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# Wind Tunnel Evaluation on the Performance of Blown Airfoil

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## Abstract

This study investigated the performance of blown airfoil. Two types of blown airfoil were developed. The integrated parts of the airfoils were investigated in the subsonic wind tunnel to study the aerodynamic forces. Each airfoil was implemented with a blower at different locations on the upper surface and was tested in the wind tunnel, with different Reynolds numbers, and with and without blower. The results showed that the airfoil with air blower produced a very significant additional 35% lift force compared to airfoil without air blower. The experimental result also exhibited 7% higher lift coefficient for air blower compared to numerical analysis.

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## 1. Introduction

The flow control technique is the most popular research subject in the field of aerodynamics. This technology has the potential for improving the consumption of aircraft fuel. Mostly, the purpose of flow control is to delay transition, enhance turbulence and to prevent or postpone separation area, which is useful in lift enhancement, drag reduction, mixing augmentation and flow-induced noise suppression. Besides, the passive flow control technique is most commonly used and it does not require any power. The array of small passive devices is easy to build and has minimal problem. This small device is known as vortex generator. Although these devices are simple, rugged, and relatively low in cost; they too have disadvantages. This passive device cannot be controlled for landing/take-off and for manoeuvring flight envelope. Moreover, their passive configurations add parasitic drag.

On the other hand, the active flow control is a rather new approach for controlling boundary layer. These flow control devices require energy expenditure to manipulate fluid flow. In fact, active flow control (AFC) devices work on two main techniques, namely structural vibration and air jet (Kupper and Henry, 2003; Duvigneau and Visonneau, 2006). Examples of structural vibration are movable vortex generator, trailing edge deflector, vortex generator, self-activated movable flap, miniature trailing edge effectors and plasma actuator. Furthermore, the experimental work carried out by Osborn et al. (2004) revealed that high frequency deplorable micro vortex generator system (HiMVG) that oscillated between 30 and 70 Hz was very effective in mitigating flow separation on the upper surface of a deflected flap. One successful and popular actuator in this new decade is air jet. The periodic blowing (Carnarius et al. (2007)) and the co-flow jet (CFJ) (Zha and Paxton, 2004) could effectively reduce the massive separation at the flap. At low angle of attack with moderate jet coefficient, the co-flow jets enhance lift, reduce drag, and also generate thrust. Meanwhile, at high angle of attack, both lift and drag are higher compared to the airfoil without flow control, which might enhance the performance of take-off or landing within a short distance. Another blowing jet was looked into by Petz and Nische (2007). The aim was to enhance the aerodynamic quality of the complete configuration by suppressing the flow separation on the flap. The flow was excited by using a pulsed wall jet from the upper surface near the flap's leading edge through a small spanwise-oriented slot. The massive flow separation at large deflection angles was prevented; increasing the flap deflection angle by up to $10^0$. Hence, the lift was increased by up to 12%, while drag was reduced by the same amount. This enhanced the lift-to-drag ratio by 20%-25%. As a result, the overall maximum lift was improved by as much as 5%.

In addition, Rhee et al. (2003) discovered that this device had been more efficient at smaller angle of attack and momentum coefficient, especially for low-speed manoeuvring. Other than that, Mello et al. (2007) conducted a study pertaining to synthetic jet actuator on flat plate. The result displayed an increase in velocity profile more than double the value in relation to the flow profiles without the synthetic jet. The flow oscillated by the synthetic jet caused acceleration of the flow close to the surface of the flat plate. Nevertheless, some researchers used different techniques of blowing. They used both steady and unsteady-blowing techniques as tools for turbulent separation control. The results showed that these techniques had been very effective to delay or to suppress separation on a single component airfoil in the pre-stall area, focusing on cruising condition (Sun and Sheikh, 1999).

Moreover, several flow control techniques were developed previously to generate lift forces by manipulating the boundary layer. In fact, researches concerning lift generation mechanism are becoming an increasingly important area in aircraft design. In the current work, continuous blowing concepts on airfoil surface located at 30% and 40% chords designed with lateral vents were evaluated. Therefore, this study investigated the performance of blown wing concept on airfoil to generate lift mechanism.

## 2. Methodology

### *2.1 The Experimental Set Up*

#### *2.1.1 Wind tunnel set up*

The entire tests had been conducted in an open circuit subsonic wind tunnel, as shown in Fig. 1. The flow entered the wind tunnel through a settling chamber containing a honeycomb and a screen was placed after the inlet before the contraction cone. Large scale turbulence was reduced by the honeycomb straighteners. Honeycombs straightened the flow by reducing lateral velocities, while screen reduced the axial turbulence, and fine screen broke the existing turbulence into smaller vortices. Besides, a sufficient distance was provided so that these small disturbances would die out before they reached the model. The tunnel had a test section with the size of 300mm × 300mm × 600 mm; provided with transparent test section walls for visualization and measurement purposes. The maximum velocity at the test section was 50 m/s.

Fig. 1: The experimental setup with open circuit low speed wind tunnel.

*2.1.2. Design specification*

NACA 2412 airfoil was chosen to be used in this study, owing to its low speed high-lift characteristics that suited the speed of the wind tunnel. There were three designs of airfoils: 1) baseline airfoil, 2) airfoil with a blower at 30% chord from the leading edge and 3) airfoil with a blower at 40% chord from the leading edge (see Fig. 2 and Fig. 3). All the three airfoils were designed to share similar chord length at 150mm and 200mm span to compensate the dimension of the test section of the wind tunnel. Fig. 4 illustrates a one-way air compressor attached to an air hose connector at the lower surface of the airfoil.

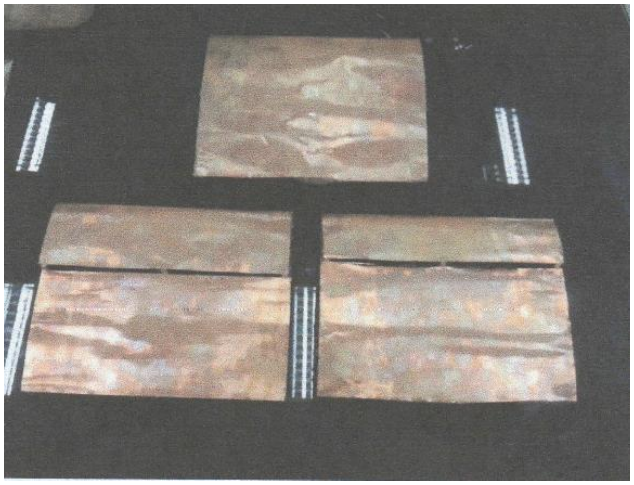

Fig. 2 : Top view of the airfoils.

Fig. 3: Three side views of the airfoils.

Fig. 4: Air hose connector attached at the lower surface of the airfoil.

## *2.2 Computational approaches for numerical analysis*

### *2.2.1 Lift coefficient Equations*

The Thin theory airfoil provides a theoretical basis for the following important properties of airfoil in two-dimensional flow:

i. On a symmetrical airfoil, the centre of pressure and the centre of aerodynamic are positioned exactly one quarter of the chord behind the leading edge

ii. On a cambered airfoil, the aerodynamic centre is placed exactly one quarter of the chord behind the leading edge

iii. The slope of the lift coefficient versus angle of attack line is $2\pi / rad$

The NACA 2412 was cambered airfoil. For cambered airfoil,

$$C_L = C_{L0} + 2\pi\alpha \quad (1)$$

where,

$C_{L0}$ = is the section lift coefficient when the angle of attack is zero

$\alpha$ = is the angle of attack measured relative to the zero-lift line instead of the chord line

If the lift coefficient for a wing at a specified angle of attack is known, the lift produced for the specific flow condition can be determined by using the following equation:

$$L = \frac{1}{2}\rho V^2 S C_L \tag{2}$$

where

$L$ = Lift force

$\rho$ = Air density

$V$ = True airspeed

$S$ = Wing area

$C_L$ = Lift coefficient at desired angle of attack

## 3. Results and Discussion

### *3.1 Different Reynolds numbers without blower*

The airfoils for baseline, 30% chord and 40% chord were investigated. All the cases were investigated without blower applied on the airfoils. Fig. 5 shows the comparisons between different Reynolds numbers for baseline airfoil, airfoil with blower 30% chord and airfoil with blower 40% chord. The results showed that airfoil with 40% chord produced the highest lift coefficient compared to airfoil with 30% chord and baseline. In fact, the lift coefficient continued to increase steadily for all the three cases until the airfoil is stalled. Besides, it was observed that the stalled angle for all the cases was $14^0$. However, the Reynolds number with 50 000 was considered sufficient for the next investigation.

### *3.2 Different pressures of blower*

The effect of blower was investigated at pressures of 0 PSI (pound per square inch), 20 PSI, and 60 PSI. Fig. 6 shows the comparison between three different blowers. The airfoil with 40% chord with Reynolds number 50 000 was considered for this purpose. The blower with 60 PSI generated the highest lift coefficient compared to 0 PSI and 20 PSI. Besides, no pressure produced the lowest lift coefficient. The error bars further displayed that the lift coefficient increased in a steady manner with approximately 30% airfoil with blowing technique attached. Moreover, it was proved that the lift coefficient was directly proportional to the blower pressure.

### *3.3 Comparison for with and without blower*

Further investigation was conducted to determine the effects of with and without blower (baseline) for three different cases. Fig. 7 depicts the comparison between with and without blower. The blower with 60 PSI had been considered in this section. The error bars in red gave the comparison value between 30% and 40% chord, while the error bars in blue portrayed different values for those between with and without blown techniques. The airfoil with 40% chord showed the highest value of lift coefficient, while the baseline showed the lowest. The lift coefficient for all cases increased steadily until $14^0$, while $16^0$ for both blowers with 30% and 40% chords. The difference in lift coefficient values between 30% chord and 40% chord was approximately 5%. Meanwhile, the lift coefficient with blower had been higher by 35% compared to that offered by baseline.

### *3.4 Comparison for numerical analysis data*

The values of lift coefficient obtained from experimental method was compared with the values retrieved from numerical analysis and XFoil database. The values are tabulated in Table 1.

The lift coefficient values from the experiment, the numerical analysis and the XFoil database are plotted and depicted in Fig. 8. It was noted that the lift coefficient values for all the three cases increased steadily until they stalled at the angle of $16^0$. The values obtained from the numerical analysis were approximately 7% less than those found from the experiment given by red error bars, while the values for XFoil had been 1% higher. Therefore, the numerical analysis validated the experimental result, whereby the higher lift coefficient from the experiment showed the effectiveness of the application of blower in the real case. The results also indicated that certain factors such as temperature, density and pressure depended on the wind tunnel environment.

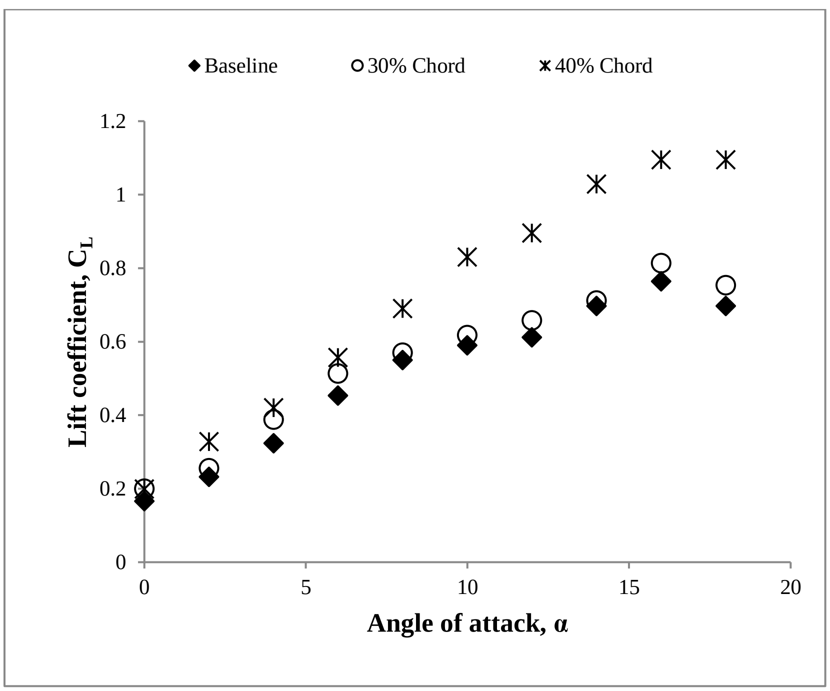


Fig. 5 (a)

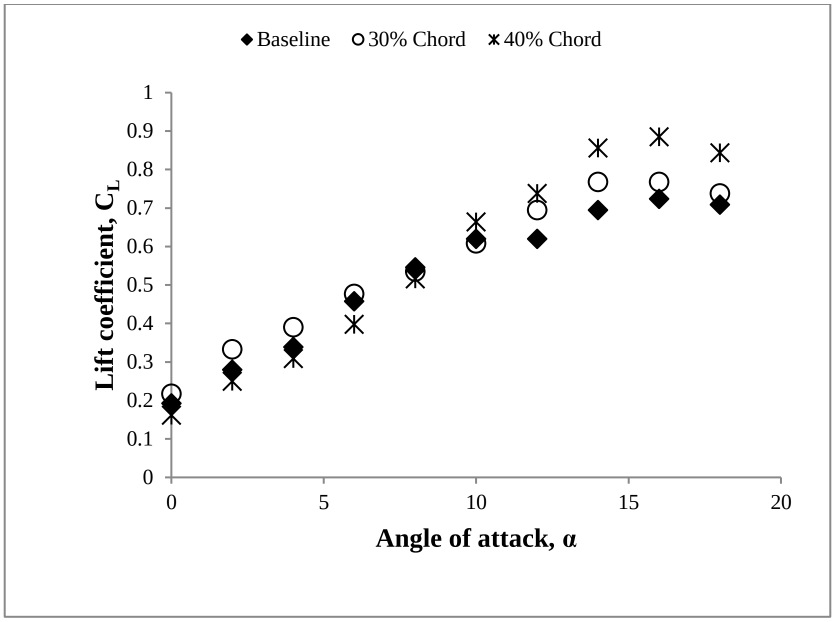


Fig. 5 (b)

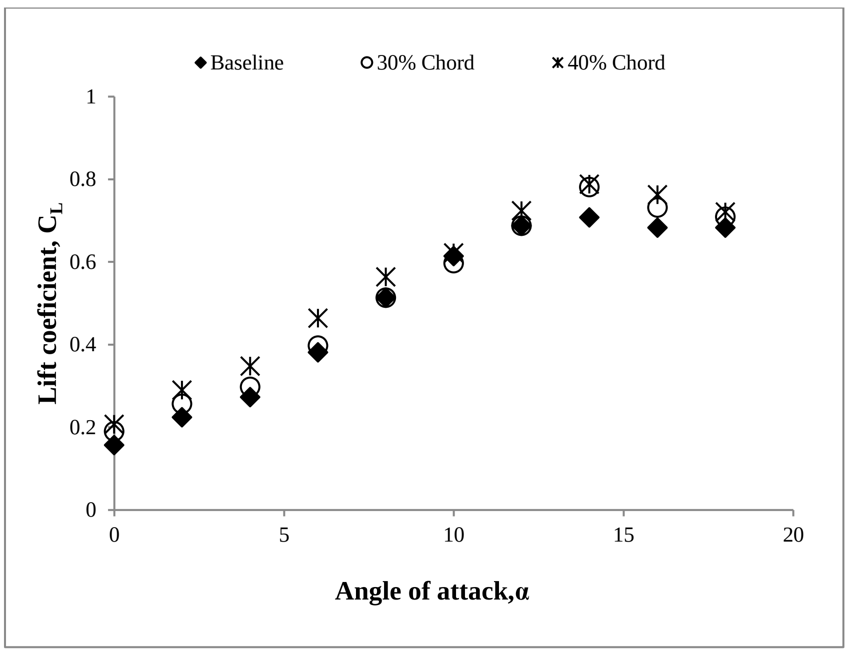


Fig.5 (c)

Fig. 5: Lift coefficient versus α, with (a) Reynolds number =15 000, (b) Reynolds number = 35 000 and (c) Reynolds number = 50 000.

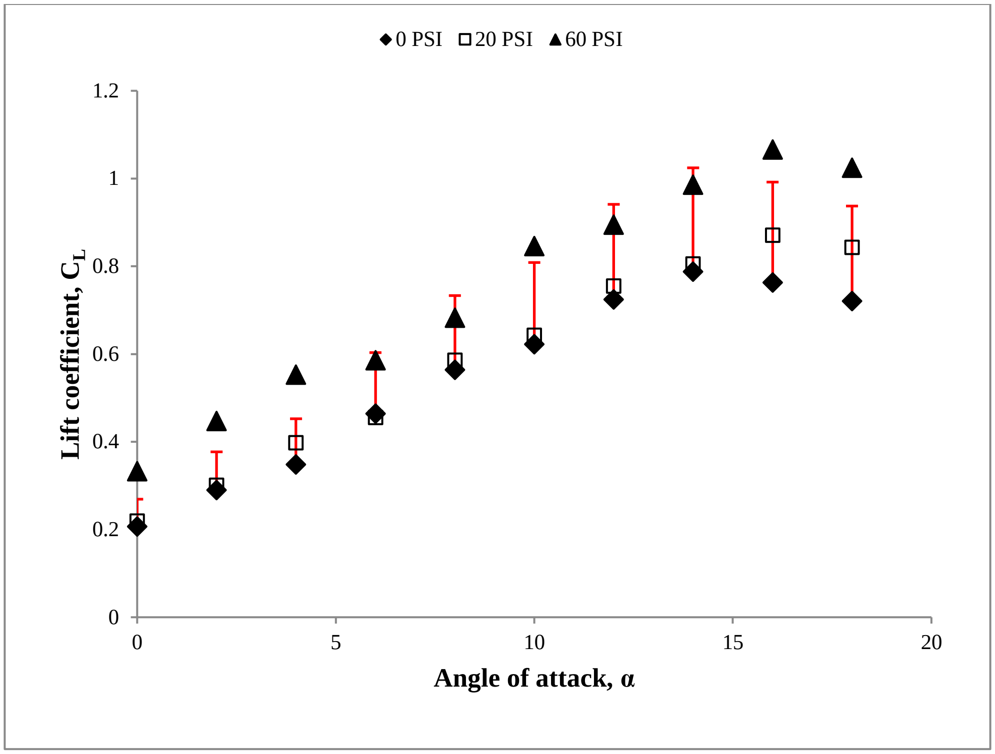


Fig. 6: Lift coefficient versus α for Reynolds number 50 000.

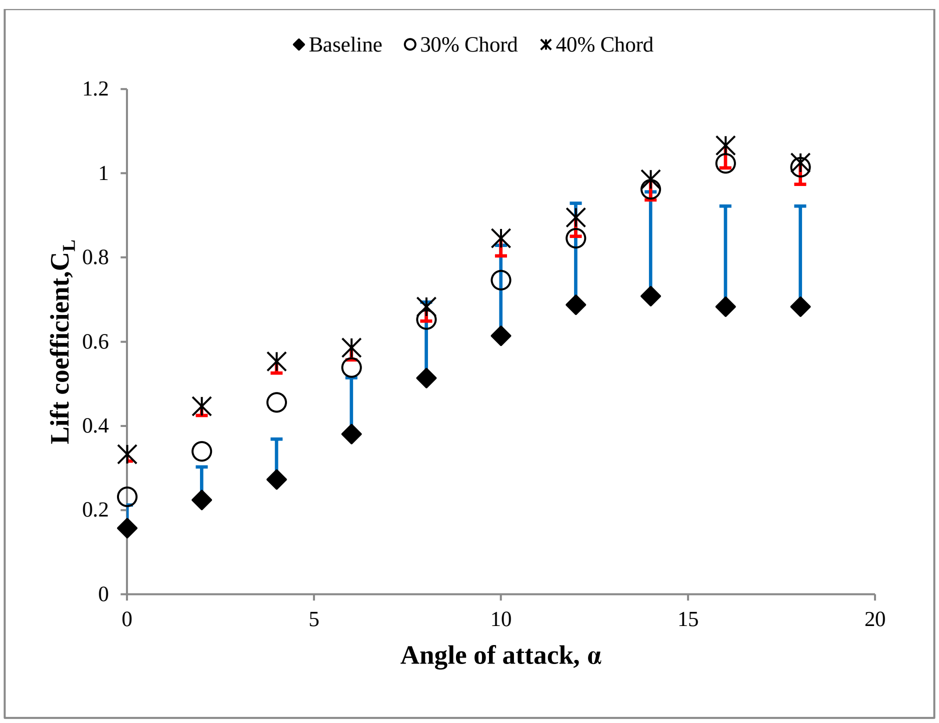


Fig. 7: Comparisons for with and without blower.

Table1. Lift coefficient values with respect to angle of attack

| Cases | Angle of attack(α) | Lift coefficient |
|---|---|---|
| Experimental method | $0^0$ | 0.333 |
| | $4^0$ | 0.553 |
| | $8^0$ | 0.683 |
| | $12^0$ | 0.895 |
| | $16^0$ | 1.066 |
| Numerical method | $0^0$ | 0.308642 |
| | $4^0$ | 0.511894 |
| | $8^0$ | 0.63234 |
| | $12^0$ | 0.828064 |
| | $16^0$ | 0.986149 |
| XFoil data based | $0^0$ | 0.2112 |
| | $4^0$ | 0.55457 |
| | $8^0$ | 0.6585 |
| | $12^0$ | 0.9709 |
| | $16^0$ | 1.1398 |

## 4. Conclusion

The investigation of blown airfoil was carried out by using different Reynolds numbers. The Reynolds number with 50 000 gave a clear significance in lift coefficient, where the flow separation occurred earlier at higher speed. Besides, the airfoil with 40% chord produced higher lift coefficient compared to the baseline. Moreover, the airfoil with blower showed significant increment in lift coefficient by delaying the airflow separation. Furthermore, the airfoil with blower was found to provide additional lift coefficient by almost 35% higher compared to those without blower. The result was further validated with numerical analysis and the higher lift coefficient from the experiment (7% higher) projected the effectiveness of the application of blower in the real case.

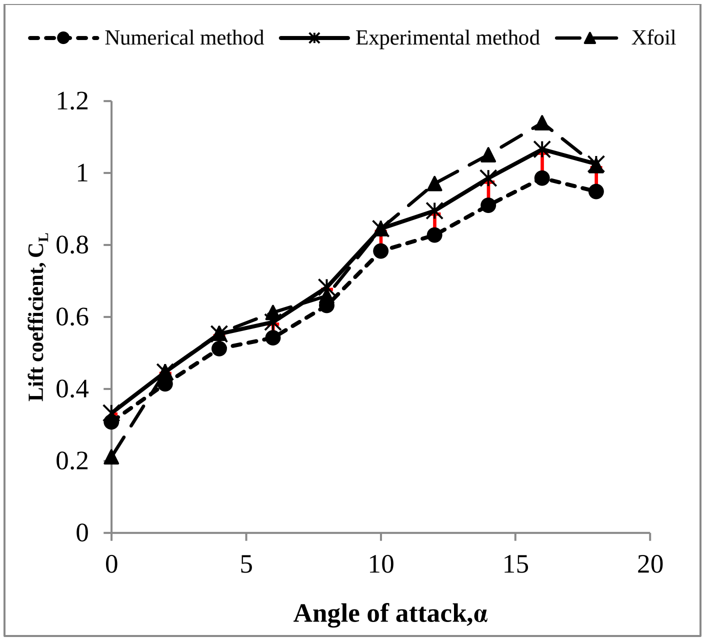


Fig. 8: Comparison between numerical method and XFoil database.

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