Aerodynamic characteristics modification of an airfoil with blunt trailing edge using offset and aerodynamic cavity

Hamid Sayadi

[1.] Faculty of Engineering, Shahrekord University, Shahrekord, Iran
hamid.sayadi2009@gmail.com

Abstract: This paper is a computational study of the behaviour of aerodynamic characteristics of airfoil with blunt trailing edge and studies the effects aerodynamic performance caused by modifications made to the trailing edge. These airfoils do have the disadvantage of generating high levels of drag as a result of the low-pressure steady or periodic flow in the near-wake of the blunt trailing edge. Also vortex shedding in this airfoils, induces fluctuating loads and radiated noise. In the present investigation, we tested the effects of an offset cavity and aerodynamic cavity on the base drag and wake of an airfoil with blunt trailing edge. In two-dimensional subsonic flows, any method that increases the base pressure of the airfoil with blunt trailing edge consequently reduces the base drag. When the cavity is introduced to the trailing edge, the base pressure increases. Also the cavity caused trapping and stabilizing the vortex.
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Keywords: forest Airfoil, Blunt trailing edge, Offset cavity, Aerodynamic cavity, Vortex shedding

1. Introduction

In most cases airfoils are known as having rounded leading edge & sharp trailing edge geometries. However, nowadays blunt trailing edge airfoils also play a significant role in aerodynamic designing. These kinds of airfoils not only have many structural advantages, but are frequently used for the purpose of improving the aerodynamic features of thick airfoils [1, 2]. Among applications of such airfoils are in big wind turbine blades, military planes, missiles and automobiles [3].

All in all, studies show that it is possible to increase the maximum ratio of lift coefficient to drag coefficient through using blunt trailing edge airfoils [4]. Besides, the studies done on blunt trailing edge airfoils indicate that they possess better lift characteristics compared to sharp trailing edge airfoils. However, the pint is that the former type airfoils produce much more noise as well as produced drag. In addition, testing the vortex in this type of airfoils reveals that there is a severe degree of vortex shedding in their ending edge which in turn is directly related to the created drag force, the produced noise and also the fluctuating loads on the airfoils [5, 6].

Likewise, scads of methods have been investigated to improve the objects for the purpose of decreasing the strength of vortex shedding, the made noises by the airfoils, the fluctuating loads created on airfoils and the drag force. Among suggested solutions are putting objects like cavity, splitter wedge, splitter edge in the end edge of the airfoil.

In 2006 Solman [7] carried out extensive lab studies on the created vortex in the end edge of airfoils with blunt trailing edge. He could measure & report the turbulence degree and the velocity field in the vortex area of airfoils with blunt trailing edge.

Lombardy et. Al [8] in 2006 also investigated the effect of the existence of a blower flow in the blunt trailing edge airfoils. The result showed that putting a blower flow with appropriate rate, at trailing edge of airfoil can lead to an decrease in the drag force imposed on the airfoil.

In 2008, van dam et. Al [9] doing several experiments on airfoils with blunt trailing edge concluded that although due to a change made in the primary bending of the airfoil, there may be some degree of lift force to be lost, they are much applicable mainly because their reduced weight and volume and also the lift force they create. In compare to their structural weight.

Abdullah et. al [10] in 2009 designed a base cavity and placed it in the airfoil trailing edge. Their studies indicated that the existence of such a cavity leads to trapping the vortex formed in the trailing edge of airfoil, reducing the produced noise, and also making a balance in the vortex shedding process.

Murcia and Pinilla [11] in 2011 produce twenty modified versions of the NACA 4421 airfoil, which were created by the cutting off and adding thickness methods. The aerodynamic performances of these airfoils were studied by ANSYS CFX. The result showed that the adding thickness method produces larger maximum lift and critical angles of attack than the cutting off method.

Yoo and Lee [12] in 2015 doing Numerical Analysis of NACA64-418 Airfoil with Blunt Trailing

Edge. The numerical results show that the drag increases, but the lift increases insignificantly, as the trailing edge of the airfoil is thickened. Re-circulation bubbles also develop and increase gradually in size as the thickness ratio of the trailing edge is increased. These re-circulations result in an increase in the drag of the airfoil. The pressure distributions around the modified NACA64-418 are similar, regardless of the thickness ratio of the blunt trailing edge.

In most of numerical studies in order to make an airfoil with blunt trailing edge, an airfoil with sharp trailing edge is cut. This cut is done in a specified distance from trailing edge and also in a vertical way. Accordingly, in this study to make the intended geometry, the standard airfoil NACA 4412 (figure 1) having one meter card is employed and a cut in the distance of 0.3 meter is done in it. Therefore, an airfoil with blunt trailing edge (figure 2) is prepared. In this figure "h" is the thick of the trailing edge of airfoil.

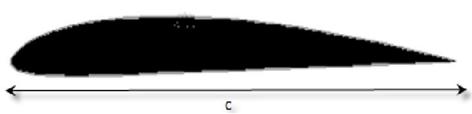

Figure 1. NACA 4412 airfoil

Figure 2. Airfoil with blunt trailing edge

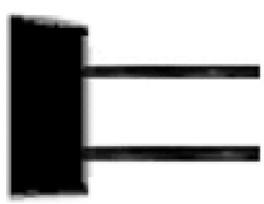

Figure 3. Offset cavity

In this paper, first of all, the aerodynamic characteristics and the flow around the blunt trailing edge airfoil will be investigated. Then, the improvement process of airfoils using the designed geometries will be dealt with. After that, the distinct aerodynamic characteristics of each airfoil along with their advantages will be examined separately. Finally a geometry whose design is innovative is investigated. The name of this form is aerodynamic cavity (figure 4) and lead to apposite and interesting results which are described below. In each case, the process of simulation in fluent software was achieved. In addition, the flow was steady state and the flow regimen was turbulent. In order to achieve high level of accuracy in simulation process in each case, the Reynolds stress model (RSM) was employed. Finally, the flow was air considered to have fixed density and physical characteristics.

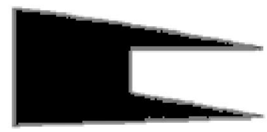

Figure 4. Aerodynamic cavity

1.1 boundary conditions

Figure 5 represents the computational space of the project. In this figure "c" stands for the airfoil cord. Notice that the selection way of this space is based on the existing papers. In addition, as it is obvious from the figure and will be understood in the result section, the pressure and velocity fields reach a steady status after being adequately far from the airfoil that in turn implies the appropriately of the space selected. Further, the reason for AE to be in a bending way is that this status will cause much more suitable results.

Boundary conditions in each case is as follows:

AB, AE, and ED boundaries were considered as the flow inlet boundary condition. BD boundary condition also was considered as the pressure outlet. Notice that due to the return flow in the trailing edge of the airfoil, using such a boundary condition (pressure outlet) is very useful.

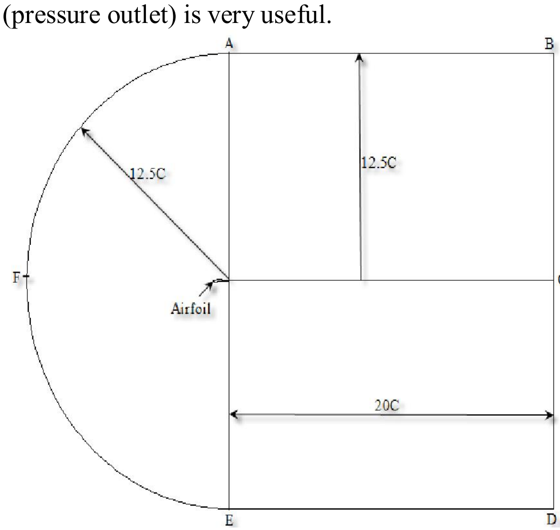

Figure 5. Computational space considered around airfoil

1.2 Solution conditions

In this paper input speed was 50 m/s, Reynolds number based on the input speed and the airfoil cord (c) was 3,400,000 and Mach number was 0.151.

Applied flow in this project was standard air which has the following features:

Density equals to 1.225 kg/m^3, special heat coefficient equals 1006.43 j/kg.k, heat conductivity

0.0242 w/m.k and flow viscosity equals 1.7894e-5 kg/m.s.

1.3 Mesh generating

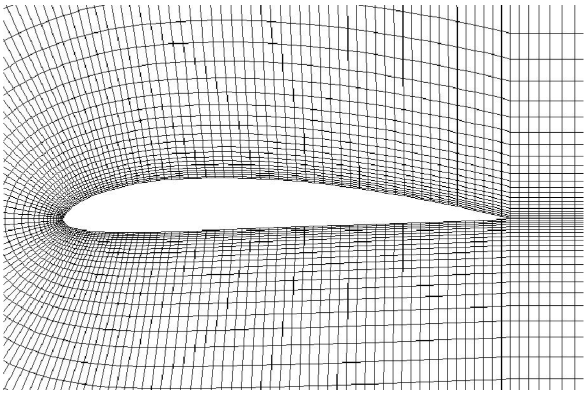

Figure 6. A view of the used mesh in the paper

The mesh generating for each geometry was done using gambit software. In this paper structured meshes for the purpose of meshing airfoils were used. Meshing the surfaces was done with square elements. Furthermore, all used geometries in this project were meshed using Quad-map method. This process is very complex and time consuming. Figure 6 is a sample of the mesh used in this project. It has been minimized as much as possible due to the severe changes on the airfoil and its back.

2. Material and Methods

2.1 paper reliability

In order to examine the strength of the utilized mesh in solving the turbulent flow with boundary conditions and also the accuracy degree of the flow in modeling the flow around the existing geometries of the project, the turbulent flow was simulated and then compared with the experimental results gained by Abbott & Doenhoff [13].

In this experiment, Reynolds number was 2,000,000 and the input velocity was 29.215 m/s. besides, the experiment was carried in unbounded flow conditions.

Table (1) Drag & lift coefficients based on the mesh nodes number

Number of nodes	Lift coefficient	Drag coefficient
10035	1.247	0.0174
10927	1.233	0.0179
11893	1.118	0.0171
12465	1.122	0.0164
13888	1.115	0.0179
14568	1.114	0.0181

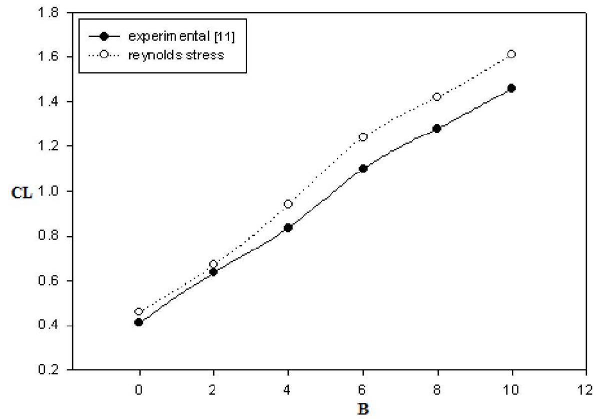

Figure 7. Diagram of numerical & experimental results of lift coefficient based on angle of attack. (B=angle of attack, CL=lift coefficient)

Since in gaining the pressure coefficient not all equations are used. In order to investigate the independence of the mesh and also to compare it with experimental results, lift coefficient was used. Table 1 involves the lift & drag coefficients in angle of attack 6 degrees. As it is conspicuous from the table, after 13888 nodes, lift indexes get independent from the number of nodes and in order to enhance accuracy, 14568 nodes were used. To compare lift coefficient in different attack angle, first the experimental diagram of lift coefficient based on attack angle was examined in xy-digitizer software and then lift coefficient numeric indexes in some different attack angles were obtained. Figure 7 shows the gained lift coefficient by RSM and also the experimental results diagram. As it is obvious, the five equation model of RSM findings are very close to the experimental diagram. That is why the same model was used in subsequent simulations.

2-2 Airfoil with blunt trailing edge

First it should be mentioned that all contours used in the present paper were drawn in attack angle 6 degrees. In figure 8 the stream lines are obvious. The big vortex area formed in the back of airfoil is also clear in the figure. In figure 9 the pressure contours have been represented in which the area having a high pressure around the stagnation point in the forward part of the airfoil is observable. Figure 10, 11 represents drag coefficient and also the ratio of lift to drag coefficient. As it is obvious from the figure, as the attack angle increases, the drag coefficient increases also. However regarding the lift to drag coefficient, it increases up to attack angle of 10 degrees but more than that, starts to decrease.

Notice that from this section onward the blunt trailing edge airfoil diagrams are used as the basis for comparison with other diagrams.

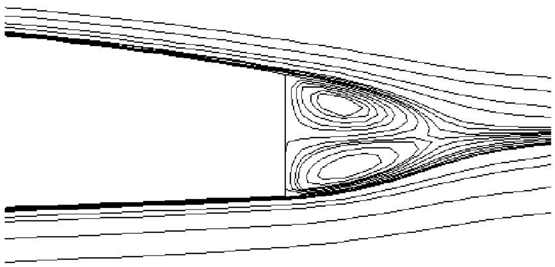

Figure 8. Stream lines for airfoil with blunt trailing edge

2-3 Airfoil with offset cavity

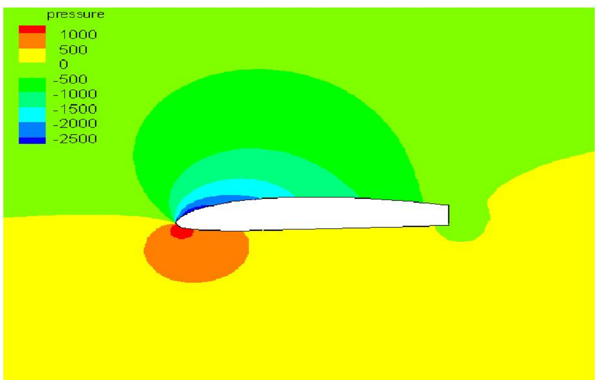

Figure 9. Pressure contours for airfoil with blunt trailing edge

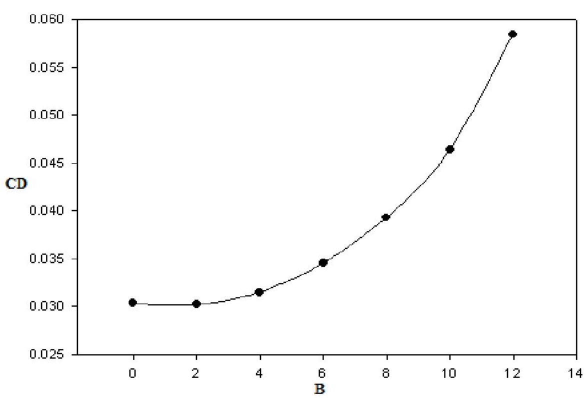

Figure 10. Drag coefficient diagram based on angle of attack for airfoil with blunt trailing edge. (CD= drag coefficient)

The geometry is formed by connecting an offset cavity (figure 3), to the airfoil trailing edge. In figure 12 the stream lines have been drown for it. As it is obvious from the figure, the cavity play an important role in adjusting the vortex shedding process through trapping a portion of vortexes. It is also apparent from the figure that the existence of this cavity caused the vortex area to be smaller in three areas in figure 13 pressure contours have been drown. In figure 14, 15 also represents the drag coefficient diagrams and the ratio of lift to drag coefficient for this geometry and the basis stance. It is possible to decrease drag coefficient and vortex shedding process remarkably by putting the base cavity in the trailing edge of airfoils with blunt trailing edge, maintaining its aerodynamic features.

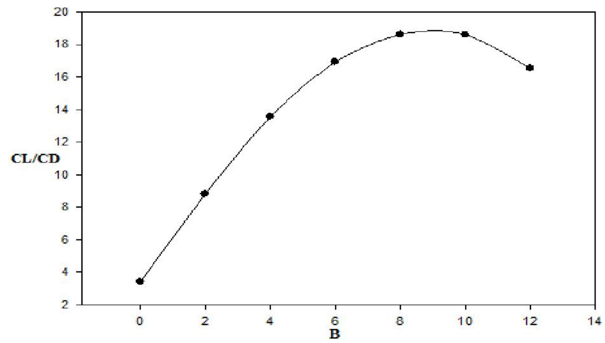

Figure 11. Diagram of lift to drag coefficient based on angle of attack for airfoil with blunt trailing edge

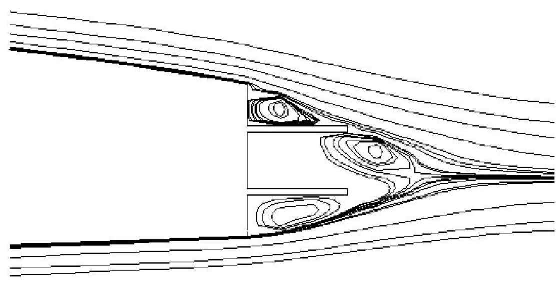

Figure 12. Stream lines for modified airfoil with offset cavity

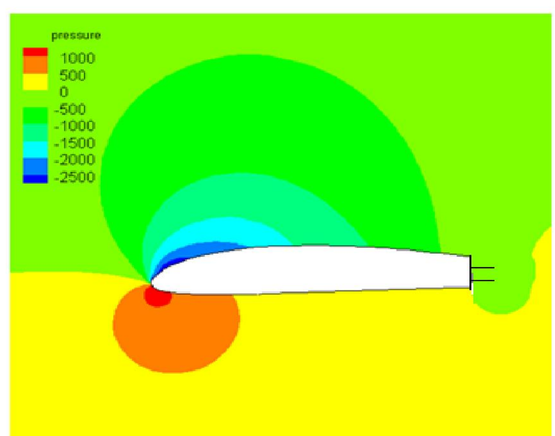

Figure 13. Pressure contours for airfoil with offset cavity

2. 4 airfoil with aerodynamic cavity

Having examined on results of different cavities and analyzed their stream lines, the obtained findings was that if instead of flat for the cavity upper & lower edges, they are designed aerodynamically, better drag and lift features would be noticed. Therefore, the cavity with aerodynamic edges were formed and was referred to as aerodynamic cavity. The existence of such cavity caused a remarkable reduction in the produced drag in small attack angles. Besides, installing this cavity in the trailing edge of the airfoil causes a suitable increase in the lift coefficient.

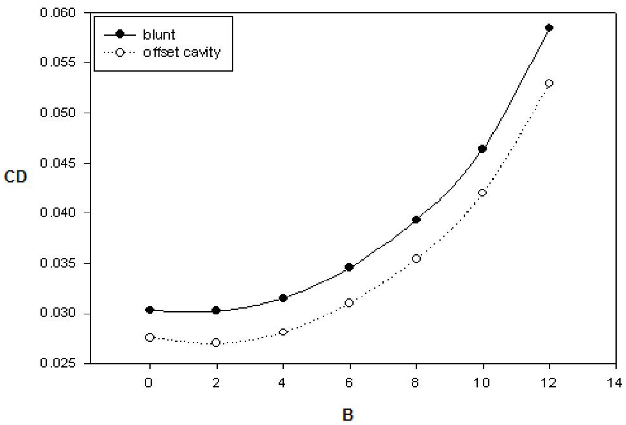

Figure 14. Diagram of drag coefficient for the modified airfoil with offset cavity and basis stance

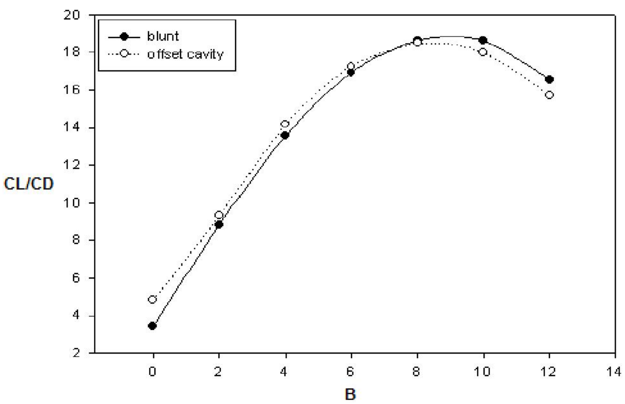

Figure 15. Diagram of lift to drag coefficient for the modified airfoil with offset cavity and basis stance

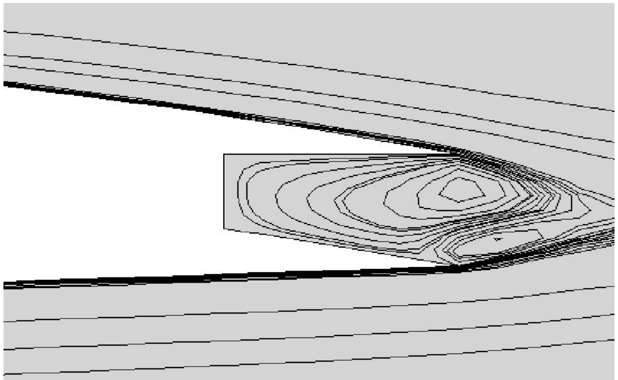

Figure 16. Stream lines for modified airfoil with aerodynamic cavity

Figure 16 shows the stream lines for this geometry. It clearly shows the trapping process of large portion of vortex, stabilization process of vortex zone, and also the formation of this zone in distances far from the airfoil trailing edge. In figure 17 pressure contours are observable. In figure 18 the drag coefficient diagram for the geometry and the basis stance is observable. It is clear from the diagram that drag coefficient for this geometry is less than the basis stance up to the attack angle of 7 degrees. In figure 19, the diagram of lift coefficient ratio to drag is seen. As it is clear, from it, putting this cavity in the trailing edge of airfoil will lead to a remarkable increase in the lift coefficient in addition to drag reduction. Therefore, using this kind of cavity in the airfoil it will become possible both to improve the aerodynamic characteristics of the airfoil and to adjust remarkably the process of vortexes shedding and the created noise by them.

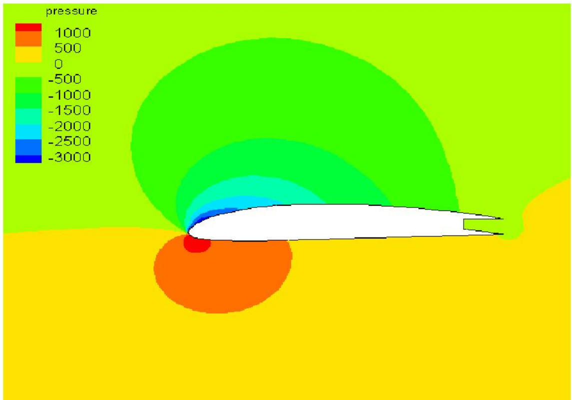

Figure 17. Pressure contours for airfoil with aerodynamic cavity

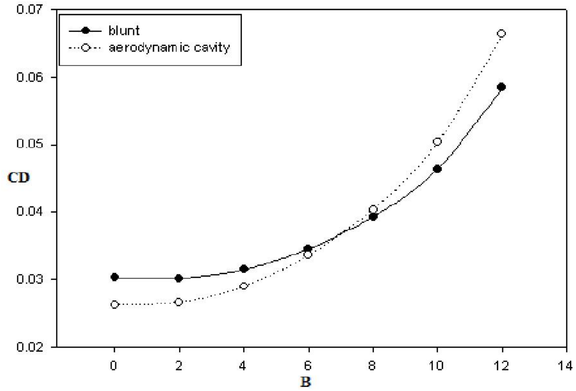

Figure 18. Diagram of drag coefficient for the modified airfoil with aerodynamic cavity and basis stance

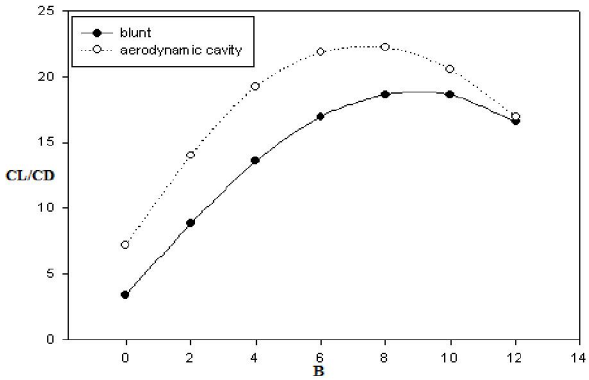

Figure (19) Diagram of lift to drag coefficient for the modified airfoil with aerodynamic cavity and basis stance

3. Conclusion

Blunt trailing edge airfoils are abundantly used in the wind turbines due to their creation of high lift force in comparison with their structural weight & volume. However due to the remarkably low pressure vortex zone behind them. A high drag force is created. Besides, due to the severe shed ejection of vortexes in their trailing edge, high noises and also huge alternative forces are produced on the blades. It is possible to not only adjust the vortex throwing process and decrease drag coefficient through using a base cavity in the airfoil trailing edge, but also to trap vortexes inside the cavity while retaining the suitable airfoil aerodynamic features. It will also lead to reducing the created noises and fluctuate loads produced on the airfoil. Finally, using aerodynamic cavity in the trailing edge of the airfoil caused an improvement in the aerodynamic features of the airfoil and an increase in the ratio of lift coefficient to drag coefficient.

Corresponding Author:
Hamid Sayadi
Department Engineering
Shahrekord University , Iran E-mail:
hamid.sayadi2009@gmail.com

References

1. Hoerner, S.F., "Base Drag and Thick Trailing Edges," Journal of the Aeronautical Sciences, Vol.17, No. 10, pp. 622-628, Oct. 1950
2. Hoerner, S.F., Fluid-Dynamic Drag, Hoerner Fluid Dynamics, Bricktown, NJ, 1965.
3. Morel, T., "*Effect of base cavities on the aerodynamic drag of an axisymmetric cylinder*", Aeronautical Quarterly. Vol. 30, part 2, pp 400-412, 1979.
4. Standish, K.J., Van Dam, C. P., "*Aerodynamic Analysis of Blunt Trailing Edge Airfoils*," Journal of Solar Energy Engineering, Vol. 125, pp. 479-487, 2003.
5. Baker, J. P., Mayda, E. A., and van Dam, C. P., "*Experimental Analysis of Thick Blunt Trailing-Edge Wind Turbine Airfoils*," Journal of Solar Energy Engineering, Vol. 128, No. 4, pp. 422–431, 2006.
6. Baker, J. P., van Dam, C. P., and Gilbert, B. L., "*Flatback Airfoil Wind Tunnel Experiment*," Tech. Rep. SAND2008-2008, Sandia National Laboratories, April 2008.
7. Souleman, E., *Anechoic Wind Tunnel Study*, Internship report, The University of Adelaide, 2006.
8. Lombardi G., Magazi M., Caldiralo L., Cannizzo F., Petrotta G., 2006, *The aerodynamic development of the Ferrari Fxx*, 6th MIRA International Vehicle Aerodynamics Conference, Warwick (England), October 2006.
9. Van Dam, C.P., Mayda, E.A., and Chao, D.D., "Computational *Design and Analysis of Flatback Airfoil Wind Tunnel Experiment*," SAND2008-1782, Sandia National Laboratories,Albuquerque, NM, March 2008.
10. Abdullah M.Al-Garni, Ahmed Z.Al-Garni and Abdurrahman Aravind., "*Experimental Investigation of the effect of Base Cavities on the Base pressure and Wake of a Two-Dimensional Bluff Body",* Submitted to 7th IASME/WSEAS conference. Fluid Mechanics and Aerodynamics (FMA ' 09) Moscow, Russia, August 20-22, 2009.
11. Murcia, J. P. and Pinilla, A., "CFD analysis of blunt trailing edge airfoils obtained with several modification methods, Universidad de los Andes", Bogota D.C., Colombia, Reving, ISSN 0121-4993, Enero-junio de, pp. 14-24, 2011.
12. Yoo, H.S and Lee, J.C., "Numerical Analysis of NACA64-418 Airfoil with Blunt Trailing Edge", Int'l J. of Aeronautical & Space Sci. VOL 16, NO 4, PP 493–499, 2015.
13. I.H. Abbott and A.E .von Doenhoff, *Theory of Wing Sections*, Dover, New York 1959.

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