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Original Research Article

# Numerical investigation of airfoils aerodynamic performances



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**ABSTRACT**

In this study, the aerodynamic performance of seven different airfoils named CLARK Y, CLARK YH, Curtis C-72, FX 66-S-196 V1, NACA4412, NACA4415, and NACA4418 was numerically investigated under seven different angles of attack ranging from 0° to 30° in increments of 5°. 2D (two-dimensional) CFD (Computational Fluid Dynamics) models of airfoils were created and performed under steady-state conditions. When the changes of the lift coefficient and drag coefficient with the angles of attack were examined, it was observed that the drag coefficient increased with the increasing angle of attack. On the other hand, the lift coefficient firstly increased and then decreased a little and remained constant. For all airfoils, this value is calculated to be the highest around 10 to 15°. The obtained results from the numerical simulations were also analyzed by using the GRA (Grey Relation Analysis) method. While determining the best aerodynamic performance with this method, "higher is the better" and "lower is the better" normalization processes were used for lift coefficient and drag coefficient, respectively. As a result of the GRA analysis made with the numerical results, it was seen that the best and the worst performances were presented by Curtis C-72 and Clark Y airfoil profiles at 10° angle of attack condition, respectively. On the other hand, at 15° and higher angle of attack conditions, the best and the worst performances were presented by NACA4418 and Clark YH airfoil profiles, respectively. The performance of the best model was also seen in the velocity distribution compared to other models.

*Keywords:* Angle of attack; Airfoil; Aerodynamic performance; CFD; GRA

## 1. Introduction

The aerodynamic performances of airfoils have recently been extensively investigated numerically by using CFD and considerable studies have been carried out in this area. The performance of a wing is directly related to its airfoil, which is determined by examining the flow around the wing. In addition, the aerodynamic performance of aircraft is determined by the structure of the airfoil. An airfoil with the least drag and the most lift during flow should be preferred [1-5]. The schematic view of an airfoil section is shown in Fig. 1.

Chumber studied lift and drag coefficients on different airfoils and concluded that the angle of attack increases, the lift force increases, but the drag force also increases [6]. Leary investigated the blades of a wind turbine to obtain the aerodynamic behaviors of the wind [7]. Sarkar experimentally investigated to observe the effects of Reynolds number and angle of attacks considering the drag and lift forces [8]. Parashar numerically investigated the aerodynamic performances of different NACA airfoils and also validated the results by using theoretical calculations obtained from the literature [9]. Dash performed CFD analysis under the different angle of attack values at constant Reynolds number and compared the results of the numerical study with the results of wind tunnel experiments [10]. Patil et al., studied the effect of Reynolds number on the drag and lift forces and found that the drag and lift forces increase with the increasing Reynolds number [11]. Haque et al. performed an experimental study under the different Reynolds number and angle of attack values [12]. On the other hand, there are a number of studies about the selecting turbulence models used in the analysis [13, 14].

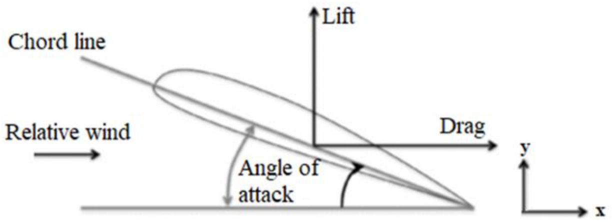


**Fig. 1.** Schematic view of an airfoil

In this study, in order to obtain the aerodynamic performances of different airfoils considering the drag and lift coefficients, 2D CFD analyses were performed under steady-state conditions at different angles of attack and constant air velocity values. The obtained results from the numerical simulations were also analyzed by using the GRA method.

## 2. Material and Methods

In this study, the aerodynamic coefficients and flow characteristics occurred in the free flow region of seven different airfoil profiles were modeled numerically in 2D and investigated. These airfoils were Clark Y, Clark YH, Curtis C-72, FX 66-S-196 V1, NACA 4412, NACA 4415, and NACA 4418, and can be shown in Fig. 2.

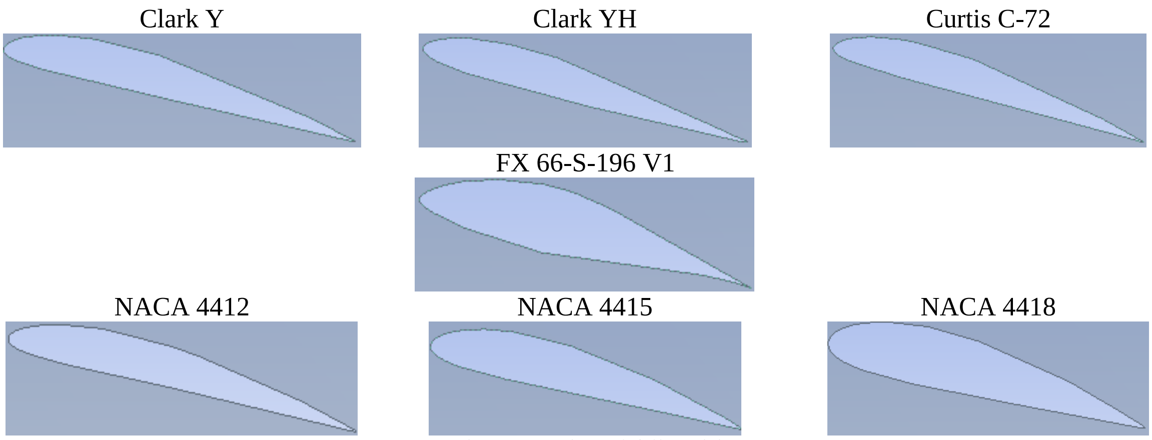


**Fig. 2.** The generated 2D airfoil models at 15°

These airfoils were positioned within a defined flow volume and the angle of attack values were ranging from 0° to 30° in increments of 5° for all profiles.

Since the critical angle of attack is 15-20°, the maximum angle of attack was determined as 30° by slightly exceeding this value in the analyzes [15]. The mesh independence study was carried out for NACA 4415 airfoil model at 15°, and it was found that about 312000 elements in total were enough for the mesh independence study (Fig. 3).

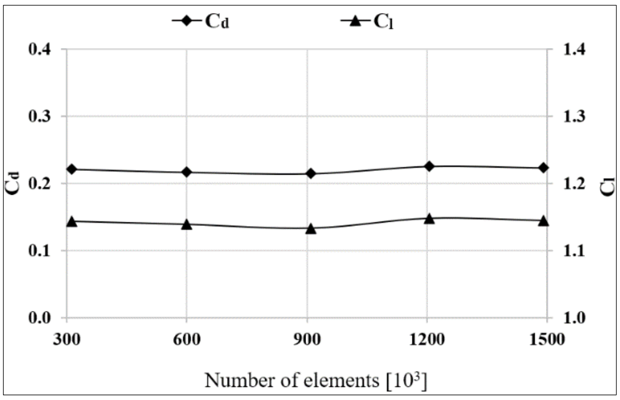


**Fig. 3.** The results of the mesh independence study

The mesh structure mainly consists of quadratic elements. The details of the generated mesh structure can are given in Fig. 4.

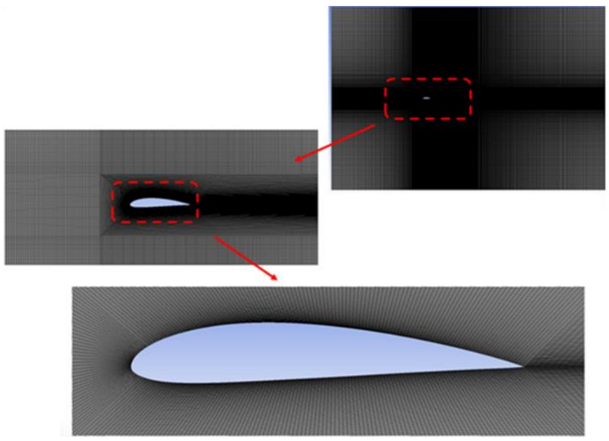

**Fig. 4.** The generated mesh structure

These models were calculated by using ANSYS-Fluent commercial software under the steady-state and turbulent flow conditions with a constant air velocity. In all analyzes, the effect of gravity was taken into account in the -y direction. The details of the boundary conditions of the study were given in Table 1.

**Table 1.** The boundary conditions

| | |
|---|---|
| Solver | Steady-state, 2D, Pressure based |
| Turbulence model | k-omega SST |
| Materials | Fluid : Air |
| Boundary conditions | Inlet : Velocity Inlet=250m/s<br>Outlet : Pressure-outlet<br>Airfoil boundary : Wall |
| Scheme | Coupled |
| Gradient | Least Squares Cell Based |
| Pressure | Standard |
| Momentum | Second Order Upwind |
| Turbulent Kinetic Energy | Second Order Upwind |
| Turbulent Dissipation Rate | Second Order Upwind |
| Monitors | Drag and Lift Coefficient |

In addition, GRA method was used to interpret the results obtained from the numerical analysis [16-18]. $C_l$ and $C_d$ coefficients calculated by using the Equation 1 and 2, respectively. The terms $F_l$ and $F_d$ in these equations represent lift and drag forces, respectively. $\rho$, $A$ and $V$ denote density, area, and velocity, respectively. And $C_l$ and $C_d$ was evaluated according to "higher is the better" and "lower is the better", respectively. In addition, the weights of these two parameters were determined equally in the GRA analysis.

$$C_l = \frac{F_l}{\rho A V^2/2} \tag{1}$$

$$C_d = \frac{F_d}{\rho A V^2/2} \tag{2}$$

### 3. Results and Discussion

When the results of the analyzes performed at different angles of attack were examined, the calculated $C_d$ values for each airfoil model were given in Fig. 5. The $C_d$ value of the Curtis C-72 model was found to be the highest at all angles of attack values except 0°. On the other hand, the $C_d$ value of NACA 4418 was the highest at 0°, then decreased and was calculated to be the lowest at approximately 10° and higher angle of attack values. The $C_d$ values of the other airfoil profiles were observed to be close to each other at all angles of attack values. In general, it was observed that the $C_d$ value increased with increasing the angle of attack in all airfoils. The $C_d$ value varied between 0.0303 and 0.5932.

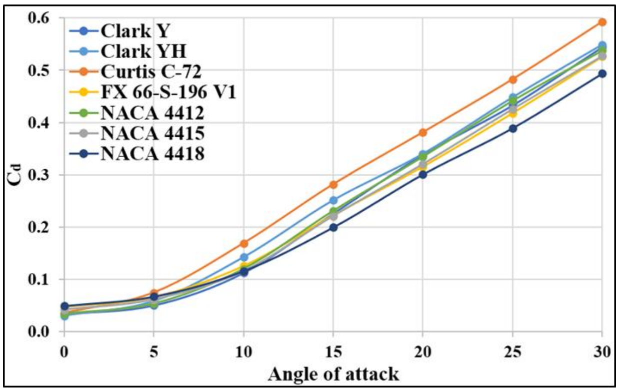


**Fig. 5.** The calculated $C_d$ values for all airfoil profiles

The distribution of $C_l$ value was given in Fig. 6. While the angle of attack value increased the lifting force up to a certain point, it caused a decrease in this value after a point. The $C_l$ value, which increased up to about 10°, decreased a little after this point and then remained horizontal. When similar studies in the available literature were examined, it was seen that the highest $C_l$ values were calculated at between 10 and 15° angle of attack conditions. While Curtis C-72 had the highest lift force up to about 10°, then the highest value was seen in NACA 4415. The lowest $C_l$ value at all angles of attack conditions was seen in the Clark YH model. After about 15°, it was observed that the $C_l$ value was around 1 in other models except for FX 66-S-196 V1 and Clark YH models. The $C_l$ value varied between 0.2507 and 1.1699, and they showed these values at 0 and 10° angle of attack conditions, respectively.

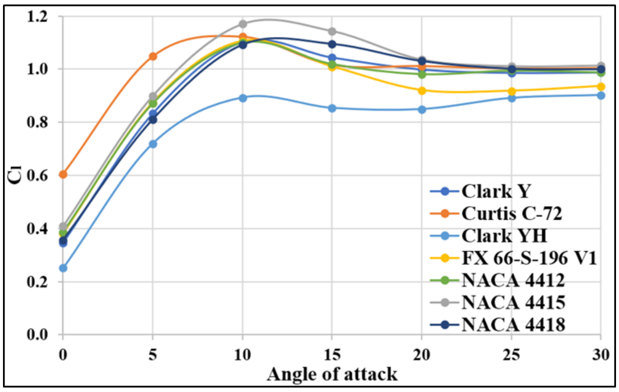


**Fig. 6.** The calculated $C_l$ values for all airfoil profiles

Comparisons of the results obtained from the GRA analyzes performed separately for each angle of attack were presented in Fig. 7. According to these results, the best case is Curtis C-72 at 0 and 10°, and Clark Y at 5°. The worst cases at 0, 5, and 10° were observed in NACA 4418, FX 66-S-196 V1, and Clark Y, respectively. At angles of attack values above 10°, the best case was seen in NACA 4418, which had the lowest $C_d$ coefficient in general. In the same conditions, the worst case was seen in the Clark YH model, which had the lowest $C_l$ coefficient at all angles of attack conditions.

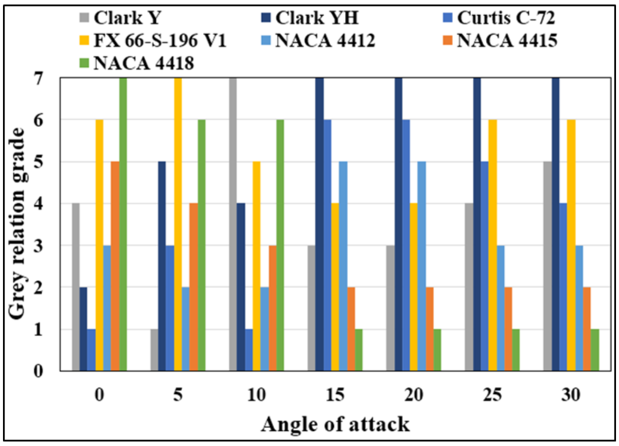


**Fig. 7.** The comparison of Grey relation values for all airfoil profiles

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The results of the velocity distributions obtained from the performed analyzes can be seen in Fig. 8. When the velocity distributions of the NACA4418 model, which has the best ranking at 15° and above angle of attack values, are examined, it can be seen that there is a higher velocity zone in the upper wing region compared to other models. In addition, the low velocity region in the wake region is less than the other models.

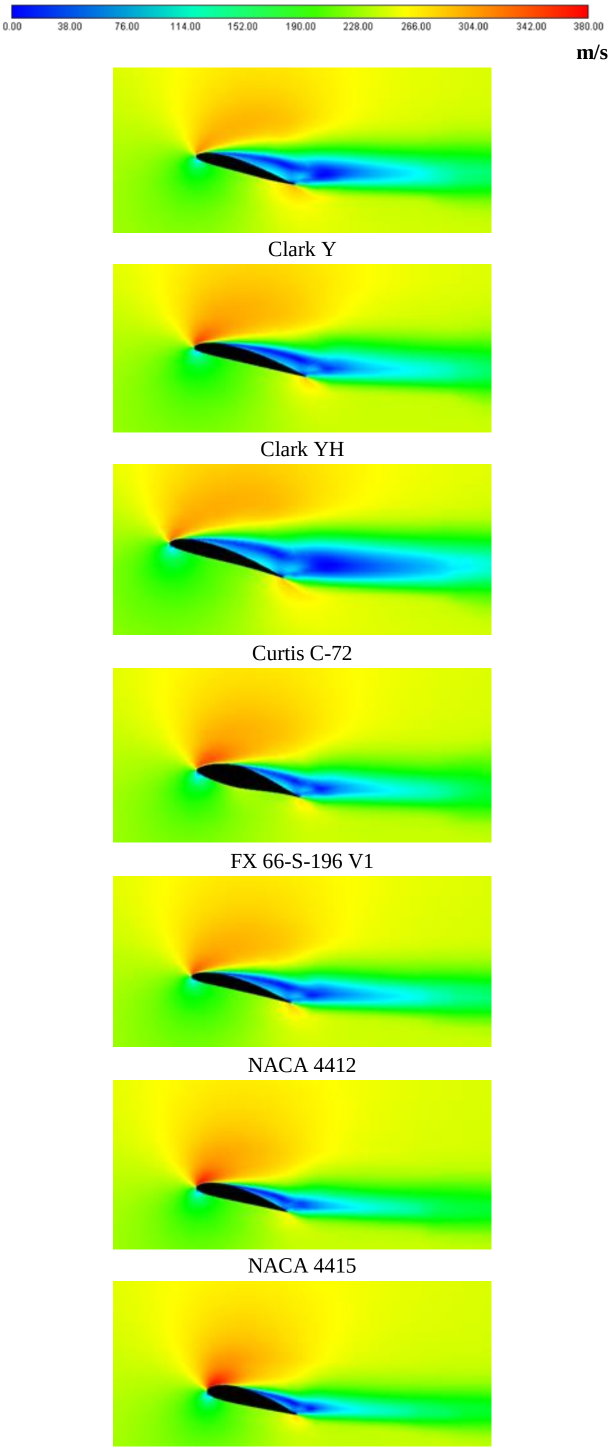


**Fig. 8.** The velocity distribution of all airfoil profiles at 15°

## 4. Conclusion

In this study, the aerodynamic performance of seven different airfoils named CLARK Y, CLARK YH, Curtis C-72, FX 66-S-196 V1, NACA 4412, NACA 4415, and NACA 4418 was numerically investigated under seven different angles of attack ranging from 0° to 30° in increments of 5°. According to the performed analyses under the steady-state conditions, the $C_d$ value of the Curtis C-72 model was found to be the highest at almost all angles of attack conditions. The $C_d$ value varied between 0.0303 and 0.5932. For all airfoil profiles, the $C_l$ value, which increased up to about 10°, decreased a little after this point and then remained horizontal. In addition, it was seen that the highest $C_l$ values were calculated at between 10 and 15° angle of attack conditions. While Curtis C-72 had the highest lift force up to about 10°, then the highest value was seen in NACA 4415. The lowest $C_l$ value at all angles of attack conditions was seen in the Clark YH model. The $C_l$ value varied between 0.2507 and 1.1699, and they showed these values at 0 and 10° angle of attack conditions, respectively. According to the results obtained from the GRA analyzes, that calculated by using the CFD results, the best case is Curtis C-72 at 0 and 10°, and Clark Y at 5°. While determining the best aerodynamic performance with this method, "higher is the better" and "lower is the better" normalization processes were used for lift coefficient and drag coefficient, respectively. The worst cases at 0, 5, and 10° were observed in NACA 4418, FX 66-S-196 V1, and Clark Y, respectively. At angles of attack values above 10°, the best case was seen in NACA 4418, which had the lowest $C_d$ coefficient in general. In the same conditions, the worst case was seen in the Clark YH model, which had the lowest $C_l$ coefficient at all angles of attack conditions.

## Conflict of interest

The author declares that he has no conflict of interest.

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