

How Do Wing Length and Thickness Affect Flight Performance?

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ABSTRACT: With the rise of globalization, airplanes as a form of transportation are more important than ever. Besides merely transporting people and goods from one location to another, they are one of the main reasons countries are now more interdependent and interconnected as goods and people integrate across the globe. As the world continues to innovate and improve airplanes, there are many factors, such as the shape of the airfoil, that affect the flight performance of airplanes, and understanding how this affects airplanes is crucial in the development of airplanes. This paper will discuss the history of airplanes starting from the Wright Flyer, the possible dangers associated with airplanes, and the effect of changes in wing shape on the flight performance of airplanes.

KEYWORDS: Engineering Mechanics, Aerospace and Aeronautical Engineering, Wing Shape, Flight Performance.

■ Introduction

Created by Sir George Cayley of England,¹ aeronautics is the scientific study of flying. Over the past few years, advancements in technology and aeronautics have led to many significant innovations, like the creation of airplanes, which have resulted in globalization. Airplanes allow people to fly from one country or continent to another in a short amount of time. As such, countries are now more interconnected and interdependent. Heavier objects are able to stay in the air for a long time because of their wings, or airfoil, that would be able to create a pressure difference between the top and bottom of the wing, to give rise to a lift force. This lift force is directly proportional to the lift coefficient, density, velocity, and wing area. I am interested in studying aerodynamics and airplanes because I would like to dive deeper into what makes airplanes able to stay in the air and the importance airplanes have on our daily lives. Changes in the length and thickness of wings can affect flight performance; thus, this research paper seeks to find out the impact of these changes on the distance travelled by airplanes.

Section 1 will discuss the history of airplanes, followed by Section 2, which touches on airfoils in general. Section 3 focuses on the experiment and methods used, while Section 4 presents the results of the experiment. This paper will end with a conclusion stating future work and insights. It was hypothesized that the airplane with the longest wings would fly the longest horizontal distance.

■ History

1.1. Origins of Airplanes:

The invention of airplanes first started out in 1899 by the Wright Brothers and was achieved in 1903 when they successfully created the first airplane (Figure 1), which flew at Kitty

Hawk, North Carolina, with Orville Wright managing and flying the plane.²



Figure 1: Picture of the first airplane created by the Wright Brothers, which was called the Wright Flyer. This took place in 1903 at Kitty Hawk in North Carolina.³

This invention came about as a result of growing up in Dayton, Ohio, where their favorite toy was a tiny object that resembled a helicopter, powered by rubber bands to spin its blades. This piqued their interest, and they wanted to be able to create a plane that was large enough to be able to accommodate both of them.⁴ This was achieved when the Wright Brothers carried out their flights in public for the first time in Europe and America in 1908, showing their creation to the public.⁵

1.2. Evolution of Airplanes:

Over time, there have been many innovations to airplanes, and much research has been conducted in this area. (Figure 2).

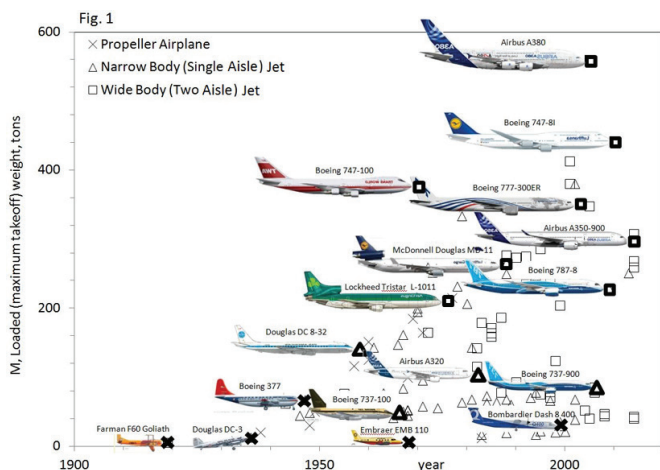


Figure 2: Evolution of airplanes from 1900 to the 2000s. It first started as the Farman F60 Goliath, to become Boeing and Airbus airplanes.⁶

Figure 2 shows how airplanes changed from propeller airplanes to jets. Besides the planes mentioned above, other planes include the Travel Air S6000-B, operating from 1929 to 1930, and the Stinson A, operating from 1935 to 1938.⁷

Over the years, companies started innovating and improving their aircraft, creating more efficient planes. Efficiency of the aircraft was achieved by reducing the lift to drag ratio,⁸ using more efficient engines, and creating more fuel-efficient planes. As stated by McKinsey and Company, the new generation airplanes are found to be 15% to 20% more fuel efficient than older airplanes. One example is the Concorde (Figure 3).



Figure 3: Picture of a Concorde aircraft, which was built during the 1960s through a collaboration between the United Kingdom and France.⁹

Having a maximum speed that is faster than the speed of sound,¹⁰ the Concorde unlocked the possibility of being able to travel from one end of the world to another in a matter of hours, further changing how the world was connected. However, on July 25, 2000, the fuel tank of Flight 4590, travelling from Paris to New York, exploded and erupted into flames as it came into contact with debris created from a tire that had burst. This resulted in an engine failure, and the aircraft crashed into a nearby hospital, killing all 109 on board and 4 others on the ground.¹¹

1.3. Dangers of Airplanes:

Over the past decade, the dangers of airplanes were evident at times. Although few, there are fewer than 50 commercial airplane crashes happening every year, with even fewer causing deaths.¹² Despite this being a small number, this shows how the chances are never 0. There have also been cases where

aircraft have experienced terrible and extreme turbulence, and this was what happened on the SQ321 in 2024, causing the death of a 73-year-old British man and leaving 7 people in critical conditions.¹³ As such, all these highlight how travelling in airplanes can come with risks, especially when safety precautions are not taken seriously.

Present Day Aircraft:

Advancements in technology and aerodynamics have led to the creation of many different types of airplanes, like commercial airplanes, aerobatic airplanes, seaplanes, and more, all serving different purposes.

1.4.1. Commercial Airplanes:

One example of a commercial airplane is the Boeing 737 (Figure 4). Having 12000 planes built as of 2024,¹⁴ it is one of the most popular commercial aircraft in the world today, and it enables the transportation of large numbers of passengers from one place to another.



Figure 4: Picture of a Boeing 737 by Singapore Airlines, an example of how advancement in technology and aerodynamics was applied.¹⁵

The Boeing 737 has a vertical and horizontal stabilizer (Figure 5), located at the back of the aircraft, ensuring the stability of the plane by preventing the nose of the aircraft from swaying around when traveling in the air.

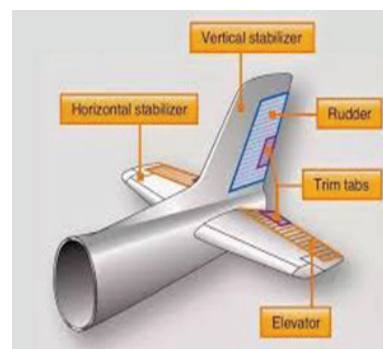


Figure 5: Picture of the features on the back of a Boeing 737 aircraft, which includes a horizontal and vertical stabilizer.¹⁶

1.4.2 Helicopters:

With an increase in versatility, the next example is helicopters (Figure 6), which can access locations that are hard to reach and fly through adverse weather conditions.

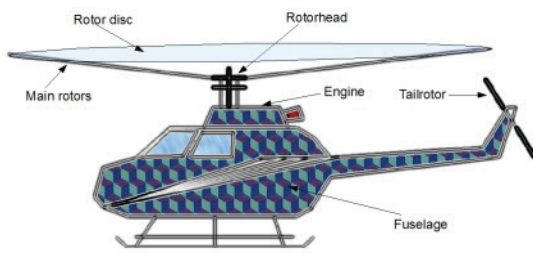


Figure 6: Picture of a helicopter where rotors are able to create lift with no runway.¹⁷

Helicopters are able to transport large objects, reach people in locations that are difficult to access,¹⁸ and overcome obstacles and bad conditions. Instead of having 2 wings, like airplanes, helicopters have 2 rotors, which are able to create comparable lift with no runway.¹⁹ When the rotor is tilted at an angle, the lift force is able to be converted into thrust, allowing the airplane to fly.²⁰

1.4.3. Seaplanes:

Imagine a plane that is able not only to take off on land but also to do that on water. Those are the characteristics of seaplanes (Figure 7).



Figure 7: Picture of a seaplane that allows landing and take-off in the water.²¹

On seaplanes, the wheels of a normal aircraft are exchanged for floats, where they can have either straight or amphibious floats. If the seaplane has straight floats, this means that the plane does not have wheels and thus is unable to travel on land. Conversely, seaplanes with amphibious floats have wheels that can retract, allowing them to travel on both land and water.²²

■ Airfoils

2.1. Definitions:

Airfoils (Figure 8) are a part of the plane that generate more lift than drag. One of the main functions of airfoils is to be able to generate a lift force, allowing heavy objects like planes to fly in the sky. Lift force is a force that is perpendicular to the direction of motion of airplanes, and being an aerodynamic force, it acts on a streamlined body that is traveling in the air.²³ With the lift force, heavy objects are able to overcome their weight to give a net upward force. The lift equation is given by $L = \frac{C_L \rho V^2 A}{2}$ where L is the lift, C_L is the lift coefficient, P is the density, V is the velocity, and A is the wing area of the airfoil.

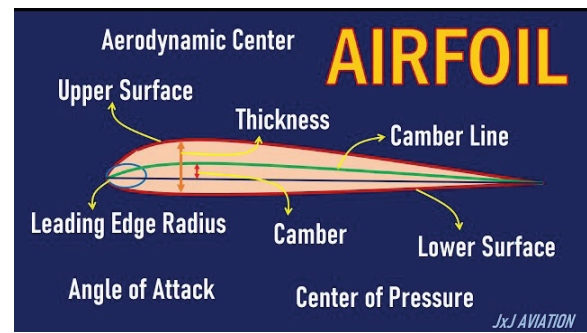


Figure 8: Diagram of an airfoil that shows the curved surface area of the wing.²⁴

2.1. Mechanisms of Airfoils:

As shown in Figure 8, airfoils have a curved surface area on the upper surface. The air moving above the airfoil flows at a faster rate than the air moving below the airfoil. This creates an area of higher pressure below the wing and an area of lower pressure above the wing, creating a pressure difference. This pressure difference gives rise to a lift force, which acts in the upward direction, resulting in a net upward force, allowing the planes to fly.²⁵

Additionally, Newton's third law, which explains how when a body exerts a force on another body, the latter will exert an equal and opposite force on the first body. When the wing pushes down on the air, the air will generate a force that is equal in magnitude but in the upward direction on the wing too, generating lift.²⁶

■ Experiment

3.1. Overview of Experiment: Hypothesis, Apparatus Used, and Experimental Setup:

It was hypothesized that the airplane with the longest wings would travel the furthest horizontal distance, while the airplane with the thickest wings would travel the shortest horizontal distance.

This is because, for the airplane with the longest wings, it would be able to generate a greater lift force through its greater curved surface area, allowing the plane to have more time in the sky. This enables the plane to travel a further distance horizontally. On the other hand, while increasing the thickness of the wings can increase the lift force generated, it also increases the entire mass of the object, shortening the time the plane has in the air. Thus, the airplane with the thickest wings would travel the shortest horizontal distance.

An experiment was conducted to test the effects that changes to the length and thickness of the wings have on the flight performance. The airplane with the thickest wings (Figure 9) and the control airplane (Figure 10) were created using an A4 piece of paper, while the airplane with the longest wings (Figure 11) was created using an A4 and an A3 piece of paper. Both papers have a density of 80 grams per square meter.

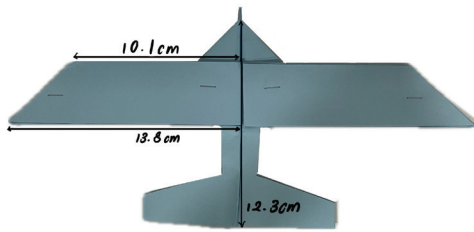


Figure 9: Paper airplane with the thickest wings (Plane T) of mass 6g that was used in the experiment.

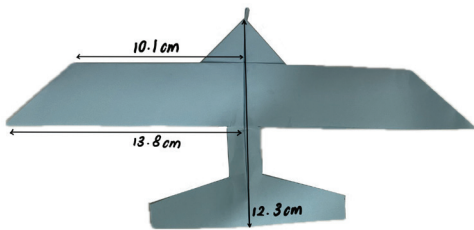


Figure 10: Control paper airplane (Plane C) of mass 3g that was used in the experiment.

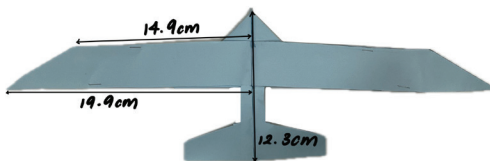


Figure 11: Paper airplane with a longer wing (Plane L) of mass 3g to experiment with the different structures of wings.

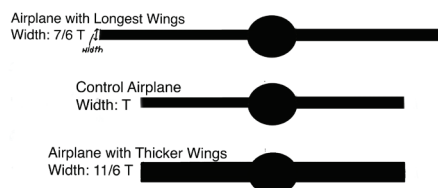


Figure 12: Overview of the thickness of all 3 paper airplanes that were used in the experiments.

During the experiment, I used a 5-meter measuring tape to measure the horizontal distance travelled by the airplane, and also used masking tape to indicate the starting position. Using a camera, I recorded the entire flight path of the airplane to allow for the checking of the flight distance later on. The launch angle and height were standardized by making sure that it started from the shoulder and was released at around a 45-degree angle from the horizontal. To ensure consistency between the data values, the experiment was conducted on the same day, and the windows were closed. Fans were also turned off to prevent any changes to the physical environment that may affect the flight performance of the planes. This ensures that any changes to flight paths were strictly due to the changes in the shape of the airplane. The drawings of the experimental setup are shown below.

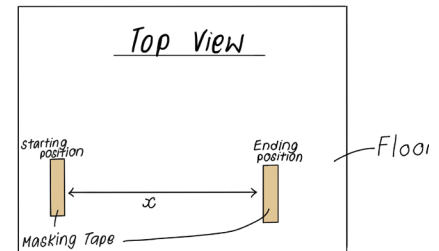
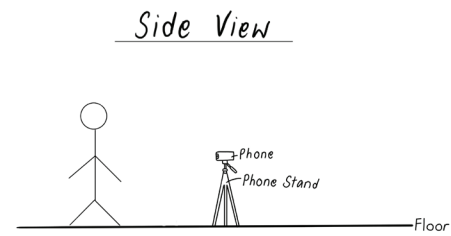


Figure 13: Experimental setup (not to scale) that was used to derive the results.

Results and Discussion

4.1. Overview of Experimental Results:

Table 1: Distance travelled by Plane C, Plane T, Plane L.

Horizontal distance travelled/m	Plane C	Plane T – plane with thicker wings	Plane L – plane with longer wings
Experiment 1	3.07	1.00	2.50
Experiment 2	2.72	1.09	2.75
Experiment 3	4.00	0.98	2.25
Experiment 4	3.00	1.21	2.76
Experiment 5	2.50	1.23	2.46
Experiment 6	2.60	0.98	2.22
Experiment 7	3.58	0.96	3.00
Experiment 8	2.19	1.08	2.48
Experiment 9	2.70	1.13	1.90
Experiment 10	2.33	1.15	2.77
Average	2.87 + 0.38	1.08 + 0.07	2.51 + 0.22

The confidence interval is reported at 95%.

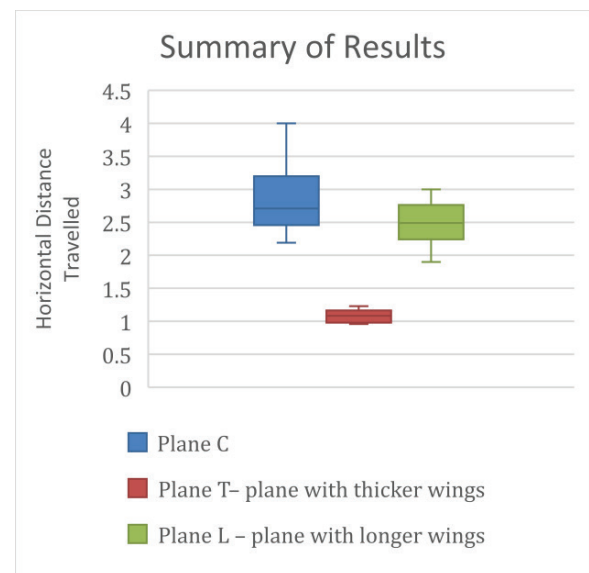


Figure 14: Box and whisker diagram of the results showing the spread of the horizontal distance travelled of each plane.

4.2. Discussion of Results:

The average horizontal distance travelled by Plane C was 2.90m with a standard deviation of 0.534, to 3 significant figures. The average horizontal distance travelled by Plane T was 1.10m with a standard deviation of 0.0936, to 3 significant figures. The average horizontal distance travelled by Plane L was 2.51m with a standard deviation of 0.309, to 3 significant figures.

From our results, it shows that Plane T travelled the shortest horizontal distance of an average of 1.10m, and this aligns with our hypothesis in section 3.1. This is because the increase in mass due to the thicker wing outweighed the increase in lift force for this experiment, resulting in an overall reduction in flight time and distance travelled. With an increase in the total mass, this would mean that the gravitational force acting on the object increases as the weight is proportional to mass. This would increase the downward force acting on the object, reducing the net upward force exerted on it. With a reduced net upward force, this would reduce the total time the object has in the air.

Furthermore, wing loading, which is the ratio of the total surface area of the wing and the weight of the object, should be taken into consideration in thicker wings.²⁷ A larger wing loading can reduce the lift the object is able to generate, as it leads to an increase in the separation of the leading-edge vortex.²⁸ As such, a balance must be achieved between increasing the lift force by using a thicker wing and increasing the mass of the airplane.

Plane L, with an average distance of 2.51m, did not travel the longest distance, and this contradicts our hypothesis. This may be because while an increase in length does increase the lift force, it makes the airplane less aerodynamic, thus increasing the drag experienced by the plane. This increase in drag slows the plane down, resulting in a shorter distance travelled.

Friction drag is due to the viscosity of the fluid the airplane is in and acts in the opposite direction to oppose the relative motion of the object in the air. Because the fluid is viscous, this will result in a frictional force exerted on the object, creating shear stress.²⁹ This is because for the object to move through the air, the object would have to push away the air molecules surrounding it. This drag force increases with speed, depends on the dimensions and shape of the object, and the type of liquid. With laminar flow, the drag force is directly proportional to the velocity, but with turbulent flow, the drag force is directly proportional to velocity squared. The proportionality constant reflects the shape and dimensions of the object, with a more streamlined shape resulting in a lower constant and thus a lower drag force.

When the length of the airfoil increases, more surface area is exposed to air flow, which could have made the object less streamlined. This would create more resistance to the motion of the plane in the air and hence increase the drag force acting on the object.

Since Plane C travelled the longest horizontal distance, this means that it was the most aerodynamic. On the other hand, Plane T travelled the shortest horizontal distance, showing how it was the least aerodynamic. Plane C's design is the most

optimal because it balances the creation of lift with the mass and length of the wing, such that the weight of the wing does not result in too large a wing loading, and the length of the wing does not create too much drag force on it.

■ Conclusion

The experiment conducted investigated the flight performance of airplanes with three different wing shapes using: i) Control Plane C, ii) Plane T with a thicker wing, and iii) Plane L with a longer wing.

The results may show a relationship between the thickness of the wings and the mass of the airplane. The optimal ratio between the total mass of the airplane and the thickness of the wing is 5g to 1mm, but the ratio is based on the material used. This is because Plane C with a mass of 3g (figure 10), travelled the longest distance with an average of 287cm followed by Plane L with a mass of 3g (figure 11) which travelled an average of 251cm and lastly Plane T of mass 6g (figure 9) which travelled the shortest distance with an average of 108cm.

The result from the experiments applies to the real world. It highlights the need to consider factors such as wing loading and friction drag on the wings when constructing an aircraft that is the most efficient, as increasing the length or thickness of the wing excessively to increase the lift force can have a counterproductive effect on it.

If I had more resources, I would have crafted paper mâché planes, sealed them with glue, and tested them in a wind tunnel to obtain a more accurate set of data. Future work can include crafting a mathematical relationship between the wing cross-section and drag coefficient for different size classes of airplanes. A following experiment that can be carried out is experiments using an equal-mass build with a fixed-angle launcher, and to calculate the small aspect-ratio or thickness sweep to map trends.

Over the past 122 years, there have been great improvements and innovations to aircraft. It first started as a small 2-passenger plane with the Wright Flyer in Section 1.1 and now has advanced into larger 800-passenger planes, which are used by many today as a method of travel from one country to another. As of 2022, about 90% of Americans have taken a flight before, an increase from 63% in 1977.³⁰ In the future, one can expect the airline industry to further innovate and advance, changing how the world is connected.

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