Proceedings of CONF-MCEE 2026 Symposium: Geomaterials and Environmental Engineering
DOI: 10.54254/2755-2721/2026.MH31568

The Influence of Fluid Mechanics on Wing Design

Zihan Ren

Beijing No.80 High School, Beijing, China
Fcbarcelona-Eric-Vamos@outlook.com

Abstract. A safety and long-distance aircraft normally feature high-performance wings. Aircraft wing design is an complicated engineering that in accordance heavily on fundamental principles of fluid mechanism. Over decades, humanity had accomplished a huge progression on the design of wings for various aircrafts, from a simple and crude wings on the Wright brother's plane to modern innovative designs that allows aircraft either achieve risky flight or long-distance traveling. This thesis will explore the profound influence of these principles on different types of wing designs that affect the flying efficiency of an aircraft , from the basic force composition of an airfoil, to the advancement of wings configuration on different types of aircraft. By illustrating details explanation, well-documented evidences and data, and historical evolutions, the paper demonstrates how Bernoulli's equation and other fluid mechanic's concept have shaped the development of plane's wings with varies types—including jet's plane, glider, and battle-plane. The overall essay mainly contains a brief introduction Concepts explanation, details illustration on different types of wings and their affects on flying distance, and a final conclusion of the paper.

Keywords: Aircraft, Wings and airfoil, Bernoulli principle, Designs of airfoil

1. Introduction

The wings is regarded as the most critical aerodynamic equipment, responsible for maintaining the aircraft flight and its stability in the air. In 17th century, Daniel Bernoulli has demonstrates his Bernoulli equation, which made an breakthrough contribution on fluid mechanism by explaining the principle of flying, that lay a solid foundation for later aviation development. Human's journey on flight begun in 1903, when Wright Brothers successfully launched the first powered aircraft in north Caroline, which lasted for mere 12 seconds in the midair [1]. By the 1930, airplane Douglass DC-3 was invented with a more robust and effective wings,and the plane became the aircraft with the fastest speed and the longest cruse distance around 30s and 40s century [2]. The 1970s-1980s witnessed the global proliferation of jet planes, including Boeing and airbus aircrafts, which equipped advanced engines and wings that enable intercontinental travels within only a few hours, increase the efficiency of world transportation [3]. Human has made a substantial progress on airplanes's enhancement thanks to the emergence of advanced engines and perfect design of wings. In this paper, let's mainly shift our attention on the study of wings. Some core questions will be answered in the thesis: What force support the flying of an aircraft? What is Bernoulli equation and

DOI: 10.54254/2755-2721/2026.MH31568

how does it exist on the wing of the plane? How does Bernoulli equation driven the development of wings for different types of aircraft? How does it affect the flying characteristics for these aircrafts? In next section, there will be a specific discussion on the concept of Bernoulli equation.

2. Concept explanations and analysis

2.1. Force composition and Bernoulli principle

An aircraft mainly subject to four forces when flying: weight, drag, lift, and thrust, which shown in figure 1. Weight refers to a force on an aircraft that always directed toward the center of the earth, produced by earth gravity. Drag force act along and opposed to the flight direction, which resists the motion of the aircraft though the air. Thrust force is generated by the propulsion system, it provides power for the plane. Lift force is an uplifting force that acts on the wings or the airfoils of a plane, counteract the aircraft's weight [4]. The generation of lift force is deeply rooted in a foundational fluid mechanic's principle: Bernoulli's principles.

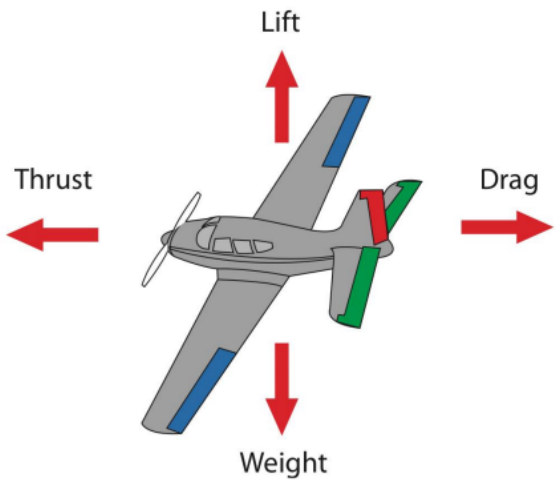

Figure 1. Four forces of flight

Bernoulli principles came up by Daniel Bernoulli, an outstanding Swiss-French mathematician and physicist. He discovered the principles and it was later form into an famous equation, also known as the Bernoulli equation:

$$P + \frac{1}{2}\rho \mathrm{v}^2 + \rho g h = constant \tag{1}$$

$$P + \frac{1}{2}\rho \mathrm{v}^2 + \rho g h = constant \tag{2}$$

P: static dynamic
P : density
V: velocity
$\frac{1}{2}\rho \mathrm{v}^2$: dynamic pressure
P gh: gravitative pressure

DOI: 10.54254/2755-2721/2026.MH31568

The Bernoulli equation states that for an ideal, incompressible fluid flowing along a streamline, the sum of pressure energy, kinetic energy, and potential energy per unit volume remains constant. This had led to the core of Bernoulli principle: as the speed of the fluids increase, its pressure decrease and vise versa [5]. This idea can be explained using crowd as a case. When dense crowd simultaneously move slowly in a confined area, individual either shift their location in slow rate or remain stationary. This results in frequent collision between each other increase the pressure; In contrary, when everyone is running towards a same direction, the likelihood of interactions between individuals can be diminished therefore reduce the pressure.This principle is crucial to aerodynamic, successfully explains the lift in airplane's wings. This understanding has subsequently contribute to the design of various wing, each yields different flying efficiency to the aircraft [6].

2.2. Wings, airfoil, and the Bernuolli principle

An airfoil is a cross-sectional structure that designed to generate the lift force when a fluid flows over it.

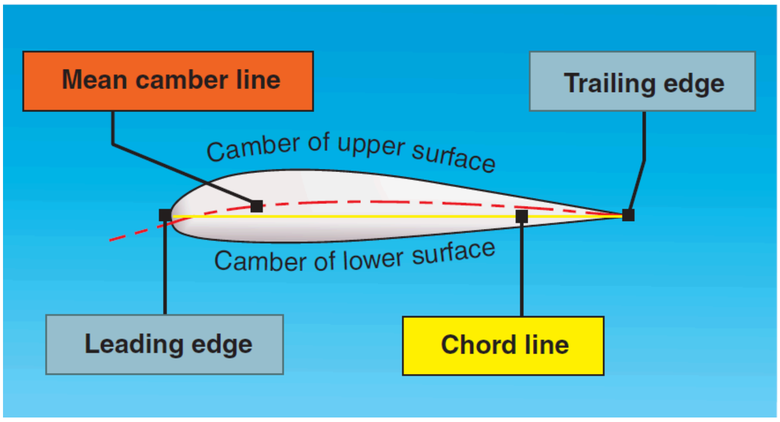

Figure 2. The structure of an airfoil

According to the Figure 2, airfoil has a leading edge: the front part of an airfoil where the air first makes contact; a trailing edge: the rear part of an airfoil where air exit; chord line: an imaginary straight line connecting the leading and trailing edge; chamber line: the curvature of ai airfoil. The upper surface of the airfoil curved more to create a longer path length from the leading to trailing edge. The lower surface is relatively flat, resulting in a shorter path length compared to the upper surface [7]. How could this simple structure produce lift for an aircraft? When the aircraft is flying in the sky, the air will flow though the upper surface and the lower surface of the airfoil, and two air stream must reach the trailing edge simultaneously. Since the upper path is longer, the air over the upper surface must accelerate to cover the greater distance in the same time as the lower stream. According to the Bernuolli's principle, the speed of the fluid and the pressure are inversely proportional. The faster airflow over the upper surface generates a low-pressure region, while the slower airflow under the lower surface maintains a high-pressure region. This pressure differences creates the net upward forces known as lift—the force that keep the aircraft in the air. This entire process is shown in Figure 3 [8].

DOI: 10.54254/2755-2721/2026.MH31568

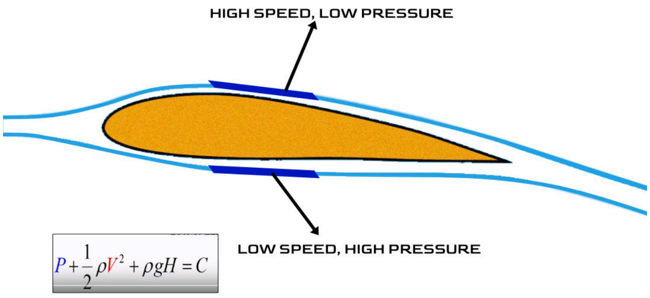

Figure 3. Bernoulli principles on an airfoil

2.3. Wings aspect ratio

While the airfoil's cross-sectional shape is the foundation of lift generation, the aspect ratio (AR)—a key parameter defining the wing's planform geometry—plays a decisive role in optimizing overall aerodynamic efficiency shown in figure 4. It is defined to be the square of the span divided by the wing area, mathematically expressed as AR=b^2/S, where b represent the wings span and S refers to the total wing area. For example, a wing with a 10-meter span and 2-meter mean chord has an aspect ratio of 5, or a 12-meter span with a 30-square-meter area also yields AR=12^2/30=4.8.

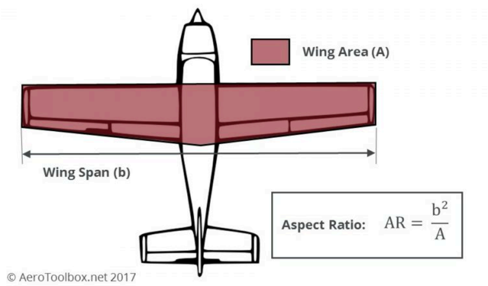

Figure 4. A graph of the wing aspects ratio

There are two main types of drag forces in this case: friction drag and induced drag. Friction drag related to the entire surface area of the wing; Induced drag is generated due to the pressure difference between the upper and lower wing surfaces that causes air to flow around the wingtips, it's a dominant drag source for a plane. For a higher AR wing, induced drag is drastically reduced while parasitic drag remains or increases minimally, resulting in a higher lift-to-drag ratio, which indicates more lift is created. Therefore, as AR ratio increase, the plane can be able to fly over a longer distance, and vise versa [9].

3. Airfoil design of different aircrafts

The idea of Bernoulli's principles and its affect on the airfoil has already introduced so far. It is important to study specifically on several types of airfoil designs that has been applied on different aircraft's and their influence on the flight behavior of these aircrafts.

DOI: 10.54254/2755-2721/2026.MH31568

3.1. Symmetric airfoil

The airfoil is considered to be symmetrical when the upper surface of the airfoil from the centerline mirrors that of the lower surface shown in figure 5, which means that upper and lower surfaces are identical. At zero angel of attach where the chord line is completely parallel to the airflow, the air will split evenly when hitting the leading edge traveling though the upper and lower at the same distances. Since the traveling length are same, the velocity of the airflow must be exactly the same on both surfaces, resulting in the equal pressure between upper and lower section that generate zero lift. The lift in this structure will generates only when the angle of attack begin to increase. In this case, the airflow on the upper surface must accelerates to cover a curved path (which has a further distance) in the same time as the air flow over the lower surface. As a result, the lift will appear due to the pressure differences explained by the Bernoulli's principles. Additionally, because of symmetric property on the airfoil ,the wings are also capable to generates the lift for the plane even if the planes upside down. Symmetric airfoil provides stable lift for an aircraft through the entire flight , allows the pilot to manipulates the plane more precisely and effectively at any orientation. The design of symmetric airfoil has been applied on battle planes, included F-16. These typical aircraft relays heavily on the symmetrical design, it gives them privileges to climb vertically, or shift their position from positive to negative within a few seconds when engaging in an arial combat. Symmetric airfoils ensure that lift generation remains consistent across these extreme orientations, allowing pilots to execute complex maneuvers without losing aerodynamic stability [10].

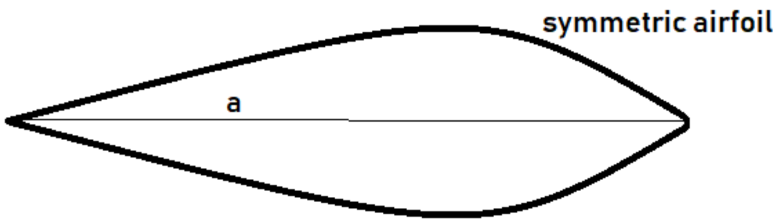

Figure 5. The sectional graph of a symmetric airfoil

3.2. Supercritical airfoil

The design of supercritical airfoils is distinct from traditional airfoil, its typically design for those subsonic aircrafts shown in fugure 6. The airfoil has a blunt leading edge that slow down the acceleration of the airflow as it hit the airfoil. The upper surface of the airfoils is relatively flat with minimal curvature, it prevent excessive airflows acceleration over the wings. At the trailing edge of the the airfoils, there is a concave lower surface that compensates the reduced lift caused by the flat upper surface by enhancing the camber of the wing's rear section, ensuring sufficient lift generation. When the aircraft with this typical supercritical airfoil reach at an extremely high speed (subsonic speed), the shock waves formed are weak and positioned far back on the wing. This decrease the impact of shock waves, delays drag divergence, and allows the aircraft to maintain high subsonic speeds efficiently without excessive power consumption. This properties quickly boosting fuel efficiency for the plane, reduce the cost for operating for a continental traveling. The typical design of airfoil is applied to modern subsonic commercial air jet, including Airbus A330, Airbus A380, and Boeing 747, aircrafts that requires to fly in an substantially fast speed for a quite long time length [11].

DOI: 10.54254/2755-2721/2026.MH31568

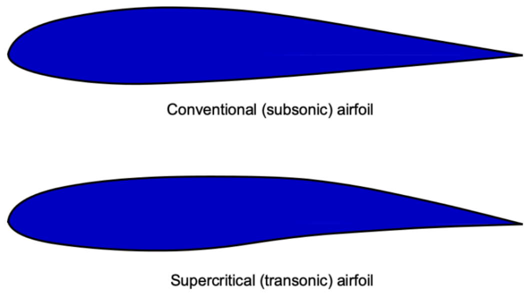

Figure 6. A composition between normal and supercritical airfoil

4. Conclusion

The complete page discussed the radical concept of fluid mechanism, particularly Bernoulli equation, which explained specifically by visualized graph and data's, and subsequently lins this towards its application on wings design on modern aircraft. Based on the analysis on two chief categories of airfoil, it is crucial for us to realized the significant impact to the airfoil design that contributed by the core principle from the Bernoulli equation. Overall, every component on a wings is crucial and indispensable, that they can produce determinate impact on the flying behavior and security for an aircraft, that it will extend the flight efficiency, or it might reduce the power and increase the risks for an aircraft through a flight. Human have made a extensive breakthrough on the studies of aerodynamics over the past centuries, laying a solid foundation for the continuous advancement of the aviation technology. Looking ahead, with a deeper research on fluid mechanisms and innovation of wing's designs, humanity will further optimize aircraft performance, improve flight efficiency and safety, and even explore more advanced aviation solutions, lead this industry to a more sustainable, efficient and safety future.

References

[1] Page, B. R. (2021). What Physics Students Can Learn from the Wright Brothers. The Physics Teacher, 59(5), 340-344.

[2] Boyer, A. (2023). Structural Design Analysis of the Burnelli CBY-3 Loadmaster and DC-3 (Doctoral dissertation, Worcester Polytechnic Institute).

[3] Lo Verde, A. (2024). Competition Dynamics and Market Power: Analysis of the Duopoly Between Airbus and Boeing in the Civil Aircraft Manufacturing Industry (Doctoral dissertation, Politecnico di Torino).

[4] National Aeronautics and Space Administration (NASA). (n.d.). Four forces on an airplane. NASA Glenn Research Center. Retrieved from https: //www1.grc.nasa.gov/beginners-guide-to-aeronautics/four-forces-on-an-airplane/

[5] Johnson, L. (2022, March 24). Bernoulli's principle: Definition, equation, examples. Sciencing. Retrieved from https: //www.sciencing.com/bernoullis-principle-definition-equation-examples-13723388/

[6] Buya, S. B. Bridging the Bernoulli Equation and the Navier–Stokes Equation.

[7] National Aeronautic Association (NAA). (n.d.). Airfoil design. National Aeronautic Association. https: //www.naa.edu/airfoil-design/

[8] Liu, T. (2021). Evolutionary understanding of airfoil lift. Advances in Aerodynamics, 3(1), 37.

[9] Hammer, P. R., Garmann, D. J., & Visbal, M. R. (2022). Effect of aspect ratio on finite-wing dynamic stall. AIAA Journal, 60(12), 6581-6593.

[10] Cadence. (2022). Exploring the aerodynamics of symmetrical airfoil. Cadence System Analysis Resources. Retrieved from https: //resources.system-analysis.cadence.com/blog/msa2022-exploring-the-aerodynamics-of-symmetrical-airfoil

[11] Cadence. (2022). The importance of a supercritical airfoil in aerodynamics. Cadence PCB Design & Analysis Resources. Retrieved from https: //resources.pcb.cadence.com/blog/msa2022-the-importance-of-a-supercritical-airfoil-in-aerodynamics