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ANALYZING THE AERODYNAMIC CHARACTERISTICS OF AIRFOILS WITH UPPER SURFACE MODIFICATION

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Abstract*- Nowadays, the purpose of modifying the design of airfoil is to reduce the drag force and enhance the lift force. In this present work, the upper surface condition of an airfoil is modified and aerodynamic characteristics such as drag and lift are measured. The airfoils are being conducted in a subsonic wind tunnel at a distinct angle of attack. NACA 0010 airfoil is used as a reference airfoil model. Parallel strips and dimple slot are used to modify the airfoil model's upper surface. These types of modifications create a delay in the separation of flow on the surface. The delay separation of flow reduced the wake formation. As the wake formation reduces, it enhances the lift force and reduces the drag force. The objective of this study is to increase the aerodynamic efficiency of an airfoil model by suppression of flow separation and compare with different types of modified airfoil surfaces.*

Keywords: Airfoil, Design modification, Drag and Lift, Wind Tunnel

1. INTRODUCTION

From the ancient era of mankind, people are trying to make some excellence in aerodynamics. Fly high in the air is a cherished dream for the people from the very beginning of mankind. In the study of scientific history, Leonardo Da Vinchi was the first person to design a wing by which man can fly in the air. But the Wright brothers were the pioneer who makes the dream possible. They manufactured the first-ever aircraft which fly in the air for the first time. Till then, the development of aircraft is done. The aircraft is now so updated and the aircraft's performance is in a satisfactory place [1].

At the present time, there are several types of modifications done in the aircraft and airfoil design. The objectives of these modifications are to reduce the drag force and enhance the lift to drag ratio that results in good aerodynamic efficiency. When an aircraft flies in the air, some force acts on the surface of the aircraft. These forces are drag, lift, thrust and weight. The airfoil was designed to control these forces in a new way. Boundary layer theory is an important term in aerodynamics and the importance of boundary layer theory is beyond description in aircraft designing. The boundary layer means a thin layer of fluid over the surface of the aerodynamic model when fluid flows over the model. The fluid becomes stationary at the wall of the model because of the viscous effect. The viscous effect reduces when the vertical distance increased and then the flow is converted in free stream velocity [2].

Different types of modifications are being studied nowadays for the improvement of the airfoil model. The purpose of design modification is to improve the maneuverability of the aircraft and improve aerodynamic efficiency. Vortex generators are the most popular form of modification at this present time. By using different shapes of the vortex generator, the aerodynamic forces can control. This vortex generator also can control the boundary layer. There are different types of vortex generators such as circler, cylindrical, triangular, stripes, etc. The vortex generator creates vortices on the surface of the model. The boundary layer is therefore segregated and there is a delay in the separation of the boundary layer. As boundary layer separation is delayed, the pressure drag reduced because of the thin wake length. Many researchers worked on the roughness of the surface for the boundary layer suppression using different types of a dimple. In this study, the effect of surface modification is analyzed. Adding roughness on the airfoil surface was done by so many people. Among the types of roughness, triangular was common and suggested by many for enhancing the separation control in the airfoil. A. Dhiliban et. al. did an analysis on implementing triangular roughness in the upper and lower surface of the airfoil as well as a vortex generator. Experimental measurements of surface pressure distributions and wake profiles were obtained for a NACA 0012 airfoil to determine the lift, drag, and pressure coefficients for various configurations. The addition of triangular roughness was analyzed at a different angle of attacks. There was, however, the lower surface gives better results than the upper surface. Some studies had been done on adding dimple on the airfoil surface to determine the change of drag and lift at different angles [3]. In 2015 E. Livya et. al. worked on the dimple effects on an airfoil. They found that the airfoil which contains dimples will have comparatively less drag than the plain airfoil Adding dimples on the aircraft wing will create turbulence by creating vortices that delay the boundary layer separation resulting in the decrease of pressure drag. They also said that the vortex generator creates turbulence by creating vortices that reduce the pressure drag and increases the overall lift of the aircraft. The dimples delay the flow separation by energizing potential energy into kinetic energy [4]. Deepanshu Srivastav also worked on a dimple effect. He used inward and outward dimple on the upper surface of the airfoil. He did CFD analysis on the airfoils and choose the better one. He found that the dimple delays the flow separation and reduce the drag drastically. He used NACA 0018 as an aerodynamic model and modifies its surface with the inward and outward dimple. He determined that outward dimple is more efficient and produces less drag [5]. Riyad Belamadi et. al. worked on the performance of slotted airfoil for the application of wind turbine blades. They showed the difference between the performance of airfoils at a certain angle of attack. They also discuss the pressure distribution on the airfoil surface. They used different types of simulation models for detecting the separation point on the airfoil. They found in the standard k-ε model the separation point is at 64% and for the others such as k-ω model, Spalart allamaras, k-ω SST at 64%, 58% and 52% [6]. Dinesh Kumar G. et. al. worked on the boundary layer suppression using a bumped surface in the airfoil. They used surface roughness on the airfoil among several methods of boundary layer control. They built up several graphs of the coefficient of lift vs angle of attack. They tested NACA 4412 airfoil with and without bump surface and found that the bumps at the trailing edge are effective only at higher angles of attack. The lift is increased is by 15.92% [7]. In 2017, Amit Kumar Saraf et. al. built up an analysis of an airfoil based on CFD. They solved equations for building the CFD analysis. They gave a conclusion that was there was a deviation with the CFD data and the practical data. They also showed that the k-ε standard model and the k-ε RNG model gives a better solution [8]. The objective of this work is to study the change of lift and drag force after modification of the airfoil model.

2. Design and Fabrication of Model

2.1 Design of the airfoil: Selecting an airfoil to study is a difficult task to perform. The NACA airfoils are airfoil forms for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). In this investigation, NACA 0010 was selected and the scaled schematic of NACA 0010 is shown in figure 2.1. The airfoils are controlled by 4 digits which designate the camber, position of the maximum camber and thickness. For NACA 0010 airfoil model, the camber is 0C; the maximum camber is at 30%C and thickness are 0.10C. It is a symmetric model. The designed airfoil models are shown in Figures 2.2 and 2.3.

Figure 2.1: Plain Airfoil

Figure 2.2: Slot type dimple Airfoil

Figure 2.3: Striped airfoil

2.2 Fabrication of airfoil: The modified airfoil models are fabricated by wood in the workshop of CUET. The figures 2.4, 2.5, 2.6 show the fabricated airfoil models. Prototyping of an airfoil body is designed to investigate the variance of outcomes by contrasting the simulated and experimented results. A prototype of NACA 0010 with inward stripes and slot type dimple on the upper surface was built for wind tunnel experiments with a predefined chord length of 150 mm and a span of 300 mm. The prototype fabricated in the workshop was not as precise as wished for. The slot and stripes are used for the suppression of the boundary layer on the upper surface of the airfoil surface.

Figure 2.4: Plain Airfoil

Figure 2.5: Striped airfoil

Figure 2.6: Slot type dimple Airfoil

3. METHODOLOGY

3.1 Subsonic Wind Tunnel: The AF100 Subsonic Wind Tunnel located at the aerodynamics laboratory of CUET provides a compact and practical open-circuit wind tunnel in which to study low-speed aerodynamic effects. In the studies of aerodynamics, the laboratory-based wind tunnel gives very accurate results, as long as the scale effects and reduced Reynolds numbers are taken into account. The wind tunnel used here is of the closed working section, open return suction type. It is supported on a tubular steel framework with lockable castors, this makes the apparatus very mobile. Air enters the tunnel through an aerodynamically designed cone that accelerates the air in a linear manner. It then enters into the working section and passes through a grille before moving through a diffuser and then to the variable speed axial fan. The air leaves the fan, passes through the silencer unit and then back to the atmosphere. Figure 3.1 shows the wind tunnel setup.

Figure 3.1: AF100 Subsonic Wind Tunnel

3.2 Simulation Setup:
A NACA 0010 airfoil model was created for the precise airfoil and the modified others in CAD software and then the simulation was performed. Chord length and span have been taken 150 mm and 300` 1 mm for the convenience of the airfoil in the wind tunnel.
The simulation will be carried out using the following parameters:

- The fluid will be assumed as incompressible
- Fluid type: Air
- Temperature: 298 K
- Pressure: 101325 Pa
- Velocity for air: 10 m/s
- Air density: 1.15 kg/m^3
- Standard k-ε model (2 equations)
- The SIMPLE algorithm
- Inlet: Constant Velocity
- Outlet: Constant Pressure

4. RESULTS AND DISCUSSIONS

Figure 4.1 illustrates the comparison between experiment drag coefficient information. The objective of this research is to decline the drag force and increase the lift force. The data between plain, striped and slot type dimple airfoil are evaluated in this graphical analysis. The stripped airfoil has the smallest drag coefficient among three airfoil prototypes. As the angle of attack rises, the drag coefficient improves for the three airfoil kinds. The drag coefficient decreases at an angle of attack of 8º. For the stripped airfoil, the drag coefficient reduces the most. This angle is called the angle of the stall. The models of the airfoil were produced from wood. The values were therefore not ideal because the model's surface was not completely smooth.
Figure 4.2 shows the comparison among the data of the coefficient of drag of simulation. In this study, the objective is to reduce the drag force and enhance the lift force. In this graphical analysis, the data among plain, striped and slot type dimple airfoil are analyzed. Among the three airfoil models, the striped airfoil has the lowest drag coefficient. With the increase of angle of attack the coefficient of drag increases for the three types of the airfoil. At 8º angle of attack, the drag coefficient reduces. For the striped airfoil, the drag coefficient reduces the

most. This angle is called the stall angle. The simulated data have some error with the experimental values, as the simulation was performed in a laptop whose processor capacity is low regarding do simulation. For this reason, the grids in the mesh analysis cannot increase at a high number.

Figure 4.3 demonstrates the comparison between the lift coefficient information of the experiment. The goal of this research is to decrease the drag force and increase the lift force. The airfoil type plain, striped and slot are evaluated in this graphical analysis. The slot type dimple airfoil has among the three airfoils the largest lift coefficient. But at distinct angles of attack, the stripped airfoil has more lift coefficient than simple airfoil. The stripped airfoil has the most effective lift co-efficient at 8º angle of attack than the others. The raw surface delays the flow separation and generates a thin wake is a reason behind the lift improvement.

Figure 4.4 indicates the simulation comparison between the lift coefficient information. The goal of this research is to decrease the drag force and increase the lift force. The airfoil type plain, striped and slot are evaluated in this graphical analysis. The slot type dimple airfoil has among the three airfoils the largest lift coefficient. But at distinct angles of attack, the stripped airfoil has more lift coefficient than conventional airfoil. The stripped airfoil has the most efficient lift co-efficient at 8º angle of attack than the others. The reason for improving the lift is that the rough surface delays the segregation of the flow and creates a thin wake.

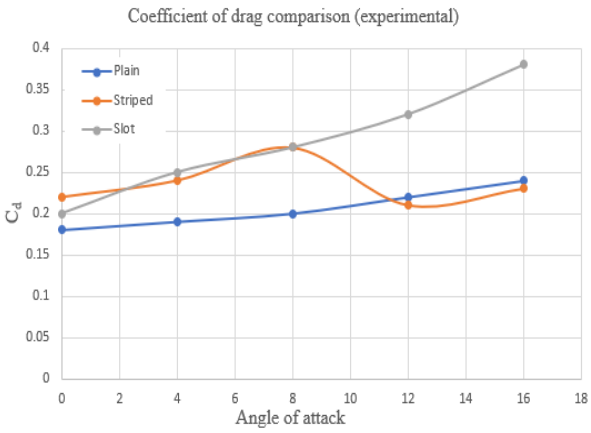

Figure 4.1: Coefficient of drag (Experimental)

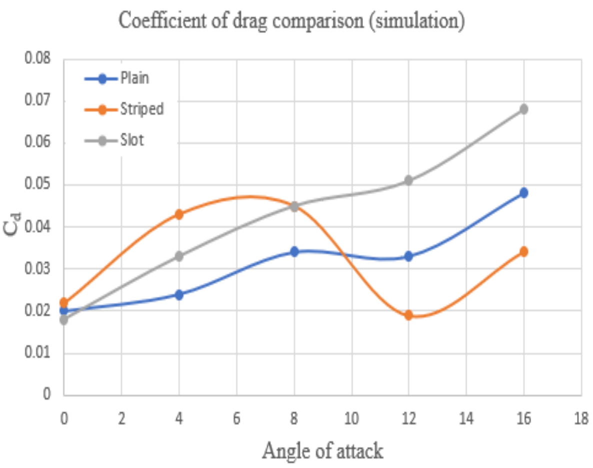

Figure 4.2: Coefficient of drag (simulation)

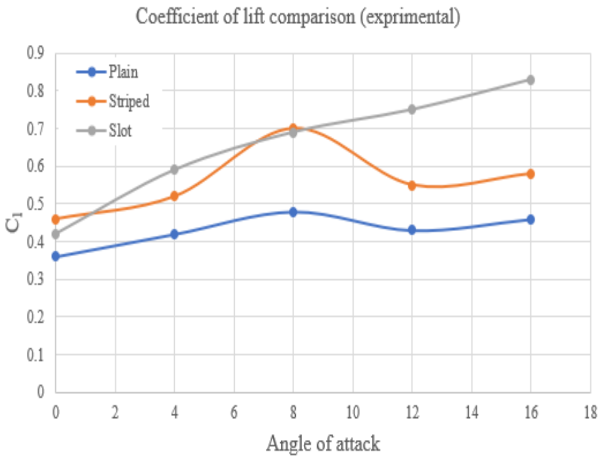

Figure 4.3: Coefficient of lift (experimental)

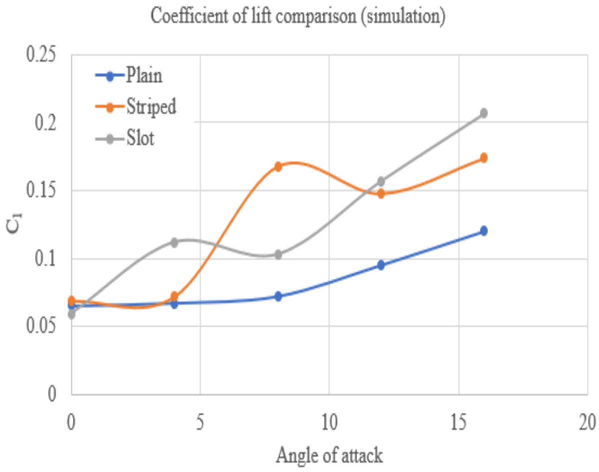

Figure 4.4: Coefficient of lift (simulation)

5. CONCLUSIONS

In this study, the objective is to reduce the drag force and increase the lift force. The aero vehicle or different types of wind turbines can work efficiently if the drag reduces and lift increases. It also results in a low consumption of fuel. But the drag force is not always negligible. When the aero vehicle takes off and lands on the runway there needs some drag force. The results gained from the experiment and simulation differed to a certain extent. The experimental value showed a higher value of lift and drag force compared to the numerical value. The difference between the experimental and numerical analyses caused due to the difference between actual and computational environmental variables that were set before proceeding with the analysis. The reasons behind the modification are to delay the separation of flow on the upper surface and reduce the wake length. As the wake length reduced, the pressure drag is also reduced. As the concluding remark,

- The NACA 0010 airfoil with inward stripes on the upper surface has the lowest drag coefficient.
- The NACA 0010 with the slot type dimple on the upper surface has the highest lift coefficient.
- Overall the NACA 0010 with inward stripes on

upper surface is the most preferable considering the overall lift and drag at different angle of attacks.

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