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ANALYSIS OF THE INFLUENCE OF REYNOLDS NUMBER AND MAXIMUM THICKNESS ON AN AERODYNAMIC PROFILE

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Abstract. *Aerodynamics is the science that studies the influence of the gas movements over solid bodies. This branch of science has been target of much interest mainly because of the large use of aircrafts and auto-vehicles nowadays. Using a numerical simulation software, this paper proposes a study on the influence of Reynolds number and maximum thickness of an airfoil on the aerodynamic forces. Stall angle, Lift and Drag forces were evaluated on different conditions. Lift and Drag coefficients in function of the angle of attack were obtained numerically and compared with experimental data from literature. The results* *showed that the software is able to simulate the main variables that influence the aerodynamics of NACA profiles with limitations.*

Keywords: *Lift, Drag, NACA profile, Aerodynamics, XFLR5*

1 INTRODUCTION

Aerodynamics is the science that studies the effect of the movement of the gases over solid bodies (ANDERSON,2011). One of these effects is the force that these fluids apply on these bodies. In aviation, airfoils are used to change the direction of the fluid in order to create a pressure difference between its surfaces. When a fluid flows through an airfoil the pressure on the upper surface is lower than the pressure on the bottom surface. This occurs due to the geometry of the airfoil that makes the flow on the upper surface faster than that of the bottom surface (WHITE,2011). The pressure difference between the surfaces creates an aerodynamic force which can be decomposed in lift force and drag force (ANDERSON,2011). The aerodynamic force is not only affected by the geometry of the body, but also by the flow conditions and the angle of attack of the airfoil.

Abbott and von Doenhoff (1959) showed through experimental tests that a variation on the Reynolds number of the flow have significant effects on the lift force that acts on an aerodynamic profile. Yemenici (2014) used a wind tunnel in his experiment to show that increasing the Reynolds number, the lift coefficient increases and the angle of attack that the stall occurs also increases. Reddy (2014) showed that the thickness of the airfoil has important effects on the aerodynamic force. He concluded that if the thickness of the airfoil increases the lift force on the airfoil increases and the drag force decreases.

In this paper, the software XFLR5 was used to simulate the effects of Reynolds number and thickness on the aerodynamic forces and stall angle acting on standard profiles NACA. Lift and drag coefficients in function of the angle of attack were evaluated. The simulation was validated comparing the data of the simulation with the literature. Additionally, the comparison was able to evaluate some of the software limitations.

2 METHODOLOGY

This section describes the procedures used to validate the simulation and analyzes the influence of the parameters of interest. For all simulations, four digits NACA profile airfoils were used.

2.1 Validation of the simulation

To validate the simulation of the software XFLR5, experimental data from Ladson (1988) study was used. To compare the values obtained from the software with the experimental data, a simulation with the same boundary conditions as the experimental test was done. The input settings in the software were: NACA profile 0012, Reynolds number $2x10^6$ and Mach number equal to 0.15. The angle of attack varied from -4º to 16º with a step increment of 4º. The results obtained from the experimental data and the results given by the software were plotted in the same graph allowing the comparison between them.

2.2 Reynolds number simulation

To evaluate the influence of Reynolds number, a NACA 0012 profile was used. The Mach number was fixed as 0.1, the angle of attack varied from -4º to 20 º with a step increment of 4º. Five different simulations were implemented. All of them considered different Reynolds number. For each Reynolds number a curve of lift and drag coefficients were obtained in function of the angle of attack. All the curves were plotted in the same graph to allow the comparison. The Reynolds number chosen to the calculations were: $1x10^5$,$5x10^5$, $9x10^5$, $2.1x10^6$, and $4x10^6$.

2.3 Maximum thickness simulation

To evaluate the influence of the thickness, the Reynolds number was fixed as $2x10^6$, Mach number fixed as 0.1 and the angle of attack varied from -4º to 20 º with a step increment of 4º. Five different NACA profiles were used, for each profile, curves of the lift coefficient and drag coefficient in function of the angle of attack were traced. All the curves were plotted in the same graph allowing comparison. The NACA profiles chosen to do the analysis were: NACA 0004,0008,0012 and 0016. The two last digits represents the maximum thickness in percentage of chord, which means that the NACA 0004 has the smallest maximum thickness and the NACA 0016 has the largest one.

3 RESULTS

This section presents the results obtained from the simulation and its respective analysis

3.1 Validation of the simulation

Figure 1 shows the graphic of the lift coefficient (Cl) in function of the angle of attack (α) using both, the data from the experimental test and the result obtained from the simulation.

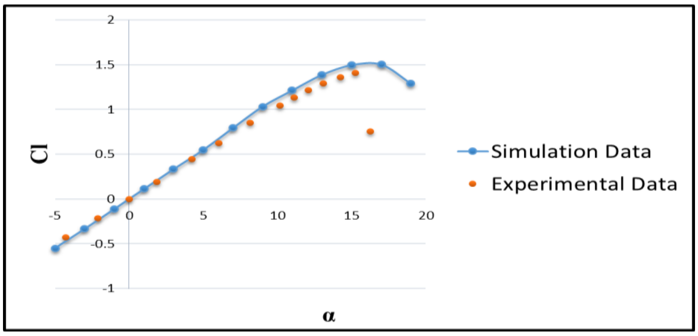

Figure 1. Cl vs α: Experimental and simulation data

It can be seen that the software obtained results close to the ones of the experiment until stall occurs (Angle that has the higher lift coefficient of the curve. i.e where the derivative of the curve is 0).

Figure 2 shows the drag coefficient in function of the angle of attack using both, the data from the experimental test and the result obtained from the simulation.

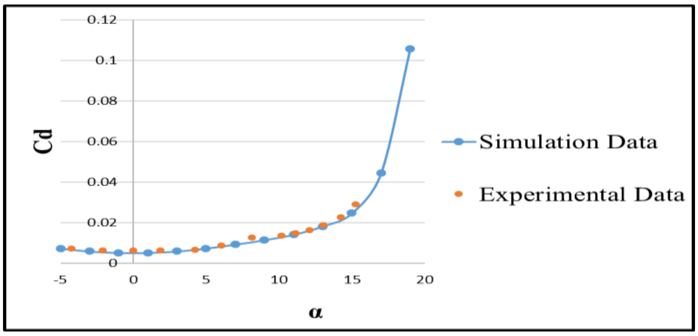

Figure 2. Cd vs α: Experimental and simulation data

It can be seen that the software obtained closed values in the entire range that was calculated.

3.2 Reynolds number

Figure 3 shows five curves of lift coefficient in function of the angle of attack. Each curve was calculated using a different Reynolds number.

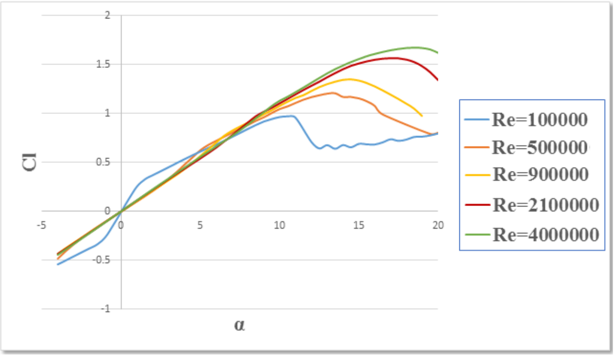

Figure 3. Cl vs α: Reynolds number curves

It can be seen that the maximum lift coefficient and the angle in which stall occurs increase as the Reynolds number increases.

Figure 4 shows five curves of the drag coefficient(Cd) in function of the angle of attack. Each curve was calculated using a different Reynolds number.

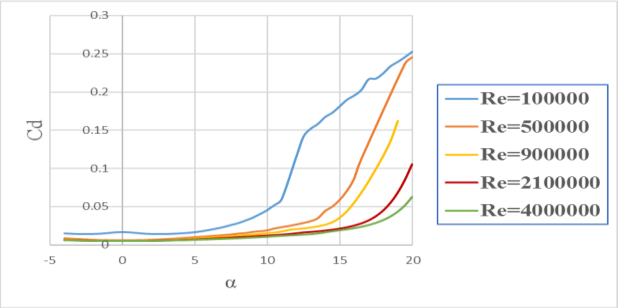

Figure 4. Cd vs α: Reynolds number curves

It can be seen that the drag coefficient decreases as the Reynolds number increases.

3.3 Maximum thickness

Figure 5 shows four curves of lift coefficient in function of the angle of attack. Each curve was calculated using a different NACA profile.

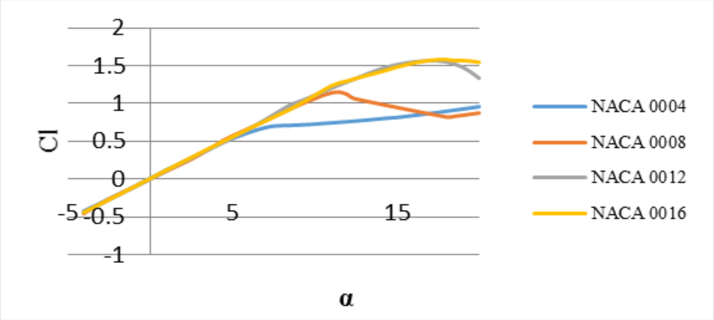

Figure 5. Cl vs α: Maximum thickness curves

It can be seen that the maximum lift coefficient and the angle in which stall occurs increases as the maximum thickness of the profile increases.

Figure 6 shows four curves of the drag coefficient in function of the angle of attack. Each curve was calculated using a different NACA profile.

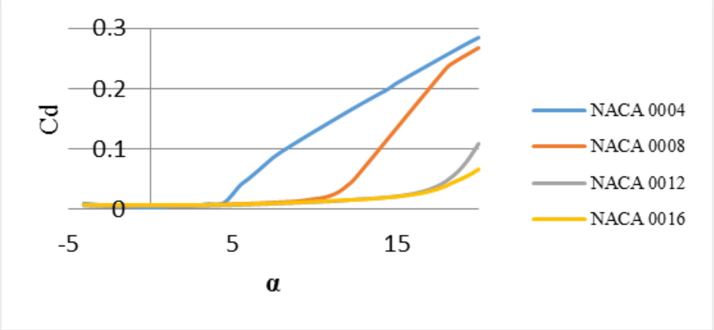

Figure 6. Cd vs α: Maximum thickness curves

It can be seen that the thickness of the profile doesn't have a significant influence on the drag coefficient before the stall occurs, but the figure shows that the angle in which stall occurs increases as the thickness increases. The stall can be identified as the angle at which the curves have a sharp increase in its slope.

4 CONCLUSIONS

The software XFLR5 presented accurate results for angles of attack lower than the angle of stall. For angle of attacks higher than the stall angle the results were different than that of the experiment. The stall angle is not its only limitation, the software also failed to converge solutions where Reynolds number was higher than 8x10^6 and Mach number higher than 0.3 (compressible flow).

Regards to the Reynolds number, it was concluded that increasing the Reynolds number of the flow, the drag coefficient for the same angle of attack decreases and the maximum lift coefficient on the airfoil and the angle in which stall occurs increase.

For the effect of the change in the maximum thickness of the airfoil, it was shown that increasing the maximum thickness of the profile, the maximum lift coefficient and the angle in which stall occurs increase.

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