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Study and Analytical Work Analysis on Aerodynamic Investigation of Flow Field over Airfoil in Subsonic Wind Tunnel

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ABSTRACT

Aerodynamic analysis of a low Reynolds number airfoil is critical for numerous applications in the fields of aerodynamics and aeronautics, both basic and industrial. In a subsonic wind tunnel, an experimental evaluation was conducted over a symmetrical airfoil NACA 0014. The studies on the airfoil were carried out in an open circuit, suction-type subsonic wind tunnel. Because Reynolds number and angle of attack are two critical parameters in the performance of an airfoil, all experiments were carried out on an airfoil with the angle of attack varied at four different Reynolds numbers. The angle of attack and Reynolds number were adjusted from m 0º to 18º with 3º steps and 1.49x10^5 to 2.98x10^5 respectively. In this experimental investigation, the pressure distributions over the bottom and top surfaces of the airfoil were acquired, as well as the coefficients of lift and drag. At high Reynolds numbers, maximum coefficients of lift and drag of 1.53 and 0.18 respectively are attained. The stall condition was virtually achieved at a 15º-16º angle of attack.

Keywords-- Aerodynamics, Airfoil, Angle of attack, Coefficients of lift and drag, Reynolds numbers

INTRODUCTION

Since the previous six centuries, aerodynamics has become one of the most fascinating areas in science. However, in recent years, aerodynamics has attracted a lot of attention due to its wide range of applications in engineering, military, and civilian fields. It now has a wide range of applications, including the design of aircraft, trains, automobiles, submarines, torpedoes, turbine blades, and pumps, among others. All components that come into touch with a fluid must be engineered to withstand both static and dynamic forces. In the subject of fluid mechanics, resistance caused by the movement of a body in a static fluid or by the flow of fluid around a stationary submerged body is of critical relevance [1]. Lift and Drag are the two forces that make up aerodynamic forces [2].

Streamlined Bodies and Bluff Bodies

Drag is a resistance or a waste of energy, thus scientists and engineers aim to reduce it. That is why, with the exception of certain instances such as parachute, components should be constructed to lower drag coefficient as much as feasible. To lower drag coefficient, a round leading and elongated with the flow direction is provided, as well as a curvature to reduce boundary layer separation. Separation of the boundary layer occurred solely along the object's trailing edge as a result of these procedures. Wakes that arise as a result of boundary layer separation become minimal, and form drag is greatly decreased. Streamlined bodies and bluff bodies are shown in Fig. 1.

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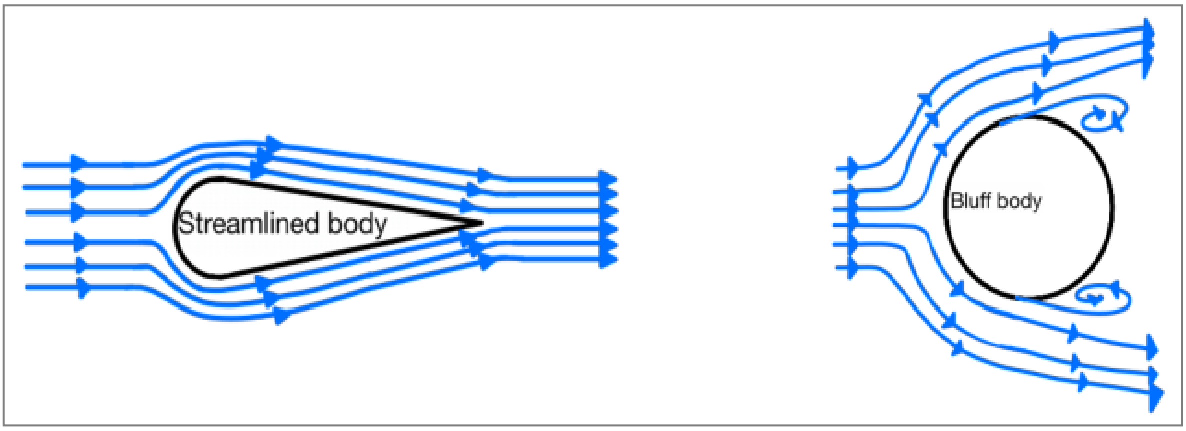

Figure 1: *Streamlined and bluff body.*

The net effect of drag forces on the body is minimized because the object is stretched along the flow direction, causing it to exceed the friction drag. Because there are many other types of drag forces connected with objects, their contribution to total drag is minimal, form or pressure drag, and shear drag are regarded the main three constituents of total drag. Wings, blades, and other streamlined shapes are employed to achieve this. In contrast to streamlined bodies, bluff bodies have low skin friction but create a high pressure differential due to boundary separation accompanied by substantial wakes, resulting in a high pressure drag setup and a high total drag force when compared to streamlined bodies.

Airfoil

A streamlined body with a rounded or sharp leading edge that is stretched in the direction of flow to produce high lift and low drag force is known as an airfoil. Airfoils are the cross-sectional shape of aeroplane wings and turbo machinery blades. It was once thought that a sharp leading edge airfoil produced less drag, however research revealed that these airfoils stalled quickly and generated significant drag, prompting engineers to switch to a rounded leading edge airfoil.

Basic Governing Principles

In the case of airfoil functioning, there are numerous notions and principles at work, but we will simply cover the essential governing equations here. The behavior of an airfoil is governed by three principles:

1. Newton's second law of motion,
2. Newton's third law of motion, and
3. Bernoulli's principle

The force acting on the airfoil when air strikes it is proportional to the rate of change of momentum of the hitting air, according to Newton's second law of motion. The third law also states that an airfoil will produce a reactive force in response to the force applied by the air.
Bernoulli's equation is one of the most useful principles in the study of any object's aerodynamics [3]. Bernoulli's equation is the most promising principle since airfoils often deal with the kinetic and pressure energy of the moving fluid.
Bernoulli's equation is written like this:
$P/\rho g + V^2/2g + Z = \text{constant}$

This equation demonstrates that the entire sum of these energies in a flowing fluid is constant, as well as the fact that the kinetic and pressure energies are inversely proportional. When one is diminished, the other is boosted. This phenomenon aids in the generation of lift on the airfoils. The air passing around the airfoil strikes its surfaces; the velocity of air at the lower surface of the airfoil is lower than that at the upper surface, and according to Bernoulli's equation, the pressure at the lower side is greater than that at the upper side. As we know, all matter tries to travel from a higher pressure region to a lower pressure region, which is why a force acts from higher to lower pressure [4].

Aerodynamic Forces

Aerodynamic forces divided in two types- Lift and Drag. These two forces described as follows:

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Lift Force

Lift is an aerodynamic force caused by a differential in pressure distribution along an object's upper and bottom surfaces. It acts upward and is regarded as the most critical parameter without which planes cannot fly. For an aeroplane to take off from the ground, the lift force must be greater than the weight of the aircraft. To generate lift force, the body's geometry is critical, as the pressure differential must be large enough to exceed the weight of the object. Lift force is supposed to act on a single location known as the centre of pressure in the case of aircraft [5].

Various studies are still being conducted in order to increase the lift force of the aeroplane. So that they become able to carry heavier load.

Drag Force

A lot of investigations have concluded that as an object moves through a fluid, the fluid on that body provides resistance. Whether a body moves inside a static fluid or a fluid flows over a solid body, the resistance force stays the same. The propulsion unit must exert a force sufficient to balance the resistance force exerted by the fluid in order to maintain a steady motion, a force in the direction of relative motion accordingly. Drag force is the name for this type of resisting force. Drag is essentially a form of energy loss. Drag is primarily determined by the Reynolds number, but it is also influenced by the form and direction of the body, as well as the type of the incident flow. Drag is defined as the sum of all forces that try to prevent the body from moving. A variety of tests have been carried out in order to lower drag force, and the process is still ongoing. The sum of skin friction drag and pressure or form drag is known as total drag [6].

LITERATURE REVIEW

Yemenici [7] investigated a symmetrical airfoil in an experimental setting. The trials were carried out with a NACA 0012 airfoil, which was subjected to angle of attack and Reynolds number variations. The Reynolds number, which is determined by chord length, ranged from $9.7\text{x } 10^4$ to $1.9\text{x } 10^5$, and the angle of attack ranged from 0º to 14º. The pressure coefficient at the suction side increased at the leading edge and decreased at the trailing edge at all angles of attack, according to the experiment. Both lift and pressure coefficient is strongly dependent on angle of attack and Reynolds number, according to the experiment.

For the symmetrical airfoil NACA 0015, Sahin and Acir [8] investigated lift and drag force analyses numerically and empirically. They conducted their research at various angles of attack ranging from 0º to 20º in two degree steps. The numerical analysis was carried out using the Fluent CFD programme, and the experimental analysis was carried out using a low-speed wind tunnel. They made a graph for both the lift and drag coefficients and compared the numerical and experimental data, which revealed that the experimental value of the lift coefficient is lower than the numerical analysis. The drag coefficient in experimental analysis, on the other hand, is higher in some ways than in numerical analysis.

Yemenici [9] used a low-speed wind tunnel with a symmetrical airfoil to conduct their research. The experiment was conducted using Reynolds numbers ranging from 1x105 to 3x105 and angles of attack ranging from 0º to 14º. A constant temperature anemometer and micrometer were used to measure velocity and static pressure, respectively. And it was discovered that there is a similar variance in the distribution of pressure coefficients of the airfoil at both Reynolds numbers, and that the lift coefficient and stall angle both rise with the Reynolds number.

Munzarin et al. [10] looked at a symmetrical airfoil (NACA 0015), a cambered airfoil (NACA 4415), a cylinder, and a sphere as four different profile objects. A subsonic wind tunnel was used to evaluate these objects. At various Reynolds numbers and angles of attack, the experimental data was observed. Two airfoils were examined from 0 to 180 degrees of angle of attack in 30 stages, while a cylindrical profile and a spherical shape were tested from 0^0 to 180^0 degrees. According to tests, the cambered airfoil (NACA 4415) has the lowest coefficient of drag, whereas the spherical has the highest.

Islam et al. [11] studied a base line airfoil NACA 0015 model using an experimental

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examination in a subsonic wind tunnel. Experiments were conducted with a fixed stream velocity of 12 m/s and a Reynolds number of $1.89X10^5$ over a wide range of angle of attack from 0º to 20º. After measuring the pressure distribution on both the upper and lower surfaces of the airfoil, it was discovered that Cl and CD are 1.3 and 0.31, respectively.

Shah et al. [12] used both experimental and numerical methods to study a wing (symmetrical airfoil). Testing was carried out at varied air speeds of 20 m/s, 25 m/s, and 30 m/s, as well as at different angles of attack of 0º, 5º, 10º, 15º, and 20º.

Uddin et al. [13] conducted an experimental study to determine the drag and lift coefficients for numerous wings. A model with numerous wings was built for the inquiry, and experiments were done in a subsonic wind tunnel using it. For the tri-plane configuration, symmetrical airfoils NACA 0012 with a chord length of 21 cm were employed. The angle of attack was altered in 5º increments from 0º to 20º.

Rathod [14] used a subsonic wind tunnel with varying wind velocity to conduct his research. This experiment employed the NACA 0017 symmetric airfoil. Characteristic curves were drawn at various angles of attack and with various Reynolds numbers. The stalling condition was determined to be close to the 16^0 angle of attack in this experiment. It is also concluded that as velocity increases, drag decreases until a certain point, after which it increases significantly. Coefficient of lift increases linearly with angle of attack until stall occurs, at which point its value decreases as the angle of attack increases. The pressure over the upper surface decreases as the Reynolds number increases, according to the pressure variation graph.

The lift and separation bubble characteristics of a symmetrical airfoil (NACA 0018) were investigated by Gerakopulos et al [15]. The pressure distribution at the surfaces was monitored, and the relationship between the performance of the aerofoil and the creation of a separated flow area was calculated. Angles of attack range from 0º to 18º degrees, while Reynolds numbers range from 80 x 10^3 to 200 x 10^3. Two separate zones have been found using measured data: the first is of rapid and linear coefficient of lift increase at low angle of attack, while the second is of more slow and linear growth at high pre-stall condition.

Ahmed and Sharma [16] conducted their experiments using a symmetrical airfoil NACA 0015 with a low Reynolds number. The pressure distribution on the surface of the airfoil was measured, and the lift and drag forces were calculated. Experiments were conducted with angles of attack ranging from 0^0 to 10^0. When the airfoil is close to the ground, high pressure is obtained at the entire bottom surface at a high angle of attack, and a high value of lift coefficient is obtained. With high angle of attack at ground clearances, the pressure coefficient at the upper surface of the airfoil did not vary considerably. The suction or negative pressure gradient causes a decrease in kinetic energy on the upper surfaces at a higher angle of attack, which causes more turbulence and a thick wake, resulting in increased drag. It was also discovered that when the angle of attack is reduced, the lift force at ground clearance decreases. At 12º degrees of angle of attack, higher turbulence intensity and a thicker wake zone were obtained.

CONCLUSION

The following conclusion has been reached after investigating the aerodynamic characteristics of the specified NACA airfoil and determining the results using various parameters.

1. The value of the lift coefficient rises as the Reynolds number and angle of attack rise.
2. It has been discovered that the maximum lift coefficient is 1.53 at a 15º angle of attack, and the highest drag coefficient is 0.18 at an 18º angle of attack.
3. At a 15º-16º angle of attack, the stall situation was noticed.

The stagnation point migrated from the leading edge to the lower surface of the airfoil when the angle of attack was increased.

FUTURE WORK

In terms of pressure, drag, and lift coefficient, the current experimental investigation provides a variety of fascinating

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outcomes. However, there is still the possibility of expanding the current experimental work in the future. The following scope of work is currently being provided for future work.

1. Because of the limited capacity of the wind tunnel, the current research is focused on subsonic air velocity. In the future, research could be conducted at sonic and supersonic speeds.
2. Because the pressure tapping technique can't measure flow separation. In the future, research could be conducted to determine the flow separation point.
3. In the future, airfoils with higher lifting devices or flaps could be tested.

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