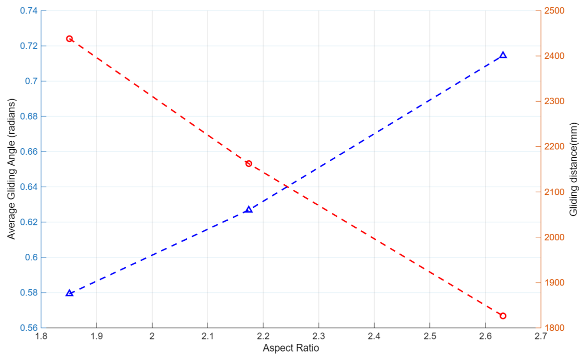

Figure 3. Relationship between AR and glide angle and distance

Clearly, a lower AR means that the plane has a steeper glide angle and doesn't fly as far as a plane with a higher AR [9]. As the experiment demonstrated, AR has a huge effect on a plane's performance capabilities. As figure 2 demonstrates, a lower AR means less glide distance, but as figure 3 shows, this means a bigger glide angle and as a result a decreased flight time [10].

3. Equations reference

To calculate the glide angle of the glider, we can use the equation below:

$$\mathrm{V}_x < 0,\ \mathrm{V}_y < 0$$

$$\tan\theta = \mathrm{abs}(\mathrm{V}_x)/\mathrm{abs}(\mathrm{V}_y)$$

In this experiment, both velocities in the equation above are in the third quadrent, so the tangent of the glide angle is simply the absolute value of the y velocity divided by that of x, and the arctangent of that value is the glide angle for the glider.

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4. Conclusion

To conclude, with the advent of modern aviation, a plane’s wing is one of the most important parts for a plane and a place where multiple advances in techonogy has taken place. From wingtip devices to aspect ratios, each factor on a wing affects the planes performance, and thus when engineers design a plane, they will almost certainly start with the design of the wing. As the experiment has shown, aspect ratio has a direct proportional relationship to the flight distance and an inverse to that of the glide angle. From wake turbulence to drag, each small factor plays a major role in the performance of an airplane. This means when engineers design an airplane, they often start with the design of the wing to suit their needs and extract maximum performance and efficiency out of the aircraft.

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