An Experimental Study on the Aerodynamics of a Symmetrical Airfoil with Influence of Reynolds Number and Attack Angle

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***Abstract*—**In this study, velocity and static pressure measurements around a symmetrical airfoil were investigated in a low speed wind tunnel under the effects of the Reynolds number and angle of attack. The experiments were carried out for the chord length Reynolds number of $1x10^5$ and $3x10^5$ and the attack angle was varied from 0 to 14^0. A constant-temperature anemometer and a micro-manometer were used for measurements of velocity and static pressure, respectively. The results showed that the streamwise variations of the pressure coefficients of the airfoil showed similar distribution at both Reynolds numbers, while the stall angles and lift coefficients increased with Reynolds number.

***Keywords*—**Aerodynamics, airfoil, lift coefficient, pressure coefficient.

I. Introduction

THE aerodynamics characteristics of the airfoils at a small chord Reynolds number is very important for many engineering applications like small wind turbines, small unmanned aerial vehicles and micro-air vehicles. Therefore, there have been several previous investigations on the airfoils in recent years such as; Singh et al. [1] designed a low Reynolds number airfoil for applications in small horizontal axis wind turbines to achieve better startup and low wind speed performance. Yilbas et al. [2] performed a numerical simulation of the flow field around a cascade of NACA0012. Analysis of ground effects on aerodynamic characteristics of airfoils using boundary layer approximation was carried out by Takahashi et al. [3]. Ahmed et al. [4] carried out a computational study into the flow field developed around a cascade of NACA0012 airfoils. Flow over an airfoil without and with a leading-edge slat at a transitional Reynolds number was investigated by Genc et al. [5]. Yen and Huang [6] studied on the Reynold number effects on flow characteristics and aerodynamic performances of a swept-back wing. Separation control on a NACA0015 airfoil using a micro jet was performed by Tuck and Soria [7].

The present study was undertaken to examine experimentally the effect of Reynolds Numbers and attack angle on aerodynamics characteristics of the NACA0012 airfoil. The measurements were performed at the chord length Reynolds number of $1x10^5$ and $3x10^5$ the attack angle ranged from 0 to 14^0.

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II. Experimental set-up and method

An open circuit and blowing-type, low-speed wind tunnel that was run by a 5.7 kW axial blower was used in the experiments. Air velocity was adjusted by a butterfly valve, where the maximum velocity was 30 m/s with a turbulent intensity of 0.7 %. Air passes through a metal duct having a length of 1070 mm and a honey comb, a nozzle with 1.5:1 contraction ratio and a straight duct of 400 mm length before the test section, as shown in Fig. 1. The test section has an initial area of 200x305 mm^2 and length of 800 mm with plexiglass side surfaces. The experiments were carried out over a wool NACA0012 airfoil with 152 mm chord length and 305 mm spanwise length which was mounted in the middle of the test section.

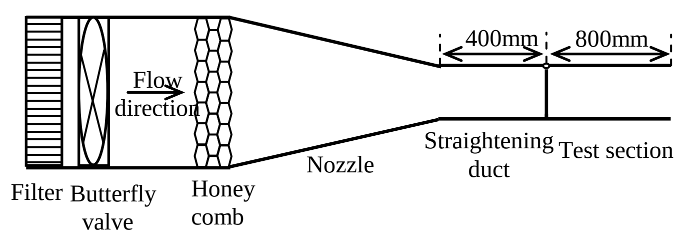

Fig. 1 Wind tunnel and test section

The mean velocities were measured by a constant temperature hot wire anemometer comprised of a model P11 probe with probe support and cable, a constant temperature anemometer, a signal conditioner, an A/D converter, and a computer was used to measure the velocities. The static pressure measurements were performed using the pressure tappings and capillary pipes, and recorded by a micro-manometer. The angles of attack with 2^0 intervals were also obtained by an angle adjuster and the mean static pressure measurements of the suction and pressure side of the airfoil were performed at both 10 location, as presented in Fig. 2.

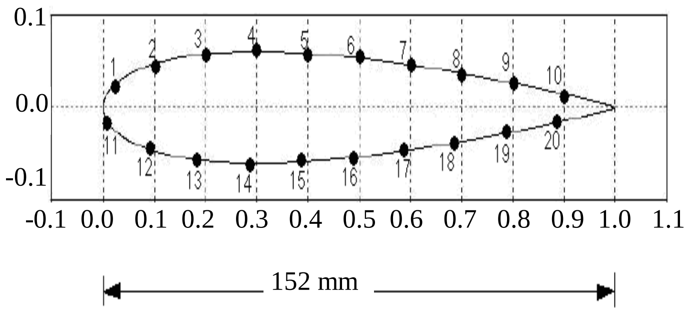

Fig 2. The airfoil pressure tappings

The pressure and lift coefficients were calculated by $C_P=(P-P_0)/0.5\rho U^2$ and $C_L=L/0.5\rho U^2A$ respectively, where P is static pressure measured at pressure tappings, P_0 is static pressure of free stream, U is free stream velocity, ρ is density, L is lift force and A is effect area.

Kline and McClintock [8] uncertainty estimation method was applied for all the measurements of velocity and pressure The maximum uncertainty of the velocity and pressure measurements were obtained as ±2.1% and 3.7%, respectively.

III. Results And Discussion

The pressure coefficients of the NACA0012 airfoil at the attack angles (α) of 0-12^0 are given in Figs. 4 and 5 for Re_C= $1x10^5$ and $3x10^5$, respectively. The streamwise variations of the pressure coefficients of the airfoil showed similar distribution at both Reynolds number. The pressure variations over the suction and pressure side of the airfoil showed a symmetric distribution for $\alpha=0^0$. For both Reynolds number and all attack angles, the pressure coefficient had a large suction peak at the suction surface near the leading edge, and followed by a gradual increase in pressure. The stall point of the pressure side was obtained near the leading edge, where the pressure coefficient had maximum value, as explained by Yilbas et al. [2]. The C_p values increased with attack angle at both Reynolds number. The separation and reattachments couldn't determine by the pressure measurements, while curves showed that the boundary layer developed after peak suction from the leading edge to trailing edge.

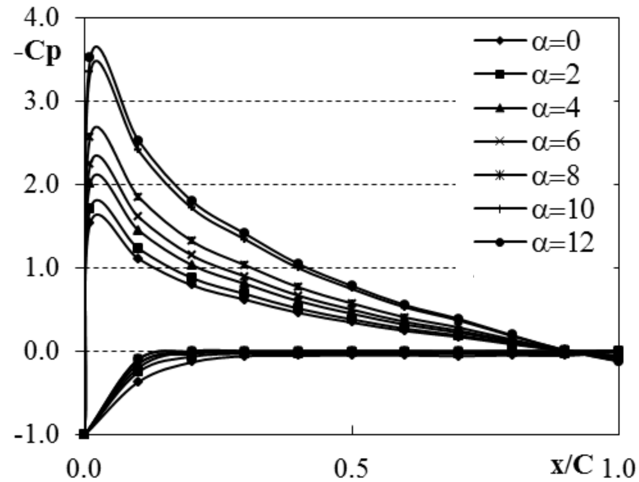

Fig. 3 Pressure coefficients of suction and pressure side of the airfoil at $Re_C=1x10^5$

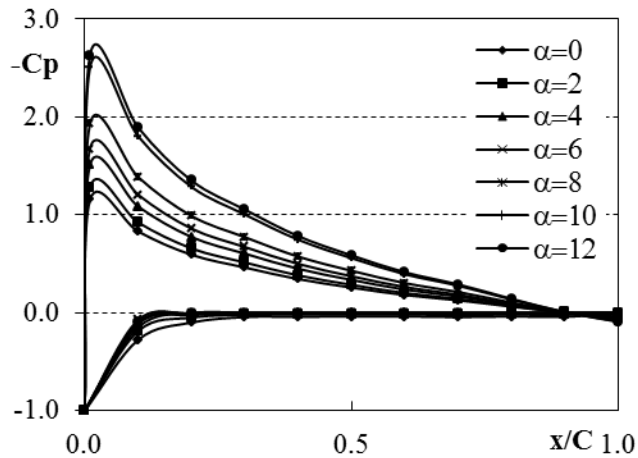

Fig. 4 Pressure coefficients of suction and pressure side of the airfoil at $Re_C=3x10^5$

Lift coefficients variations of NACA0012 airfoil with attack angles at both Reynolds numbers are presented in Fig. 5. The C_L increased monotonously with the attack angle and reached the maximum at $\alpha=11^0$ and 12^0 at $Re_C=1x10^5$ and $3x10^5$, respectively. It can be said from these results, the stall points were obtained at $\alpha=11^0$ and 12^0 and the stall angle increased with Reynolds number. The maximum C_L had 7% bigger values at bigger Reynolds number because of viscous effects.

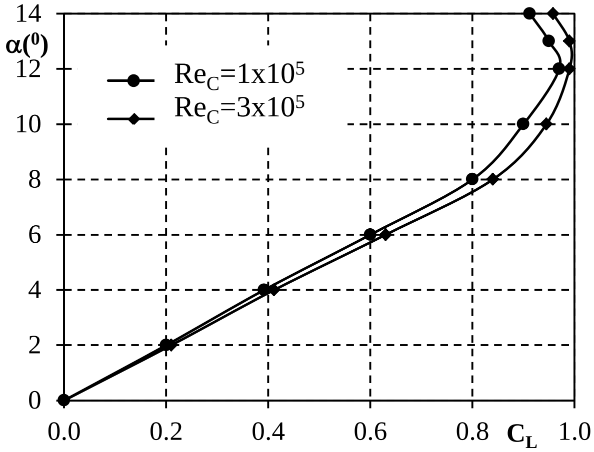

Fig. 5 Lift coefficients of airfoil at both Reynolds numbers

IV. Conclusion

The effects of Reynolds Numbers and attack angle on aerodynamics characteristics of the NACA0012 airfoil have been numerically studied. The streamwise variations of the pressure coefficients of the airfoil showed similar distribution at both Reynolds number. The C_p values of the suction side of the airfoil initially increased near the leading edge and then decreased up to trailing edge for all attack angles. The stall point where the lift coefficients had maximum values was obtained as 11^0 and 12^0 at $Re_C=1x10^5$ and $3x10^5$, respectively. The angles of stall and lift coefficients increased with Reynolds number.

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