A Study of Impacts of Airfoil Geometry on the Aerodynamic Performance at Low Reynolds Number

Ahmad A. Alsahlani*, Mohammed Al-SAAD, and Mohammed Al- Mosallam

Department of Mechanical Engineering, University of Basrah, Basrah, Iraq
* Correspondence: Ahmad.mahdi@uobasrah.edu.iq

***Abstract*—The aerodynamic performance of airfoils has been studied in several studies; however, the performance is highly relying on the airfoil geometry and the flow characteristics such as the flow type (laminar or turbulent) and Reynolds number. This paper focuses on understanding the aerodynamic performance of airfoils in a low-speed environment (low Reynolds number) versus the airfoil geometry. This paper would be a guide to the airfoil design and optimization processes toward the design target under similar flow conditions. Therefore, several parameters of the airfoil geometry, such as maximum thickness, maximum camber, their location, and reflex angle were studied in a low Reynolds number range from 0.3×10^6 to 0.8×10^6. Three airfoil parameterizations, NACA 4-digit, PARSEC, and Bezier curve, were utilised to generate the airfoil coordinates for different studied parameters. A two-dimensional aerodynamic solver, XFOIL, was used to evaluate the aerodynamic performance of the airfoils. The results show that varying the airfoil geometry results in a noticeable change in the lift, drag, and moment coefficients. Also, as expected, increasing the Reynolds number has resulted in a good performance.**

***Keywords*—airfoil, low reynolds number, airfoil shape**

I. Introduction

Low Reynolds number environment widely exists in real industry life. Such operating an aircraft or any lifting body at a low Reynolds number will make the viscous effect more dominant [1, 2]. The wing sections are usually designed to achieve the desired aerodynamic performance in a specific environment. The shape of an airfoil can be manipulated to overcome or reduce the impact of a low Reynolds number on the performance [3, 4]. At low Reynolds numbers, the rapid separation in the boundary layer will affect the aerodynamic performance of airfoils [5]. This leads to an unsteady behavior and therefore a fluctuation in the resulting moment and force with time [6]. Furthermore, the separation bubble will initiate the transition from laminar to turbulent flow [6, 7], see Fig. 1-A. The airfoil shape is definitely having influence on the location of the separation and its intensity along the upper and lower surface of the wing section. Moreover, the Reynolds number and the angle of attack also have this influence on the aerodynamic performance of the airfoils but this also could be mitigated or manipulated along with the airfoil shape [8]. The reduction in the gradient of the lift-curve and the increase in the drag-curve are obviously noticed when separation is happened [9]. A large amount of air resistance can be generated from the pressure drag at the laminar flow region when the laminar separation bubble is taken place. After the laminar separation bubble, the flow attempts to reattach to the wing and turn into turbulent flow or could remain separated. In case the flow remains separated, the lift force will abruptly decrease with a remarkable rise in the drag force. The surface roughness of an airfoil has an effect on the performance such as decreasing the lift/drag ratio when the Reynolds number at approximately more than 105. Nevertheless, below this Re, roughness can be beneficial due to the discontinuity in the surface, which can participate to forming the flow separation [10].

Reynolds number of the flow has a noticeable effect on the performance and this effect can be recognized or mitigated by changing the airfoil shape. The most impact of flying under low Reynolds number is the increase in the viscous drag and it becomes clear when separation occurs. The airfoil shape can be modified through an optimisation procedure to reach an optimal design that can perform well without any separation within certain range of angle of attack. So, the need is raised to understand how the airfoil shape parameter can affect the performance and how the Reynolds number plays its roll in that. Therefore, for a range of Reynolds number, this study will focus on the effect of the various airfoil shape parameter on the airfoil performance. The Reynolds number range chosen for this study, is from 0.3×10^6 to 0.8×10^6.

There are several equations can generate airfoil coordinates, however, not all these equations can deal with all airfoil shape parameters targeted in the study. Therefore, a combination of airfoil parameterizations is used to generate airfoil coordinates for different airfoil parameters. Table I shows the main parameters of airfoil that can be altered for three different parametrization equations. The mathematical equations of these parametrization methods are detailed in the following

Manuscript received August 21, 2022; revised September 20, 2022; accepted November 10, 2022.