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Numerical and Experimental Investigation of Airfoil Performance in a Wind Tunnel

Viktor Iliev[1], Marija Lazarevikj[1], Viktor Aleksoski[1]
[1] *"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering-Skopje*
Corresponding Author: Viktor Iliev

ABSTRACT: *In many engineering applications, it is necessary to study the phenomena that occur when an airfoil is set in a flow field or moving in still fluid in order to investigate its aerodynamic performance. In such case, airfoil is exposed to pressure and viscous forces. The airfoil characteristic is indicated by the values of the lift coefficient and drag coefficient for a certain angle of attack. The performance of the airfoil mostly depends on the surface pressure distribution.*

For the purpose of studying airfoil performance, a measurement system was developed in the Laboratory at the Faculty of Mechanical Engineering - Skopje. A symmetrical 4-digit NACA airfoil was placed in the test section of an open type wind tunnel and subjected to air flow. The importance of the measurements lies in the ability to verify numerical predictions of airfoil pressure coefficients so as to validate numerical fluid flow models. Thus, in parallel, simulations of 3D air flow over the NACA airfoil at different angles of attack were performed using computational fluid dynamics (CFD) methods to evaluate the lift and drag coefficients around the airfoil.

KEYWORDS: *aerodynamics, wind tunnel, CFD, lift, drag, pressure distribution*

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I. INTRODUCTION

Aerodynamics is the study of air flow while interacting with a solid object. A body manufactured so that air flow around it produces useful motion is called an airfoil. When an airfoil-shaped body with an angle of attack is set in a velocity field or it moves in a still fluid, an aerodynamic force is generated. The resulting aerodynamic force R is composed of lift and drag component which depend on the flow field characteristic parameters i.e. velocity, pressure, temperature and density.

Fig.1. shows the forces acting on an airfoil. The lift force L is directed upwards and acts perpendicular to the free-stream direction. The drag force D which resists the motion of the air is the axial component parallel to the free-stream direction.

If the total force is resolved in the chord direction and in a direction normal to the chord, the respective components are called normal force N and tangential force T (fig.1.). The dependences of the lift and drag force, respectively, on the normal and tangential force, in terms of the angle of attack α, are expressed as:

$$L = N\cos\alpha - T\sin\alpha \tag{1}$$

$$D = N\sin\alpha + T\cos\alpha \tag{2}$$

Since lift and drag force on an airfoil are proportional to its area S $[m^2]$ and to the dynamic pressure $q=(1/2)\rho v^2 [Pa]$, it is more common to give the drag and the lift in the form of dimensionless coefficients, i.e. lift coefficient C_l:

$$C_L = \frac{L}{q \cdot S} = \frac{2L}{\rho v^2 S} \tag{3}$$

and drag coefficient C_d:

$$C_D = \frac{D}{q \cdot S} = \frac{2D}{\rho v^2 S} \tag{4}$$

where ρ $[kg/m^3]$ is the density of air, and v $[m/s]$ is the air velocity.

In wind tunnels, these coefficients are measured for various values of angle of attack α. Angle of attack or angle of incidence is the angle made by the chord and the flow direction. For symmetrical airfoils, the axis of symmetry is always used in the definition of angle of incidence.

The relative pressure throughout a flow field is described by a pressure coefficientC_p which is connected to the aerodynamic coefficients.

$$C_p = \frac{p - p_\infty}{q} = \frac{2 \cdot \Delta p}{\rho v^2} \tag{5}$$

wherep_∞ *[Pa]* is the static pressure at the location where C_p is evaluated and p *[Pa]* is the static pressure in the freestream [1, 2, 3, 4, 5, 6].

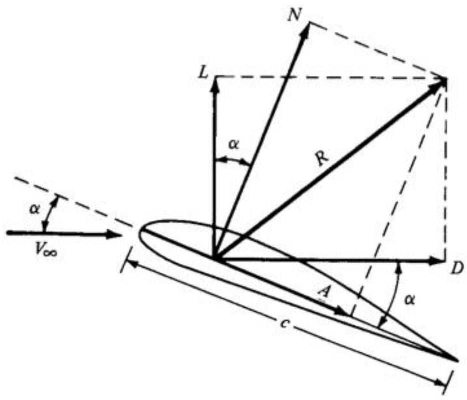


Fig.1. Aerodynamic forces acting on an airfoil

II. EXPERIMENTAL SETUP

Experimental measurements of the pressure distribution of an airfoil are performed at the laboratory of Fluid Mechanics and Hydraulics at the Faculty of Mechanical Engineering in Skopje. A symmetrical 4-digit NACA 0015 airfoil is placed in the 1,1 m long transparent section of the wind tunnel, with area of 275x275 mm. The inlet velocity of the air flow produced by the fans is 7,5 m/s. The value of the pressure is obtained in 14 locationsdistributed along the upper and lower surface of the airfoil. For this, a multi-tube manometer panel via individual tubes for each point is used. Pressure values are experimentally measured for two angles of attack (+10° and -10°).

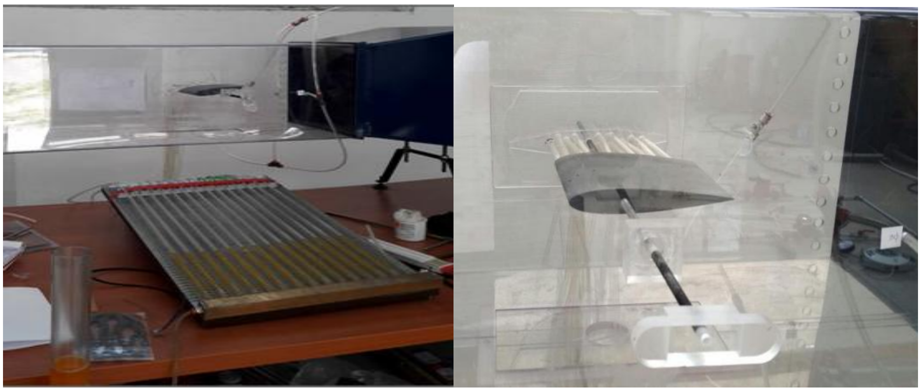


Fig.2.Experimental system: measurement section of the wind tunnel, multi-tube manometer panel and airfoil

The airfoil which is subject of analysis has a chord length of 130,51 [mm] and 120 [mm] span.

The experiment is used in order to validate the numerical model for the airflow around NACA 0015 in the wind tunnel, which can be then used for analyzing fluid flow over the airfoil at different angles of incidence.

III. NUMERICAL MODEL

Numerical setup

Airflow over NACA 0015 in wind tunnel is modeled and simulated in ANSYS Fluent 19.2. Initial boundary conditions used were inlet velocity of 7.5 m/s and 28 m/s and pressure outlet with gauge pressure of 0 Pa applied. Constant air density of 1,225 kg/m^3 is used.

At the contact areas between airfoil surface and air, the mesh is structural and fine, consisting of only hexahedral elements. At the rest of the fluid domain, coarser tetrahedral grid is found, as shown on fig.3. Total number of mesh volume elements is 4850148. The construction of the mesh is equal for every angle of incidence in order to compare results on same basis.

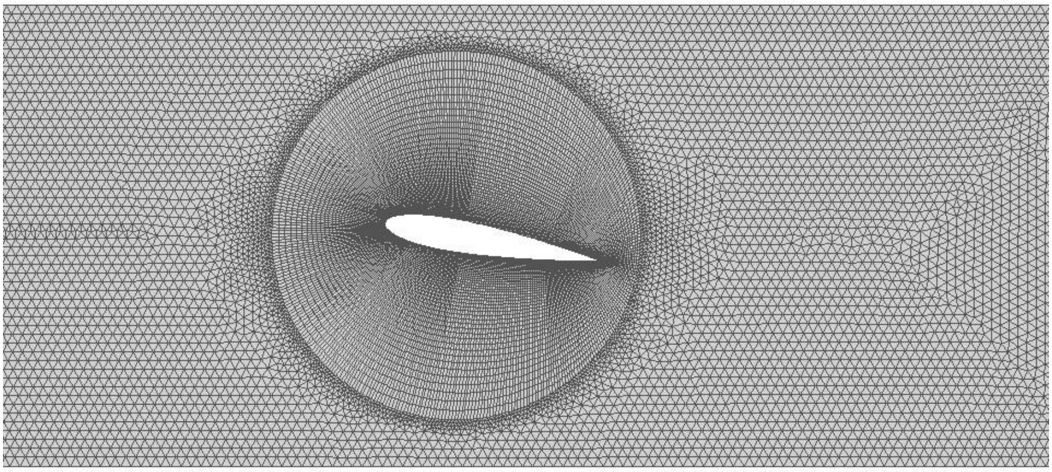


Fig.3. Fluid domain mesh

The standard *k-ε* model is used for solving turbulent air flow. This turbulence model is a two-equation model which computes turbulent viscosity μ_t by the equation:

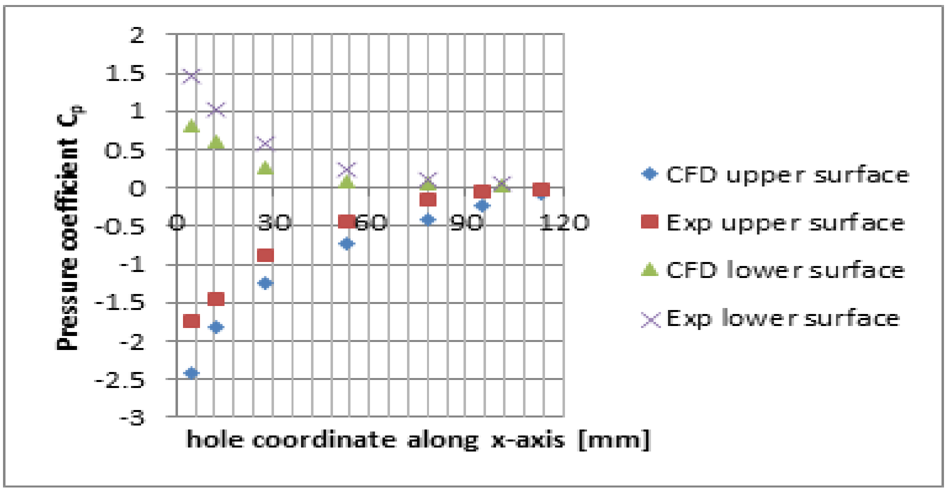
$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \quad (6)$$

where C_μ is a constant. The turbulent properties k and ε are the kinetic energy of the turbulence and its dissipation rate, respectively, and they are obtained from the transport equations proposed by Launder and Spalding. Turbulence intensity and hydraulic diameter are selected as a turbulence method [7, 8].

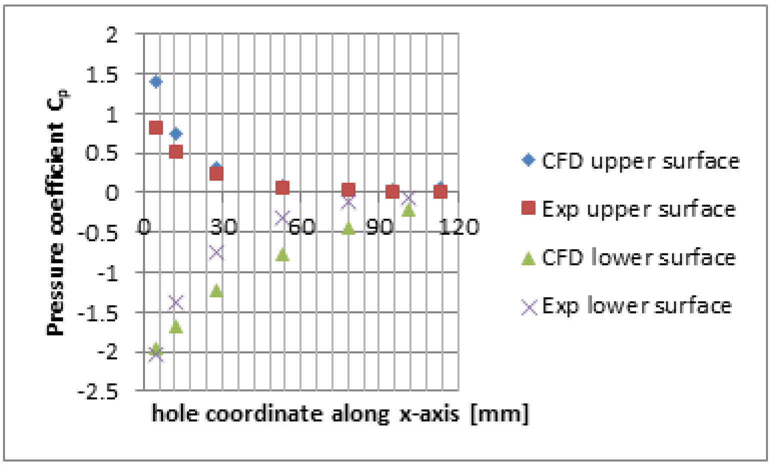
Numerical model validation

Validation of the numerical model was done by comparing the experimentally measured values and numerically obtained results for the pressure coefficient C_p of the airfoil. The values of the pressure coefficient were calculated at the 14 locations along the upper and lower airfoil surface. The comparison was done for both 10° and -10° angle of attack. Fig.4 shows the comparison between the experimental and numerical data for angle of incidence 10° (a) and -10° (b). It can be seen that the results are in good agreement. The discrepancies that exist can be attributed to the measurement errors and errors of the numerical model and computation.

After the numerical model is being validated, it can be used for simulation of air flow in the wind tunnel under different conditions i.e. other angles of attack and/or different air velocity in order to investigate airfoil performance.



a) Angle of attack 10°



b) Angle of attack -10°

Fig.4.Comparison between experimental and numerical values of pressure coefficient

IV. RESULTS AND DISCUSSION

Simulations of airflow over NACA 0015 in a wind tunnel were performed for angles of attack -15, -10, -5, 0, 3, 5, 8, 10, 11, 13, 15, 22, 27, 35, 45 and 50° at inlet air velocity of 28 [m/s] and angles of attack -10, 0, 3, 5, 8, 10, 13, 15, 16 and 20 for 7,5 [m/s].

Numerically obtained values for the pressure distribution around the airfoil are used to calculate the pressure coefficient by using equation (5). Change of the pressure coefficient along the airfoil surface for 8° angle of attack when inlet velocity of air is 7,5 m/s and 28 m/s, respectively, is given in fig.5.

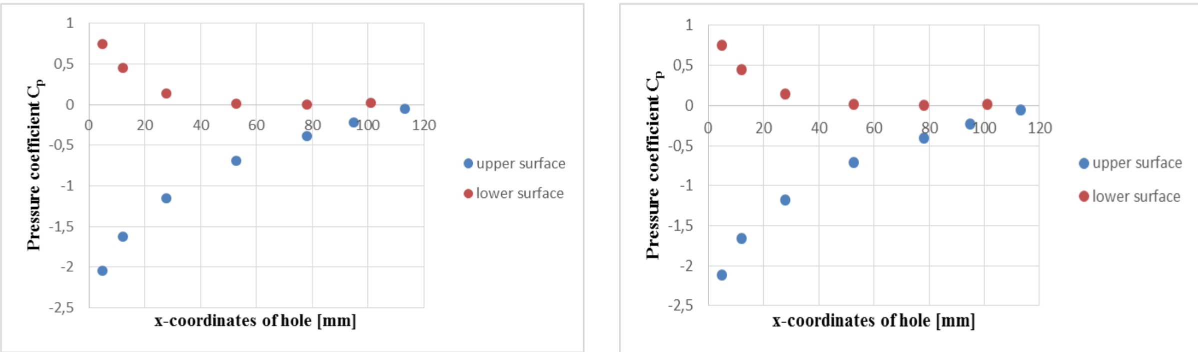


Fig.5. Pressure coefficient distribution for 8° angle of attack at 7,5 m/s (left) and 28 m/s (right)

The variation of the pressure coefficient when the inlet air velocity is 28 m/s for 8°, 22° and 35° angle of attack is given in fig.6, while fig.7 shows the pressure distribution in the wind tunnel for the same cases.

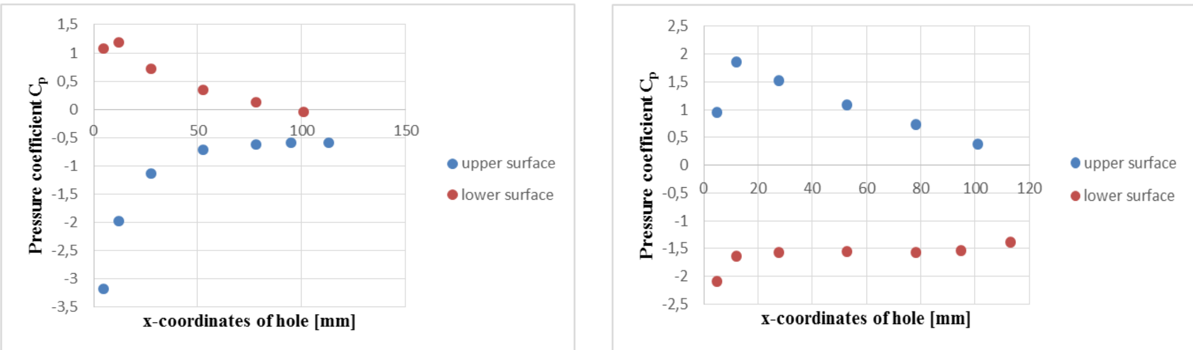


Fig.6. Pressure coefficient distribution at 28 m/s for 22° angle of attack (left) and 35° angle of attack (right)

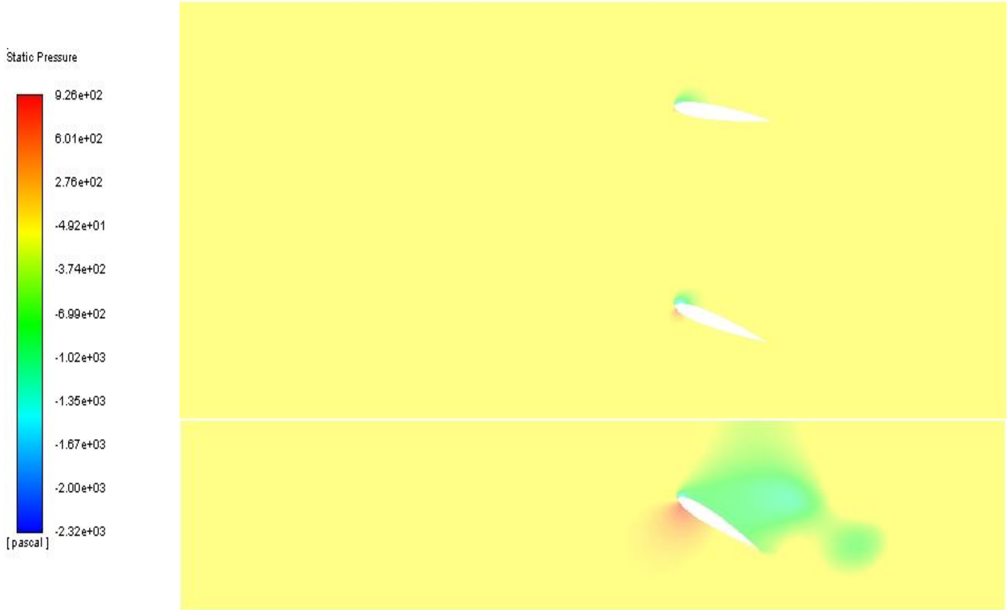


Fig.7. Contours of pressure distribution at 28 m/s for 8°, 22° and 35° angle of attack

Numerically obtained values for the lift force and drag force were used to evaluate the lift and drag coefficients by using equations (3) and (4). The airfoil numerical results for lift and drag coefficient as illustrated in Fig. 8 to Fig.10.

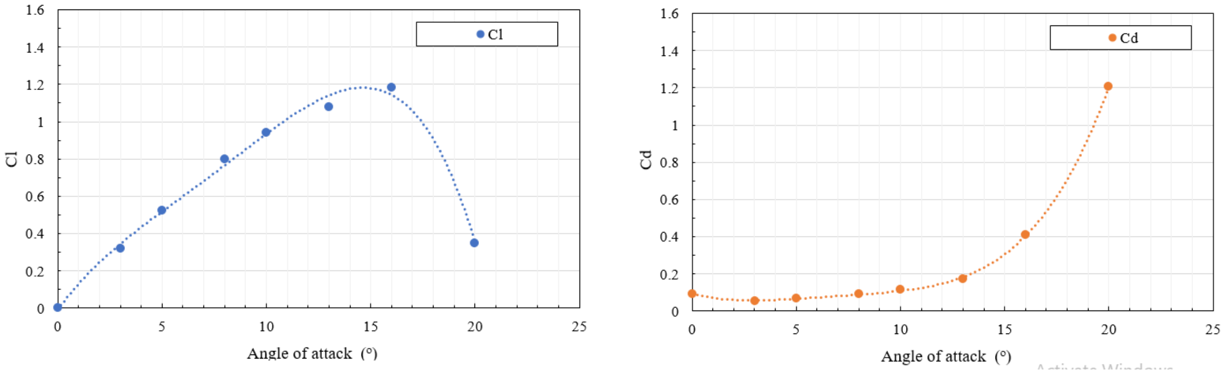


Fig.8.Lift and Drag coefficients at 7,5 m/s for various attack angle

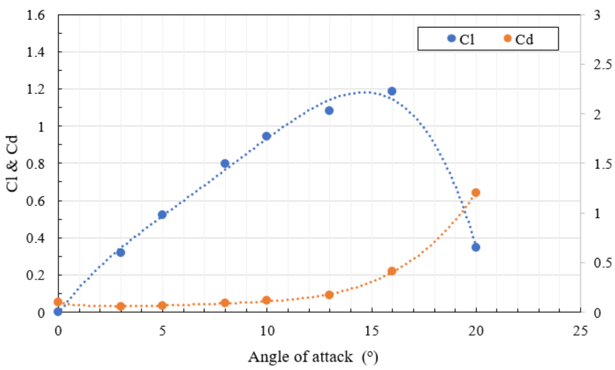


Fig.9.Cl&Cd coefficients at 7,5 m/s for various attack angle

The best results for lift and drag coefficients at 7,5 m/s inlet air velocity were obtained 15^o attack angle.

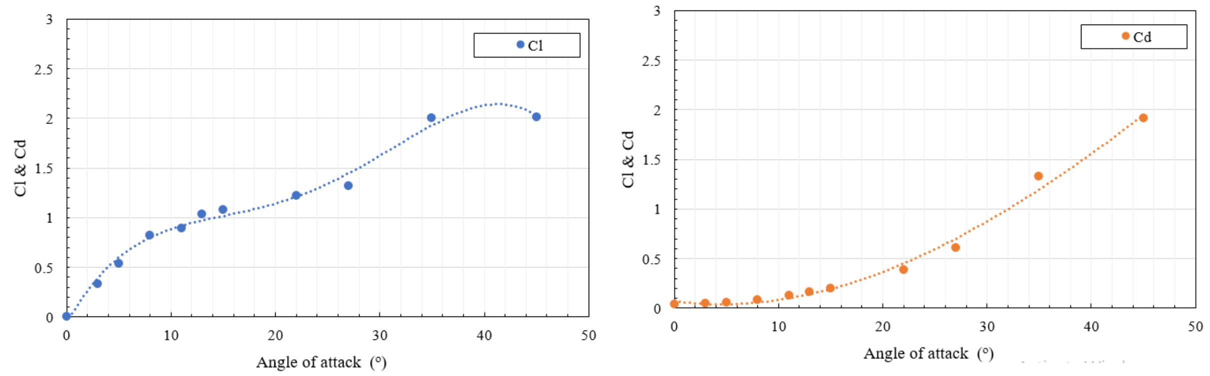


Fig.10.Lift and Drag coefficients at 28 m/s for various attack angle

In additional, the best performance (ratio Cl/Cd) of airfoil NACA 0015 was investigated as shown in Fig.11. By evaluating the airfoil ratio Cl/Cd it can be conclude that the best performance for each case of inlet air velocity was obtained about 8^o.

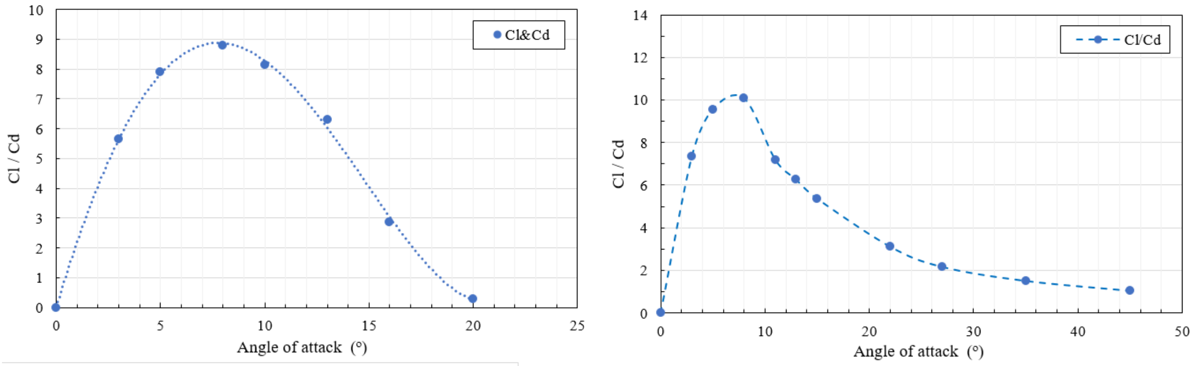


Fig.11.Ratio Cl/Cd for various attack angle at 7,5 m/s and 28 m/s inlet air velocity

V. CONCLUSIONS

In this paper, the pressure distribution around symmetrical airfoil NACA0015 was investigated, both experimentally and numerically. Also, the numerical investigation of lift and drag coefficients of airfoil performed. Investigation of airfoil performance is performed for different angle of attack and inlet air velocity. By comparing the experimental results and the numerically obtained results at 7,5 m/s inlet air velocity, it can be conclude that it showed good accuracy which contains discrepancies in range of 5-15%. Drag and lift coefficients for both case of air inlet velocity increased with increasing angle of attack. The optimum airfoil performance for both case of air inlet velocity was calculated at about 8^o angle of attack.

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