A detailed experimental airfoil performance investigation using an equipped wind tunnel

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Highlights

- Performance of an airfoil is studied experimentally using an equipped wind tunnel.
- The experiments are done for five attack angles as well as three jet velocities.
- A direct relationship between the jet velocity and the stall angle is found.
- A reverse relationship between the jet velocity and the wake effect is found.

Abstract

An experimental study is conducted to investigate the impact of different parameters on the performance of CFJ0025-065-196 airfoil. For this purpose, an equipped wind tunnel with the motor capacity of 7 kW as well as high-tech measuring instruments are employed, and the impact of attack angle on the average velocity profiles for different jet flow velocities, in addition to the self-similar velocity profiles for different attack angles, and the wake effect are found and discussed comprehensively. The experiments are done for five different values of the attack angle, which are 0, 5, 12, 20, and 25° as well three magnitude for the jet flow velocity, including 0, 19.7, and 32.2 m s^{-1}. According to the results, the attack angle in which the performance of the airfoil decreases has an upward trend when the jet flow velocity increases, and it reaches from 20 to 25° when jet flow velocity changes from 0 to 19.7 m s^{-1}. Moreover, increasing the attack angle from 0 to 12° makes the jet frountier wider whereas a downward trend happens by chaning the attack angle from 12 to 25°. Additionally, the higher the jet velocity is, the weaker wake stream has.

Keywords: Airfoil; Attack angle; Experimental study; Jet flow velocity; Wake effect;

Self-similar velocity

1. Introduction

Airfoils are increasingly being used for different purposes in the both engineering and industry areas [1]. They are made in different sizes and have a wide range of application, from wind turbines to air planes, and so on [2]. In improving design process and achieving a better condition for an airfoil, knowing the performance plays a crucial role. As a result, several studies have been conducted to investigate the performance of airfoils from different points of view [3]. In such investigations, like other topics [[4], [5], [6], [7]], either numerical modelling or experiments have been employed [[8], [9], [10]].

In the studies which have employed numerical modelling, the governing equations, including mass, energy, and momentum balances have been considered and solved to find a model describing the system behavior [[11], [12], [13], [14]]. The investigations done in references [3,[15], [16], [17], [18]] are some examples of these studies. Since in the numerical models, some assumptions have been taken into account for the sake of simplification, they have usually high level of error compared to the experimental results [[19], [20], [21], [22], [23], [24]]. Moreover, because of the done simplifications, some phenomena happen in the reality might be ignored when numerical models are considered [[25], [26], [27], [28]].

On the other hand, the experimental studies are able to reflect the aspects which might be ignored in the numerical models while they usually have higher level of accuracy [[29], [30], [31]]. Considering the mentioned benefits, several experimental studies have been also carried out in the field of airfoils.

As two examples of the experimental works, Zha et al. [32,33], examined a novel proposed way to control the flow for an airfoil, which led to having a higher lift coefficient and a better performance against stall effect. In another work, Bagheri and Kabiri-Samami [34] developed a model for free surface flow in the streamlined weirs and validated the model with the experimental recorded data. Chen et al. [35] also conducted an experimental study to analyze the transient behavior in the luminescent mini-tufts and Liu et al. [36] did an experimental study with the subject of investigating the performance of dynamic ice accretion.

Review of the literature shows that despite the valuable studies have been done so far, there are still some gaps should be filled by conducting new research items. Considering this point, in the current study, an equipped wind tunnel in addition to the high-tech measuring devices are employed to carry out experimental tests to study the performance of CFJ0025-065-196 airfoil in details. The impact of attack angle (AoA) on the average velocity profiles for different jet flow velocities, in addition to the self-similar velocity profiles for different attack angles, and the wake effect are found and discussed in details in this study. Using the results found here helps the designers to design airfoils in a better way by having more extensive information about the airfoil performance from the mentioned points of view. The experiments are done for five different attack angles, including the values of 0, 5, 12, 20, and 25°, as well as three magnitudes for the jet flow velocity, which are 0, 19.7, and 32.2 m s^{-1}.

2. The experiments

2.1. The investigated airfoil

The investigated airfoil is CFJ0025-065-196. As shows in Fig. 1, in the airfoil length, there are some holes as well as a pipe which is composed of a porous material. In addition, the airfoil enjoys a new design. Using the new design, the injection and suction processes are happening in a more uniform way.

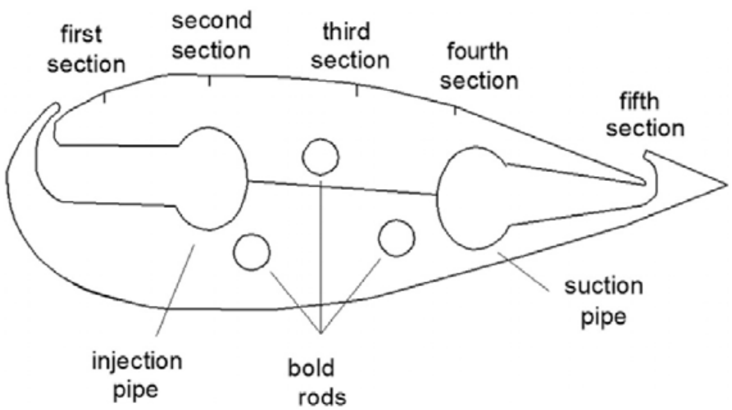

Fig. 1. The investigated airfoil, which is CFJ0025-065-196 [37].

2.2. The wind tunnel and measuring instruments

The experiments are done using the test equipment of the Hakim Sabzevari University. The equipment consists of a wind tunnel with hot wire anemometry apparatus as well as measuring devices such as the devices to measure the velocity. Having an accurate and complete set of measuring devices is necessary to obtain reliable results [[38], [39], [40], [41], [42], [43]]. In addition, there are the controlling systems to adjust the suction and injection process. This wind tunnel has a motor whose power is 7 kW, and the dimensions indicated in Fig. 2.

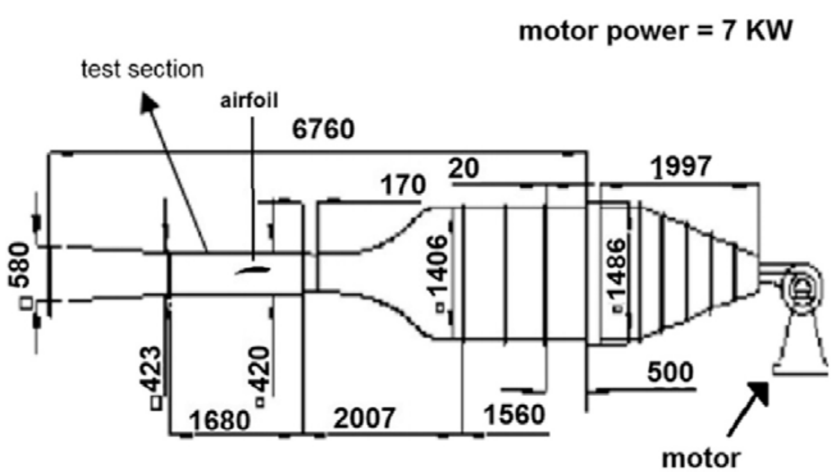

Fig. 2. The schematic figure of the wind tunnel in which the dimension are also indicated in millimeters [37].

2.3. The method of measuring the boundary layer velocity

In order to measure the boundary layer properties, the HM 170.24 boundary layer analyzer with pitot tube, manufactured by Gunt company, is employed. It is depicted in Fig. 3.

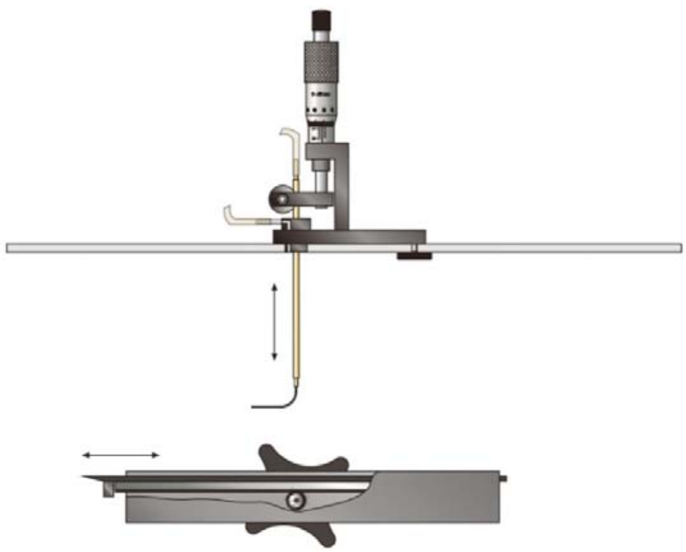

Fig. 3. The schematic of the HM 170.24 boundary layer analyzer with pitot tube, manufacture by Gunt company [44].

In this measuring device, the stream flows into the surfaces. The stream is parallel to the plate. Two surfaces have different roughness values, and it makes the possibility of recording the boundary layer properties in case they are going to be investigated.

In addition, there is a Pitot tube in the device. By employing this Pitot tube, which has the availability to move across the stream, the total pressure can be determined. The plate is also able to move in the horizontal axis, which makes the possibility of measuring flow along the path. There is a manometer in the system, and using this manometer, the pressure can be obtained. Using the manometer, the dynamic pressure as well as the velocity are determined.

2.4. Measuring instruments and their accuracy

Having accurate measuring instruments play an important role in obtaining accurate result [45,46]. Based on the comprehensive information, which is available on reference [44], the error in measuring the velocity, as the main measured parameter is 2.8%. It should be also noted that in this study, like the former similar done investigations [[47], [48], [49], [50]], more information about the measurements are considered beyond the scope of this survey, and for more details the manufacture's catalogue is referred.

3. Results and discussion

3.1. The impact of attack angle on for average velocity profiles for different jet flow velocities

In order to compare the impact of attack angle (AoA) on the airfoil flow, the profiles for average velocity are evaluated for the

in three conditions, which are jet flow velocity of 0.0, 19.7, and 32.2 m s^{-1}. The results are shown in Fig. 4. For the jet flow velocity of 0.0, the investigated attack angles are 0, 5, 12, and 20° while for two other aforementioned jet flow velocity values, i.e., 19.7 and 32.2 m s^{-1}, in addition to the indicated attack angles, the results for values of 25, 30, and 35° are also reported.

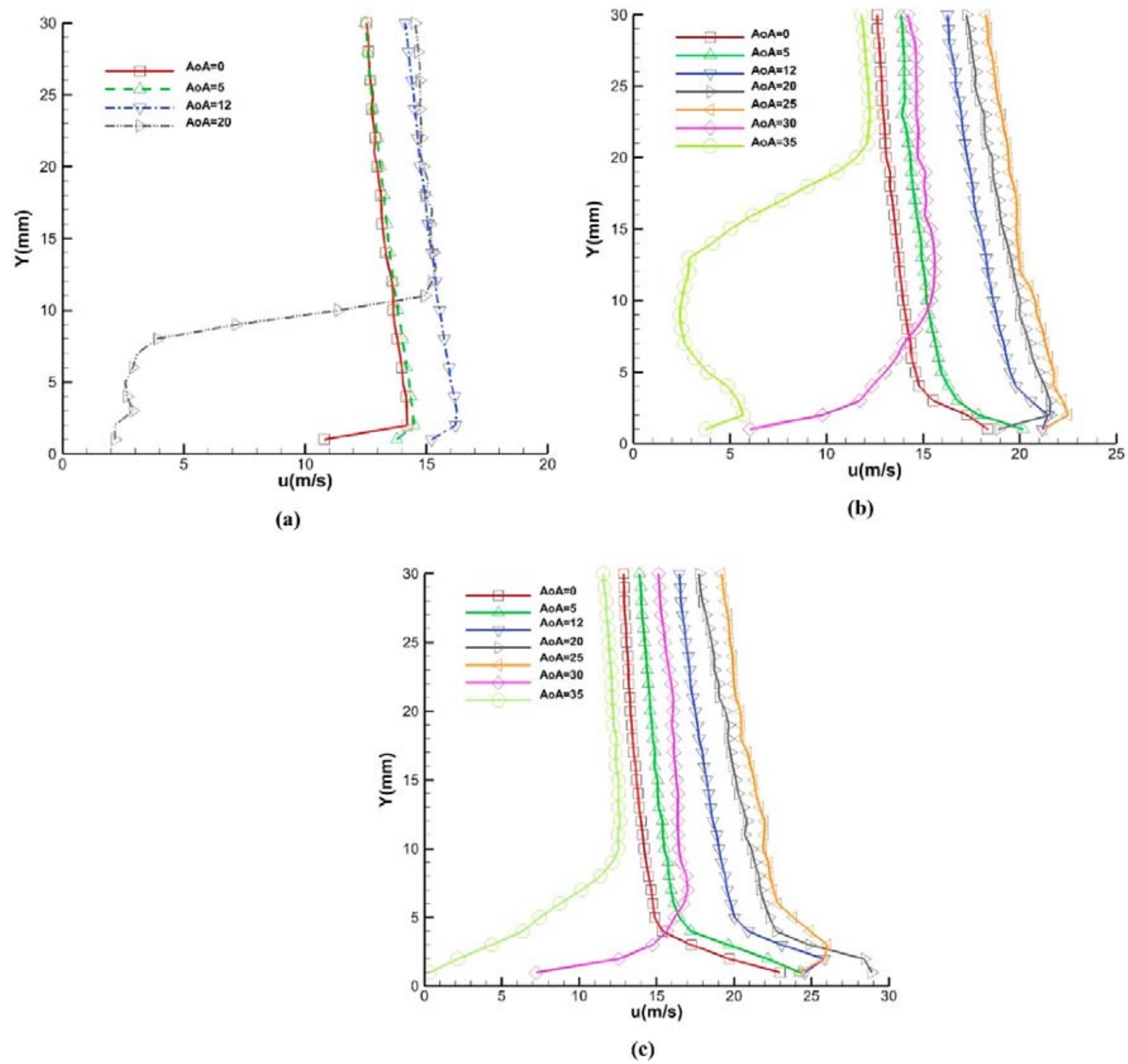

Fig. 4. The impacts of attack angle on the average velocity profiles for $\frac{x}{c} = 0.14$ in three different jet flow velocity values; (a) jet flow velocity of 0.0 m s^{-1}; (a) jet flow velocity of 19.7 m s^{-1}; (a) jet flow velocity of 32.2 m s^{-1}.

According to Fig. 4a, increasing the attack angle from 0 to 5°, and 5 to 12° for the jet flow velocity of 0.0 leads to an increase in the average velocity. It means the location of stagnation point starts to get closer to the trailing edge. However, when the attack angle changes from 12 to 20°, the average velocity goes down because of flow separation issue.

Fig. 4b demonstrates that in this case, i.e., jet velocity of 19.7 m s^{-1}, up to the attack angle of 25°, the average velocity increases. Nevertheless, for bigger angles, the average velocity has a downward trend, which indicates that the airfoil does not perform effectively in that range. In addition, comparing Fig. 4a and b reveals that the higher the jet flow velocity is, the higher angle in which separation happens, is observed.

In addition, based on Fig. 4c, the same trend as Fig. 4b is seen for the jet velocity of 32.2 m s^{-1}. Here, however, the shape of average velocity profile for some attack angles like 5 and 35° is totally different than jet velocity of 19.7 m s^{-1}, but for some other ones, the similar shape is seen.

3.2. The self-similar velocity profiles for different attack angles

In five conditions for the attack angle, which are 0, 5, 12, 20, and 25°, the self-similar velocity profile is found and discussed in details. For this purpose, the vertical distance gets dimensionless using the distance "y_0' depicted in Fig. 5, while the process of getting the average velocity profiles dimensionless for the outer and inner areas is done by employing the "U_0" and "U_m", shown in Fig. 5, respectively.

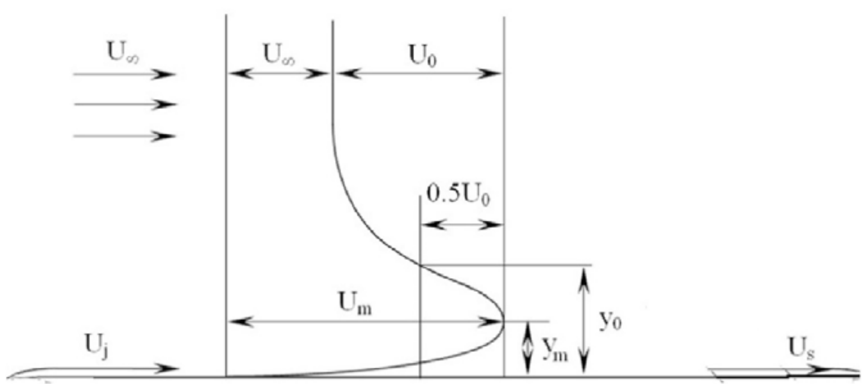

Fig. 5. Introducing the parameters used in the studying the self-similar velocity profile [51].

The results for the five aforementioned attack angles are reported in Fig. 6. The first point is for all the attack angles, good agreement between the obtained data and the results of Mitsudharmadi and Zhang [51] is observed, which proves the validity of the reported experimental information.

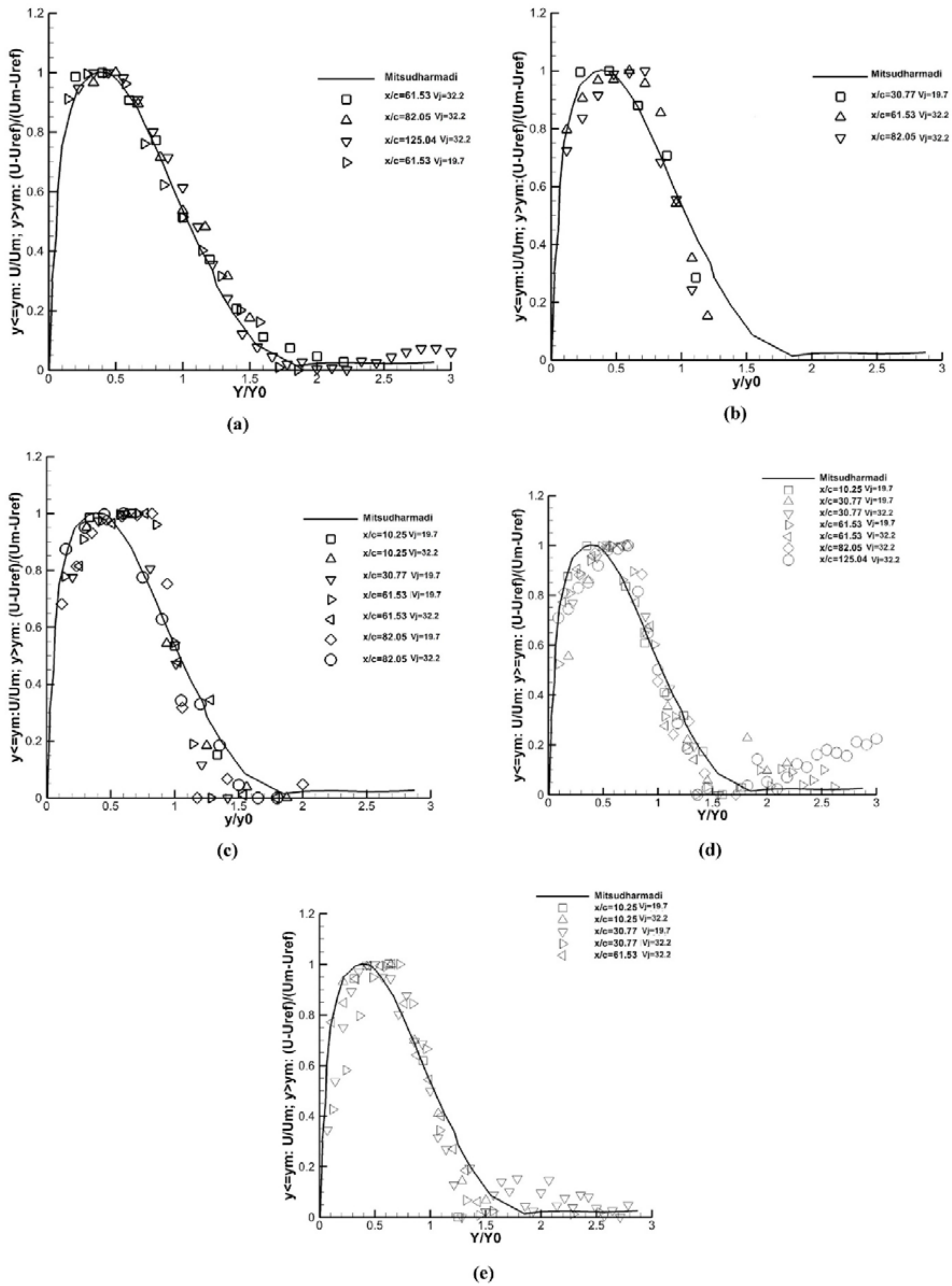

Fig. 6. The self-similar velocity profile for different attack angles; (a) 0°; (b) 5°; (c) 12°; (d) 20°; (e) 25°.

In addition, according to Fig. 6a–e, by increasing the attack angle from 0 to 12°, the jet frontier gets wider. In other words, the profile for the maximum velocity tends to be wider. Nevertheless, a downward trend happens by changing the attack angle from 12 to 25°. It is due to the point that when the attack angle becomes more, the flow is more affected by the reverse pressure. This phenomenon is also accompanied by a decrease in the distance between Y_m and $Y_{1/2}$, indicated in Fig. 5.

3.3. The wake effect

For the three investigated values for the jet flow velocity, i.e., 0.0, 19.7, and 32.2 m s^{-1}, the wake effect for the airfoil is shown in Fig. 7. In this figure, in addition to the three previously-mentioned conditions, the data for the wake of CFJ0025-065-000 airfoil is also reported for the sake of comparison in a better way.

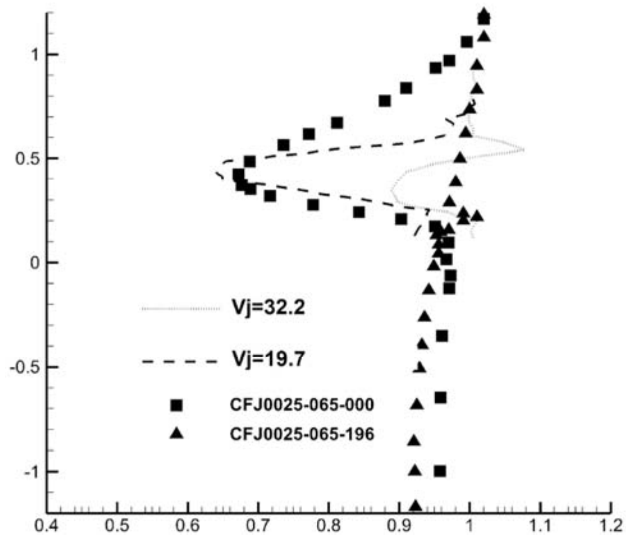

Fig. 7. The wake effect for the three investigated values of the velocity for CFJ0025-065-196 airfoil as well as the wake of CFJ0025-065-000 airfoil.

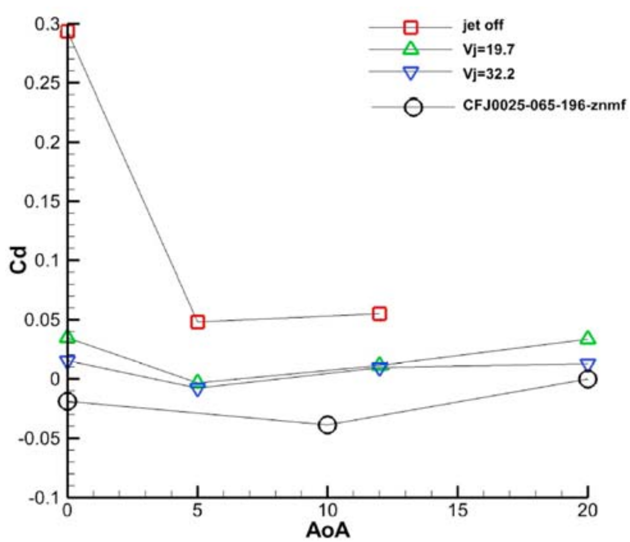

Fig. 8. The drag coefficient for different investigated conditions reported in Fig. 4 at various attack angles.

The obtained results in Fig. 7 reveal that despite the fact that the airfoil CFJ0025-065-000 has a large but low-momentum wake, the CFJ0025-065-196 airfoil almost does not have wake. The wake effect is weaker at the higher jet flow velocity magnitudes. The reason is the interaction between jet and main flow stream. The point can be discussed better by considering the drag coefficient for the investigated conditions at different attack angles, which are obtained from the correlations found in references [32,52,53], and shown in Fig. 8.

As observed, for a constant attack angle, the drag coefficient has the highest value for the velocity of 0.0 (jet off condition), and after that, the coefficients for the jet velocity values of 19.7 and 32.2 m s^{-1} are in the next places, respectively. The lowest magnitude of drag coefficient also belongs to the CFJ0025-056-000 air foil. As an example of numerical values for the mentioned point, when the attack angle is 0°, the drag coefficient for the four mentioned conditions, i.e., the velocity magnitudes of 0.0, 19.7, and 32.2 m s^{-1}, and CFJ0025-056-000 air foil, are 0.3, 0.04, 0.01, and −0.01, respectively. Since there is a reverse relationship between the drag coefficient and the wake effect, the shown trend for the wake in Fig. 4 is obtained.

4. Conclusions

Airfoil CFJ0025-065-196 was studied experimentally using an equipped wind tunnel and high-tech measuring devices to study three important performance phenomena, which are the wake effect, the impact of attack angle on for average velocity profiles for different jet flow velocities, and the self-similar velocity profiles for different attack angles. The results showed that there is a reverse relationship between the jet flow velocity and drag coefficient, based on which the wake gets weaker by increasing the jet flow velocity. In addition, changing the angle of attack from 0 to 12° made the jet frontier wider whereas from 12 to 25° a downward trend was observed. It was also found that for some attack angles like 12 and 20°, the average velocity profiles have the same shape for the jet flow velocity of 19.7 and 32.2 m s^{-1}, but for some other values such as 5 and 35°, they are completely different.

Declaration of competing interest

We declare that we have no financial or personal relationships with other people or organizations that could inappropriately influence (bias) our work entitled "A Detailed Experimental Airfoil Performance Investigation Using an Equipped Wind Tunnel.

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