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Studying the Effect of the Trailing Edge Blowing of NACA0018 Airfoil on the Aerodynamic Performance

Ahmad A. Alsahlani [1, *], Mohammed Al-Saad [2], Zainab K. Radhi [3]

[1,2,3] *Department of Mechanical Engineering, College of Engineering, University of Basrah, Basrah, Iraq*
E-mail addresses: ahmad.mahdi@uobasrah.edu.iq , mohammed.kadom@uobasrah.edu.iq , zainab.radhi@uobasrah.edu.iq
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Abstract

The flow control around the airfoil is widely investigated and utilized in the aircraft industry. The benefit of reducing the separation effect and its impact on the aerodynamic performance made the effort on this area is more desirable as this will impact to enhance the flight control as well as to reduce the fuel consumption during the flight. In this paper, the flow control using leading-edge blowing technique has been conducted for NACA0018 airfoil at Reynolds number 6.85 and 13.7 × 10^5. A CFD analysis has been conducted to examine several flight parameters and blowing speed to explore the benefit of using the blowing in this wing section. The results indicate that the lift coefficient can be enhanced to be increased by 4-6% as compared with no blowing case. However, this increase ratio is affected by the operational Reynolds number and blowing ratio. Higher speed means less benefit from blowing within the limit of blowing ratio of 1.

The benefit of using the blowing could come with an increase in the drag at some angle of attack. It is noticed that the blowing technique can generate positive pitching moment at lower angle of attack and can reduce the negative moment when the separation is happening at higher angle of attack. Also, the lesson learned in this paper is that the blowing benefit is more pronounced when the flight is under low Reynolds number environment.

Keywords: Airfoil, Trailing edge, Blowing, CFD.

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1. Introduction

The flow over airfoil has been studied over the last hundred years when the flying vehicle become widely used. Several studied are devoted on enhancing the aerodynamic performance of the wing section toward increasing the ability of lifting the airplane and also to reduce the required thrust to drive the aircraft with less fuel [1-3]. Also, the stability of airplane was the major concern to offer a safe flight and increase the maneuverability of the plane [4, 5]. One of the most effort on enhancing the aerodynamic performance was the flow control around the airfoil to reduce the drag as well as increasing the lifting force. Likewise, the main focus was to avoid the separation of the flow at higher angles of attack. Furthermore, controlling the flow also can be facilitated to adjust the laminar flow region over the airfoil to overcome the laminar separation before it happens during the flight [1, 6].

The flow control around wing section can be classified as passive and active types [2, 7, 8]. The passive control approach includes any mean of flow controlling that not requiring any auxiliary device/power or control loop. The second category is the active flow control in which the process requires auxiliary device as well as power / control loop [9]. One of the passive flow controls is using sucking or blowing air on the surface of the wing section at a location that may delay the separation in the flow or to induce the flow transition from laminar to turbulence flow before it normally happened and ended with laminar separation [10, 11]. Also, in some research area, inducing transition was conducted using vortex generators such as rough surface or fins at the upper and/or lower surface of the wing section.

The aim of flow control is usually needed when the flow is prone to separation at some flight condition such as that flight condition requiring high lift forces at low velocity (low Reynolds number) in the take-off and landing time. However, some maneuverability required to increase or decrease the speed during flight [12, 13].

Several studies such as in references [11], [14-16] investigated the suction and blowing flow control in some popular NACA symmetrical airfoil such as NACA 0012 and NACA0015. The results indicated that the lift generated could be increased to 93% in some cases. However, this increase is not constant with changing the angle of attack and Reynolds number. Each airfoil section can behave differently affected by several flow and geometric parameters. Also, the location of the blowing/suction flow control could serve particular design target and leading to a scarifying in some aerodynamic performance parameters [17-19].

A CFD analysis study was conducted by NASA to evaluate the benefit of blowing air at some locations in the upper surface of a NACA0018 wing section [20]. They used a wing-span wise slots to be pressurized by blowing air to induce the transition (from laminar to turbulence) at the upper surface. The results indicate an increase in the lift and decrease in the drag due to eliminating the laminar separation.

As the NACA0018 airfoil has a thicker wing section (18% of the wing chord), it is desirable to be used in aircraft wings to accommodate the structure elements, payload and fuel/battery. Its aerodynamic performance is good in term of high lift coefficient and less drag coefficient [21]. As it has a thicker wing section it would be suitable to be provided by blowing air at the trailing edge. Therefore, the aim of this study is to investigate the use of flow control approach to enhance the lift, drag, and moment specifically at higher angle of attack. As the separation in the flow is situated usually at higher angles of attack nearby the trailing edge, therefore the trailing edge blowing will be the target to mitigate the separation. The source of the blowing air could be normally created from air moving against the airplane passage or by using external air blower. As the target is to investigate the benefit of blowing air at the trailing edge, the source of blowing will not be considered in this study.

The main aerodynamic performance parameters of the wing are the lift coefficient *CL*, drag coefficient *CD* and pitching moment *CM*. These can be calculated using the following equations:

$$CL = \frac{L}{0.5\,\rho\,A\,U_a^2} \tag{1}$$

$$CD = \frac{D}{0.5\,\rho\,A\,U_a^2} \tag{2}$$

$$CM = \frac{L}{0.5\,\rho\,A\,U_a^2} \tag{3}$$

Where *Ua* is the air speed (m/s), *A*: wing area (m^2), *L*: lift force (*N*), *D*: drag force (N), *M*: pitching moment about the quarter chord of the wing section (N.m), and ρ: air density (kg/m^3).

As NACA0018 is symmetrical airfoil, the pitching moment about the quarter chord is very low and can be neglected. However, at higher angles of attach or when happening any separation, the pitching moment will be affected. Addition to the last reasons, blowing air at the rear side of the wing section could produce momentum that could generate moment. The blowing speed at the trailing edge of the airfoil will be denoted as *Ub*. Then the ratio between the blowing speed and flying speed *Ua* can be introduced as blowing ratio (*BR*).

$$BR = \frac{U_b}{U_a} \tag{4}$$

2. Descriptions of the model

The model consists of symmetric NACA0018 airfoil section provided with blowing jet at the trailing edge as indicated in Fig. 1. The airfoil chord is 1 m length and has an outlet at the trailing edge with 4 mm opening to provide a stream of air with *Ub* speed. For all the cases the blowing stream will be kept normal to the outlet at the trailing edge.

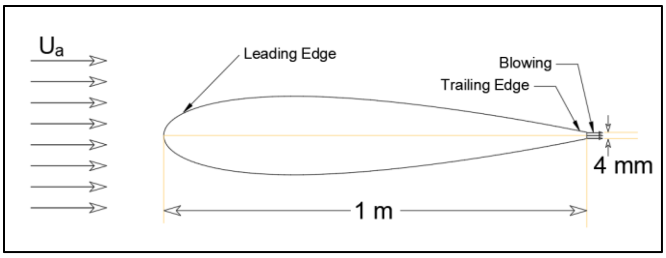

Fig. 1 NACA0018 airfoil geometry with blowing jet at the trailing edge.

Different blowing speed at different Reynolds number will be investigated in this paper. The source of the blowing stream will be assumed at the trailing edge in some point at the leading edge of the wing. However, as the study concerns only with 2D-analysis, therefore the source of the stream will not be included assuming its effect is negligible. As the performance of the airfoil is affected by the operational speed (Reynolds number), two air speed will be included in this study to have better understanding on the effect of blowing jet under high and low Reynolds number. Also, for each operational air speed, two blowing speed ratios will be investigated as showing in Table 1.

Table 1. the studied flow parameters.

Air Speed U_a (m/s)	Reynolds Number	Blowing Ratio (U_b/U_a)	Blowing Speed U_b (m/s)
10	6.85×10^5	0.5	5
10	6.85×10^5	1	10
20	13.7×10^5	0.5	10
20	13.7×10^5	1	20

3. CFD model description and validation

A high order fidelity computational fluid dynamic software ANSYS-FLUENT has been used in the analysis. The 2D-C grid shape is utilized to model the flow domain as show in Fig. 2. The mesh quality at the airfoil surface is refined enough to capture the flow characteristic and to simulate the flow boundary layer adjacent to the surface as shown in Fig. 3. The turbulence model Spalart-Allmaras model has been used for all the cases.

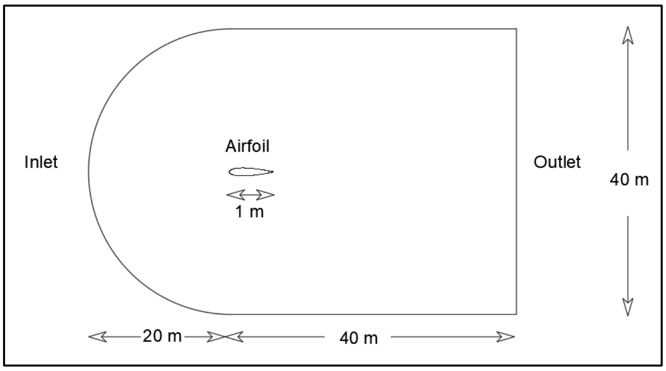

Fig. 2 schematic drawing for the flow domain and its boundary condition.

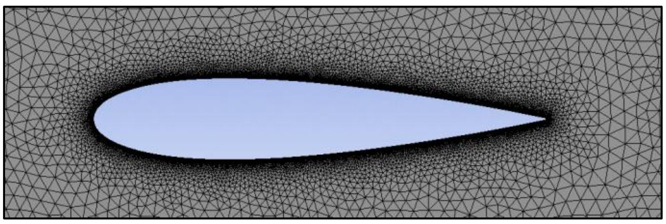

Fig. 3 Mesh intensity at the airfoil Wall.

The mesh independent study has been conducted to verify the model capability to predict the aerodynamic performance very well. Several mesh qualities are tested to predict the lift and drag coefficient at 12 degrees of angle of attack for the CFD model. The mesh quality with 106533 elements and 139258 nodes is found giving a satisfying result as shown in Fig. 4.

Moreover, for further verification, the model has been validated with another aerodynamic solver called Xfoil. The results of validation shown in Fig. 5 indicates that the results of the current model are in a good agreement with Xfoil results for the lift and drag coefficients. However, as known, the Xfoil software is not conducting very well at the region of flow separation at higher angles of attack.

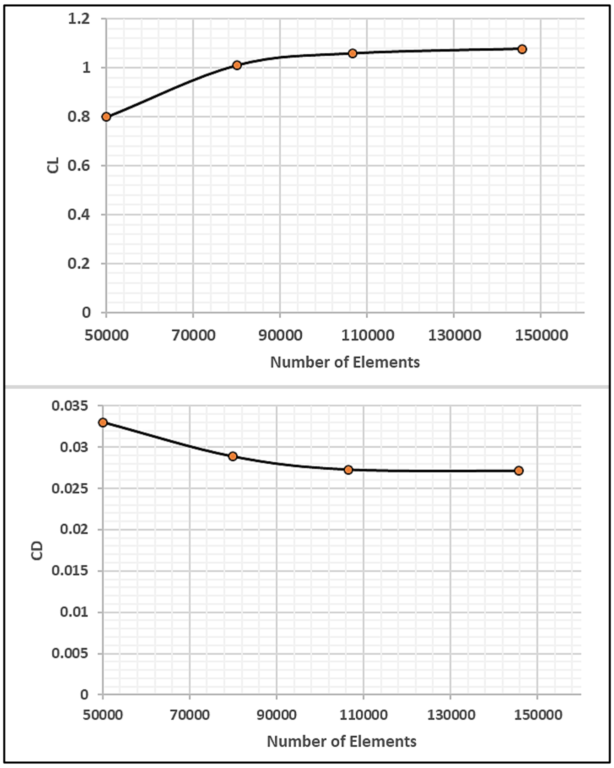

Fig. 4 mesh independent study.

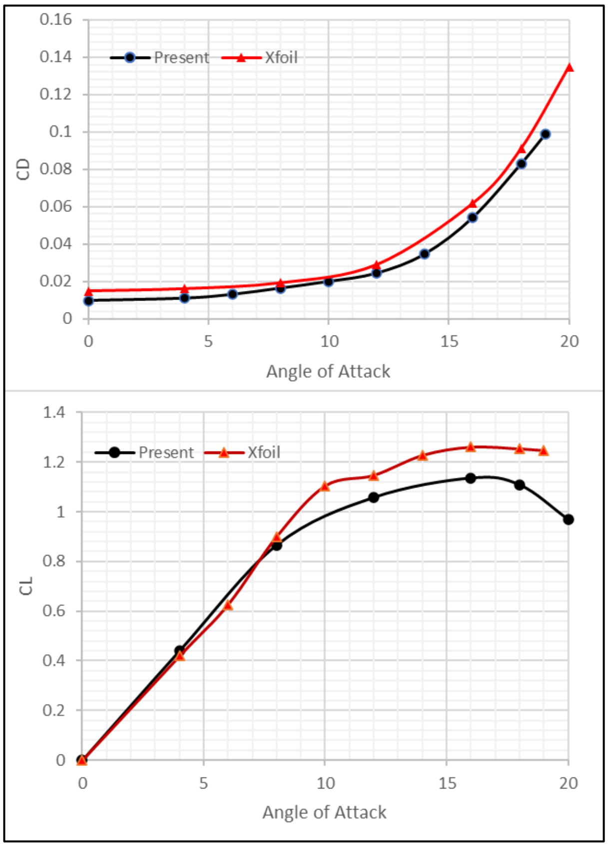

Fig. 5 results validation with Xfoil results.

4. Results and discussion

The CFD analysis has been conducted at two different Reynold number using two different blowing ratios. Also, the results were compared with the aerodynamic performance of the airfoil without using the blowing technique.

Figure 6 and Table 2 presents the lift, drag and moment coefficients of the airfoil at Reynolds number 6.85 × 10^5. The results of the lift coefficient with blowing ratio of 1 demonstrate that using blowing technique at the trailing edge can enhance the generated lift at angles of attacks from 8 to 16 degrees. The increase percentage is around 4-6 %. However, at lower angle of attack a little increase in the lift can be noticed. The drag forces demonstrate less sensitivity in the curve. However, a decrease in the drag at lower angle of attack and an increase at higher angles can be noticed in Table 2 which is around 4-6 %. It is noticed that with decreasing the blowing ratio, the behavior become less observed. The pitching moment results also is remarkably affected by the blowing technique. At lower angles of attack, the pitching moment become positive and then became negative at higher angles of attack because of separation effect. The reason of positive pitching moment at lower angle of attack is due the blowing momentum at the rear side of the airfoil. If the results compared with that of the performance without blowing, the pitching moments at higher angles of attack is highly affected at higher angle of attack due the separation at the trailing edge while with case of blowing at these angles of attack, the effect become lesser with increasing the blowing speed. The positive pitching moment is highly recommended for blended wing aircraft as this moment can accommodate a crucial factor for the stability of aircraft. Moreover, with reducing the effect of spike in the pitching moments at higher angles of attack, the flight would be safer and easily handled.

Figure 7 presents the streamline, pressure and velocity contour at angle of attack 12 and Reynolds Number 13.7 × 10^5 for the airfoil performance without blowing and with 1 blowing ratio. The blowing effect can be noticed on reducing the sizes of separation vortex and this has affected the pressure distribution around the trailing edge. The pressure values are clearly affected by the blowing at the trailing edge and looks consistence at the lower surface of the airfoil. The velocity contour looks similar for the case without blowing but the value is slightly affected.

Table 2. NACA0018 results at different blowing ratio at Reynolds number 6.85 × 10^5.

	Without TE Blowing		Blowing Ratio=0.5				Blowing Ratio=1			
AoA	CL	CD	CL	CD	Different ratio in CL	Different ratio in CD	CL	CD	Different ratio in CL	Different ratio in CD
0	0.0003	0.0156	0.0005	0.0147	86%	-0.055	0.0006	0.0148	97%	-5%
4	0.4406	0.0167	0.4413	0.0158	0%	-0.051	0.4517	0.0160	3%	-4%
8	0.8666	0.0203	0.8513	0.0183	-2%	-0.096	0.8795	0.0192	1%	-6%
12	1.0582	0.0279	1.0732	0.0276	1%	-0.010	1.1266	0.0289	6%	4%
16	1.1364	0.0586	1.1451	0.0616	1%	0.051	1.1774	0.0618	4%	5%
18	1.1095	0.0858	1.1206	0.0873	1%	0.017	1.1455	0.0910	3%	6%
20	0.9706	0.1392	0.9805	0.1416	1%	0.017	0.9732	0.1350	0%	-3%

Figure 8 presents the streamline, pressure and velocity contour at angle of attack 18 and Reynolds number 13.7 × 10^5 for the airfoil performance without blowing and with a blowing ratio of 1. As in this angle the separation is more dominant, the blowing is not highly pronounced. The blowing effect can be noticed on forcing the flow to produce more uniform pressure distribution at the lower surface of the airfoil than the case without blowing.

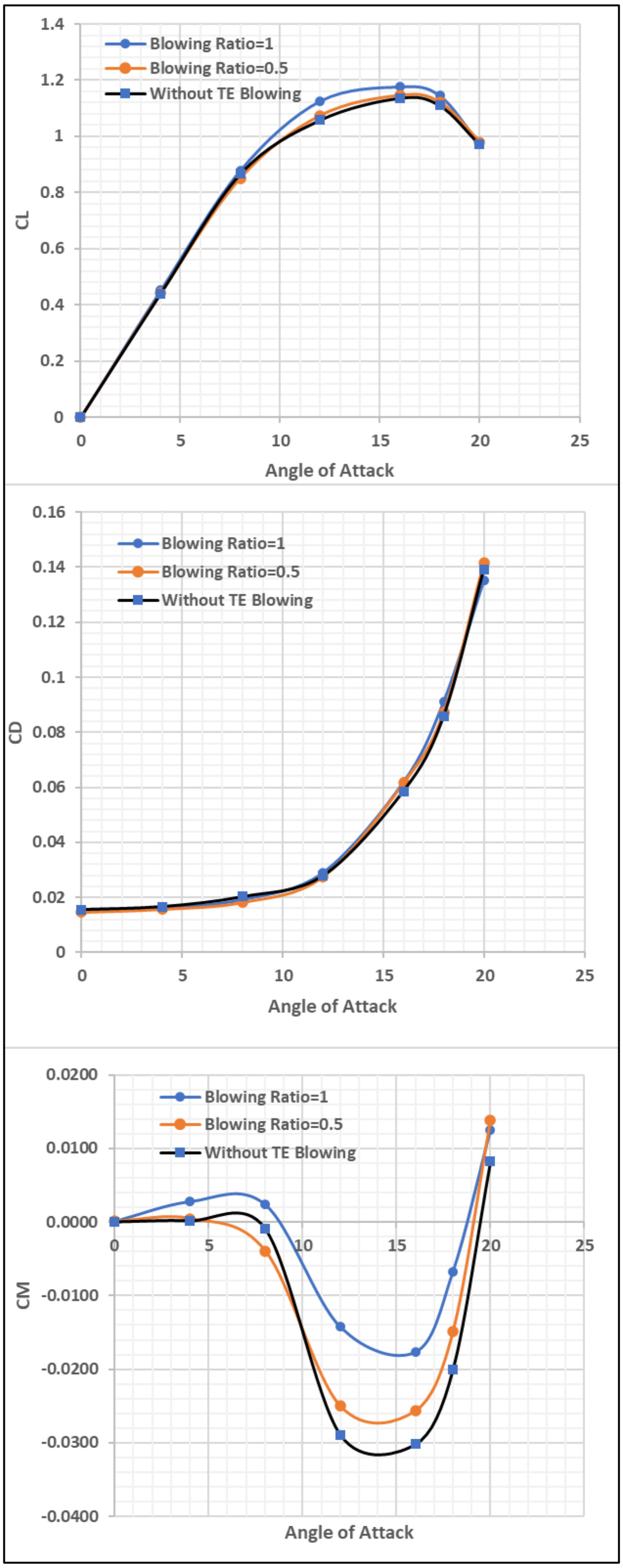

Fig. 6 NACA0018 aerodynamic performance at different blowing ratio at Reynolds number 6.85×10^5.

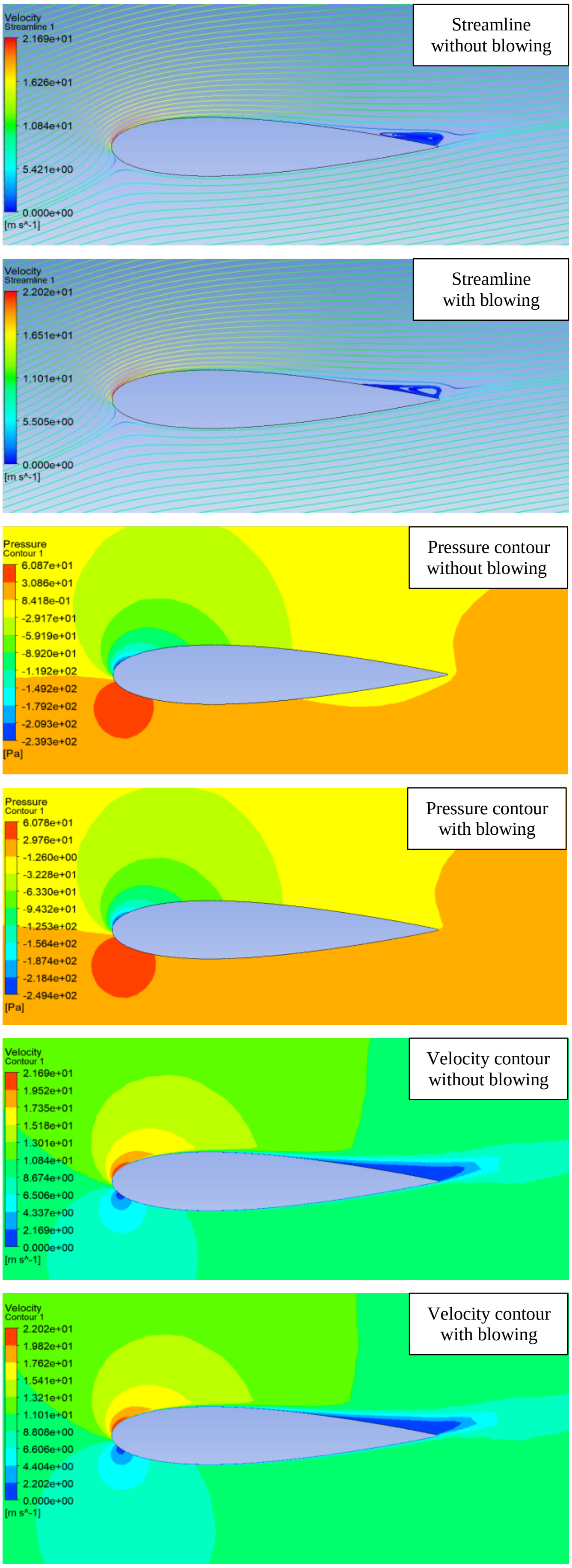

Fig. 7 Streamline, pressure and velocity contour at angle of attack 12° with and without blowing. Reynolds number 6.85×10^5.

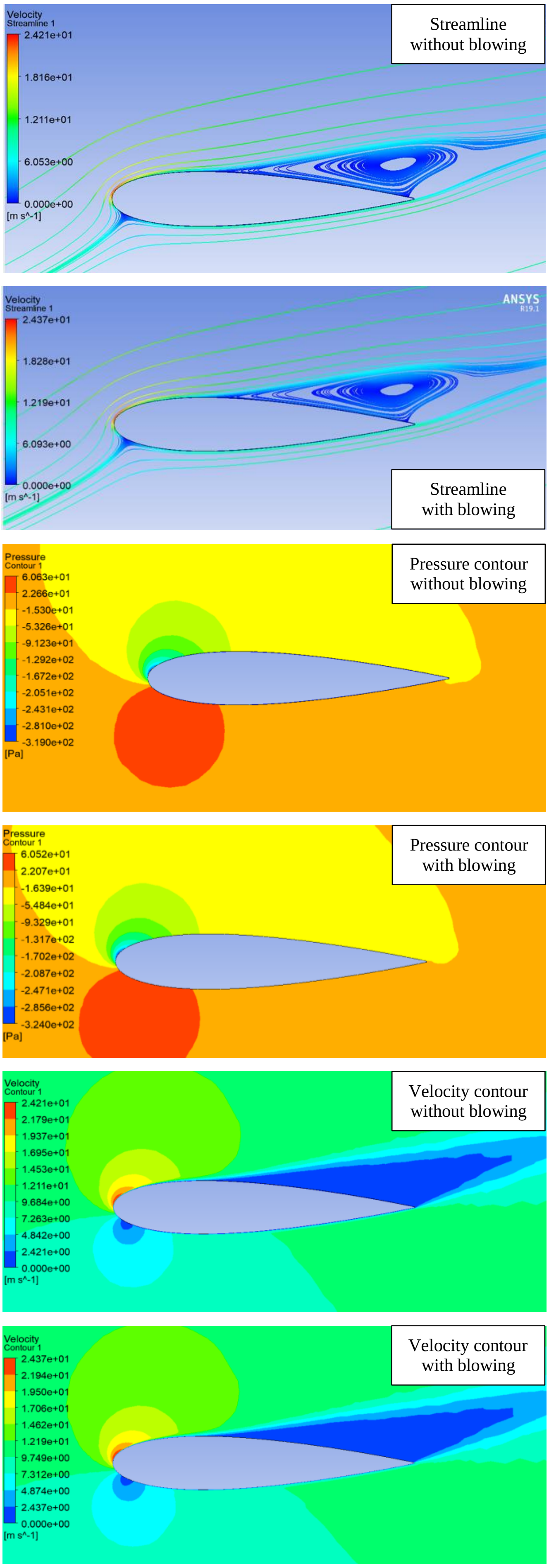

Fig. 8 Streamline, pressure and velocity contour at angle of attack 18° with and without blowing. Reynolds number 6.85 × 10^5.

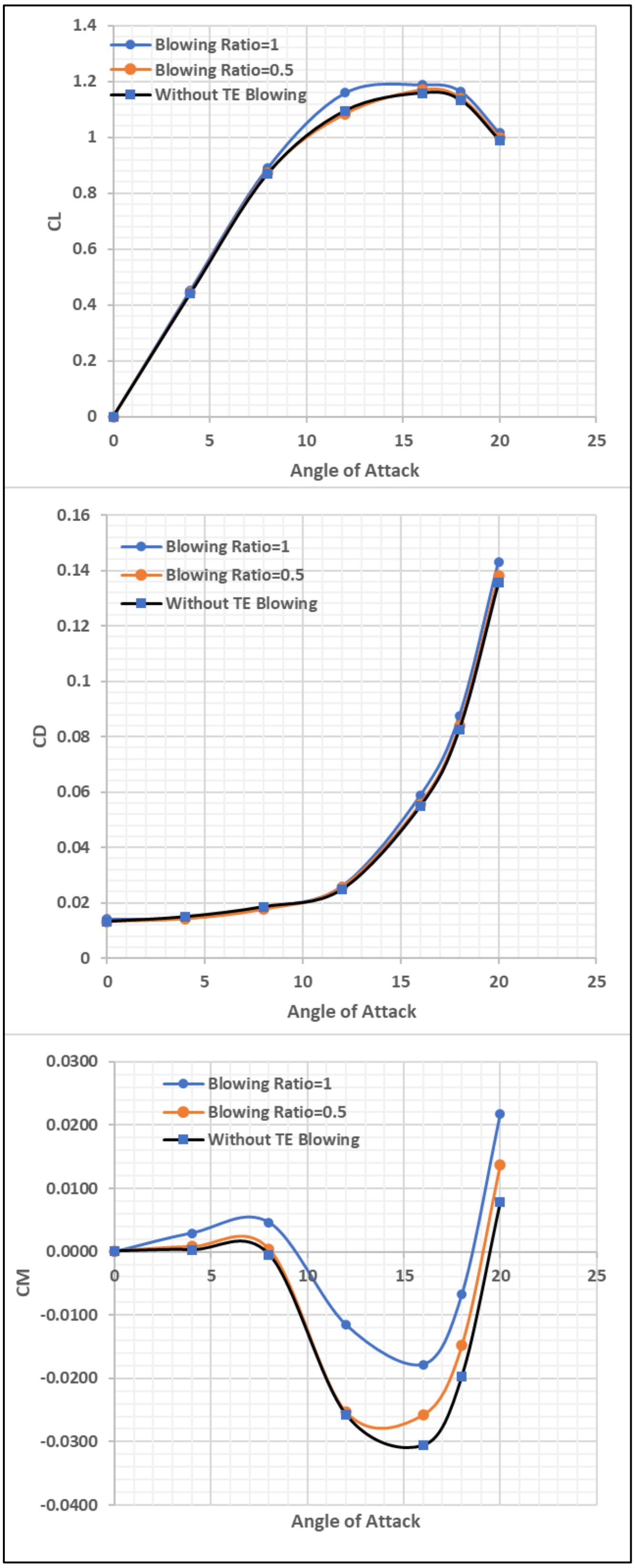

Fig. 9 NACA0018 aerodynamic performance at different blowing ratio at Reynolds number 13.7 × 10^5.

Figure 9 and Table 3 presents the results under higher flight speed 20 m/s, Reynolds number 13.7 × 10^5 for different blowing ratio as well as that of without blowing. In general, the results trend is similar but less pronounced if compared with the case with lower speed. In most angle of attack the increase in the lift coefficient has reached 3% while the drag is increased at higher angle of attack. But in some lower angle of attack, the drag become lower if compared with the case of no blowing. The trend of the pitching moments looks the same as the case with lower speed case. However, the negative moment is less than of that generated by the case of lower speed.

The both results of aerodynamic performance at low and high Reynolds number indicate a possibility of utilizing the blowing technique to enhance the lift coefficient and produce positive pitching moment. However, this could come with an increase in the drag.

Table 3. NACA0018 results at different blowing ratio at Reynolds number 13.7×10^5.

	Without TE Blowing		Blowing Ratio=0.5				Blowing Ratio=1			
AoA	CL	CD	CL	CD	Different ratio in CL	Different ratio in CD	CL	CD	Different ratio in CL	Different ratio in CD
0	0.0006	0.0132	0.0004	0.0132	-24%	-0.006	0.0001	0.0141	-86%	6%
4	0.4417	0.0150	0.4432	0.0142	0%	-0.055	0.4529	0.0143	3%	-4%
8	0.8696	0.0186	0.8732	0.0176	0%	-0.054	0.8910	0.0182	2%	-2%
12	1.0951	0.0248	1.0837	0.0256	-1%	0.030	1.1593	0.0260	6%	5%
16	1.1586	0.0549	1.1699	0.0557	1%	0.015	1.1888	0.0587	3%	7%
18	1.1325	0.0826	1.1405	0.0839	1%	0.015	1.1645	0.0875	3%	6%
20	0.9897	0.1355	0.9999	0.1380	1%	0.018	1.0160	0.1431	3%	6%

6. Conclusions

The leading-edge blowing technique has been studied for NACA0018 airfoil at Reynolds number 6.85 and 13.7×10^5. The following aspect can be concluded:

1. The lift coefficient can be enhanced to be increased by 4-6% if compared with no blowing case. This increase ratio is affected by the operational Reynolds number and blowing ratio. Higher speed means less blowing benefit within the limit of blowing ratio of 1.
2. The drag can be manipulated to be decreased or increased depending on the angles of attack. While some application of flow control is widely used in take-off or landing, the drag generated could be useful for landing and may not be the problem in the take off.
3. With using the blowing technique, positive pitching moment can be generated at lower angle of attack. This could help to achieve stability of tailless aircraft. Also, with blowing case, the divergence in the pitching moment at higher angle of attack can be highly reduced.

Many parameters such as increasing the blowing ratio more than 1 and several Reynold number operations can be investigated. Also, blowing technique including the blowing slots at the region of the flow separation at the upper surface of the wing can be investigated. These would be worth to be investigated in future work.

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