Suction and Blowing Flow Control on Airfoil for Drag Reduction in Subsonic Flow

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Abstract. Lift force is produced from a pressure difference between the pressures acting in upper and lower surfaces. Therefore, flow becomes detached from the surface of the airfoil at separation point and form vortices. These vortices affect the aerodynamic performance of the airfoil in term of lift and drag coefficient. Therefore, this study is investigating the effect of suction and jet blowing in boundary layer separation control on NACA 0012 airfoil in a subsonic wind tunnel. The experiment examined both methods at the position of 25% of the chord-length of the airfoil at Reynolds number 1.2 x 10^5. The findings show that suction and jet blowing affect the aerodynamic performance of NACA 0012 airfoil and can be an effective means for boundary layer separation control in subsonic flow.

1. Introduction
One of the most vital aerodynamic structure on an airplane is the wing itself which allows the airplane to fly and work efficiently. The airfoil faces heavy frictional and drag force on its surface which further reduces the airplane efficiency. Steady and unsteady blowing is one of the techniques in investigation for separation control on an airfoil. A wide variety of these techniques have been used in the past to delay separation by increasing the momentum of the boundary layer. Blowing has been effective in adjusting and reenergizing the flow to prevent flow separation. A delayed airfoil stall angle due to oscillatory blowing was found and this proved that steady blowing is not as efficient as oscillatory blowing in delaying separation [1]. The separation region forms when the angle of attack of the airfoil is increased, which causes the flow to fail to reattach on the airfoil surface [2]. A pulse blowing technique also was introduced which helped keeping the flow attached to the surface. Further investigations on this topic revealed that blowing also resulted in an increase in lift coefficient with the application of spanwise steady blowing [3]. The blowing system resulted in causing turbulent flow to occur earlier hence causing the flow to come closer to the surface of airfoil near the trailing edge.

The second method opposite to blowing, which is the suction system was then compared [4]. The study proved that the most important factors affecting the outcome are the suction location and the angle. The suction system was also tested on a cylindrical object to reduce drag acting on it by focusing in reducing the fluctuating amplitudes of the dynamic wind loads acting on the test modal [5]. Suction contributes to the stability of the boundary layer by delaying transition so that the flow is laminar rather turbulent [6]. The suction system can also delay the transition occurrence on the upper surface boundary layers compared with the flow without suction control [7]. These methods were then further enhanced by both simulation and experimental studies [8]. Therefore the purpose of this study is to investigate the effectiveness of the suction system and jet blowing in reducing the coefficient of drag and also in increasing the lift coefficient of NACA 0012 airfoil.
2. Methodology

2.1. Airfoil CAD Model
The airfoil model was designed using SolidWorks 2016 as shown in Figure 1. NACA 0012 was chosen as the model. The chord length of the airfoil is 150mm and a span of 240mm.

![Figure 1. Isometric view of airfoil.](image1.png)

2.2. Airfoil Model Fabrication
The airfoil model was then fabricated using a 3D printer. The material used was made out of ABS plastic. The material was first melted in high temperature to create the base which usually is larger than the model size as shown in Figure 2. After the base was complete, the fabrication process of the model was initiated and took approximately 7 hours until completion. The airfoil model was then drilled from the base with holes of diameter of 3mm to allow the insertion of the suction and blowing tubes.

![Figure 2. Base of the airfoil.](image2.png)

2.3. Air Distributor Fabrication
Aluminum was chosen as the material to fabricate the air distributor. This distributor was used in both the suction system and jet blowing for suction and pressurised air delivery. The air distributor was then connected to the airfoil model using five tubes as shown in Figure 3.
2.4. Subsonic Wind Tunnel Testing
The airfoil model was then tested in the LW-9300R Subsonic Wind Tunnel as shown in Figure 4, at the National Defence University of Malaysia. The velocity speed used was 20m/s. Temperature and static pressure were set at 293.20 K and 101.3 kPa. The angle of the airfoil was increased by 3 degrees for every data collected. The wind tunnel is equipped with a 3-component force balance, smoke flow visualization and pressure transducers for pressure measurements.

![Figure 3. NACA 0012 Airfoil connected to the Air Distributor.](image)

![Figure 4. LW-9300R Subsonic Wind Tunnel.](image)

3. Results and Discussions
3.1. Validation of experimental study for suction system
The validation process for suction system was carried out by comparing results experimentally against the results produced by Huang et al. [4]. An experiment was carried out in the wind tunnel to obtain results of drag and lift coefficients against various angle of attacks. The airfoil model was mounted inside the test section and connected to the 3-component force balance. The results produced were
similar to Huang et al which is shown in Figure 5 and Figure 6. The graph produced was of similar trend as Huang et al. for both cases of lift and drag coefficients.

3.2. Effectiveness of suction system
Figure 7 shows the drag coefficient obtained against various angle of attacks between airfoil with and without the suction system. The drag coefficient produced by the airfoil with suction system has a relatively lower value compared to airfoil without the suction system at all angle of attacks. This proves that the suction system on airfoil can indeed reduce drag acting on the airfoil at almost all angle of attack. Lift coefficient also has a vital role in determining the efficiency of an airplane. Figure 8 shows the graph of lift coefficient against various angle of attacks. It can be seen that the $C_L$ value for airfoil with suction system is higher comparing to the $C_L$ value for airfoil without the suction system.

![Figure 5. $C_L$ vs Angle of attack.](image)

![Figure 6. $C_D$ vs Angle of attack.](image)

![Figure 7. $C_D$ vs Angle of attack with and without suction.](image)

![Figure 8. $C_L$ vs Angle of attack with and without suction.](image)
Table 1 shows the difference of $C_L/C_D$ for airfoil with and without suction system at various angle of attacks. The table clearly shows that the airfoil with suction system has a higher lift over drag ratio compared to the airfoil without the suction system. Theoretically it is said that a higher lift over drag ratio is more favorable has it helps lower the glide ratio which allows a longer gliding distance and further increase the airplane efficiency.

**Table 1.** $C_L/C_D$ ratio comparison.

| Angle of Attack | No suction $C_L/C_D$ | Suction $C_L/C_D$ |
|-----------------|----------------------|------------------|
| 3               | -0.500               | -0.261           |
| 6               | -1.115               | -0.766           |
| 8               | -2.133               | -1.119           |
| 12              | -3.583               | -1.618           |
| 15              | -4.900               | -2.269           |
| 18              | -5.556               | -3.529           |

3.3. Effectiveness of jet blowing

In Figure 9, the lift coefficient value of airfoil with jet blowing has no changes at negative angle of attack but differences can be seen at positive angle of attack comparing to the lift coefficient without jet blowing. This proved that blowing device has an effect on the the aerodynamic performance of the airfoil. The lift coefficient increases as the angle of attack increases with blowing device. The lift coefficient is highest at 18° angle of attack with blowing device due to the delayed flow separation. Based on drag coefficient, Figure 10 shows an improvement for airfoil with blowing device compared to airfoil without blowing device for almost all angle of attack. Looking at 21° angle of attack, the $C_D$ for airfoil with blowing device is slightly lesser comparing to the $C_D$ for airfoil without blowing device.

![Figure 9. $C_L$ vs Angle of attack with and without blowing.](image1)

![Figure 10. $C_D$ vs Angle of attack with and without blowing.](image2)
Table 2 shows that lift and drag coefficient ratio for airfoil with blowing device has higher value compared to lift and drag coefficient value for airfoil without blowing device. Hence it proves that blowing indeed has an improvement effect in aerodynamics performance on airfoil since it is known that higher value of lift and drag coefficient ratio has higher efficiency. It can be seen that the blowing device effect is at its highest at 0° angle of attack.

| Angle of Attack | No Blowing $C_L/C_D$ | Blowing $C_L/C_D$ |
|-----------------|----------------------|-------------------|
| 3               | 7.300                | 34.000            |
| 6               | 8.769                | 28.250            |
| 9               | 8.611                | 15.500            |
| 12              | 6.963                | 10.052            |
| 15              | 3.366                | 4.166             |
| 18              | 2.696                | 3.133             |

4. Conclusion
Based on the validation results, it is valid to say that the subsonic wind tunnel indeed produces decent results. The suction system and jet blowing also has proven its capability in producing positive results in lift and drag coefficients acting on NACA 0012. Both the devices further delay the separation region by keeping the flow attached on the skin surface of the airfoil.

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