

Implementation of Continuous Blowing and Synthetic Jet Actuators to Control the Flow Separation over a Fully Stalled Airfoil

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ABSTRACT

Continuous blowing and synthetic jet actuators were implemented to investigate their effects on a fully stalled airfoil. An opening tangential to the boundary layer configuration was installed over the suction surface of the Selig-Donovan airfoil at the angle of attack of 16° and Reynolds number of 60,000. An optimization analysis was carried out to look for the optimum operational design point. Genetic algorithm, artificial neural network and computational fluid dynamic simulations were combined to perform the optimization. Inserting location, opening diameter, velocity amplitude and synthetic jet frequency were considered as design variables. Results indicated a significant improvement in aerodynamic characteristics, performance, and lift and drag coefficients. Using unsteady actuation caused a better improvement in aerodynamic characteristics compared to the steady case and also led to a remarkable reduction in the applied momentum coefficient. Contours of different flow field parameters were depicted for both cases and their similarities and dissimilarities were identified. Moreover, synthetic jet actuator displayed a lower increase in the friction coefficient than the continuous blowing actuator. Therefore, it showed a higher performance improvement in comparison with the continuous blowing jet.

KEYWORDS

Optimization, Active Flow Control, Synthetic Jet, Constant Blowing, Genetic Algorithm

Introduction

Manipulation of flow pattern to achieve the most desired condition is one of research interests in fluid mechanics. Different flow control approaches are classified as active or passive methods. Synthetic jets, blowing and suction actuators are categorized as active flow control, AFC, methods while roughness, vortex generators and dimples act passively. Active techniques have superiority to passive ones due to the possibility of being ON/OFF during the different conditions.

Müller-Vahl [1] studied the effectiveness of constant blowing in suppression of deep dynamic stall. Their

results demonstrated that a momentum coefficient of 7.2 percent was able to completely eliminate the separation over the suction side. Wang et al. [2] applied both steady and unsteady blowing over the flap part of an infinite wing with NACA0025 airfoil section. They showed that increasing of unsteady actuation frequency enhanced the lift coefficient up to a critical point. Beyond this point, the performance of cases using unsteady actuator still had higher effectiveness than constant blowing. Hosseini et al. [3] investigated the injection angle role of unsteady actuator on film cooling. Three different frequencies 2, 50 and 500 Hz, were considered in this study. Their results implied that the maximum efficiency was

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attainable at incidences tangent to the wall. Moreover, two distinct optimum effective zones in heat transfer control were detected.

Synthetic jet actuators (SJA) are zero net mass flux actuators which have periodic behavior. They have two separate half cycle, inhaling the low momentum flow from the boundary layer and injecting back the same amount of mass flow into the boundary layer, now having a higher momentum. Their performance is usually simulated with a sine function. Tadjfar and Asgari [4, 5] studied the effects of SJA and continuous blowing to control the deep stall over a NACA0012 airfoil. Their results indicated the importance of actuation velocity amplitude, phase difference of the pitching movement and actuator phase on the separation suppression. Kim and Kim [6] employed SJA to control the vast separation zone formed over the NACA23010 airfoil at high angles of attack. It was found that the low frequencies SJAs could penetrate into leading edge vortices and resize them efficiently, while reducing the penetration into leading edge vortices due to the high frequencies actuation caused a reduction in actuator performance. Moreover, it was concluded that momentum coefficient had a direct influence on the flow control, so that more momentum coefficient provided higher flow control efficiency.

Duvigneau and Visonneau [7] conducted an optimization study with three design variables to control the flow separation over the NACA0015. They introduced the momentum coefficient, injection angle and frequency as design variables. They also considered the location effects on the AFC performance. Obtained results demonstrated that the design variables had moderate effects at incidences below 18 degrees while their effects become more significant at angles above 20 degrees. Different optimization studies using various types of flow control methods were accomplished by researchers. The readers are referred to [8-10] for more details.

This study applied both continuous blowing and synthetic jet actuator as AFC over SD7003 airfoil. An optimization analysis was conducted to reach the optimum condition of actuators performance. The location, the actuation velocity amplitude, the frequency and injection angle were considered as design variables.

Methodology and Numerical Approach

The optimization algorithm used genetic algorithm, GA, and artificial neural network, ANN, to find the optimum condition. The ANNs were trained by an initial database generated by evolving some real URANS results. Then, GA used the ANNs as objective functions predictors during the progression of the optimization. The output of this coupling was re-examined by CFD solutions. If the convergence criterion was met, the optimization progress

was accomplished. Otherwise, new real data was added to the database and ANN was retrained. This trend was iterated until the suitable convergence was attained.

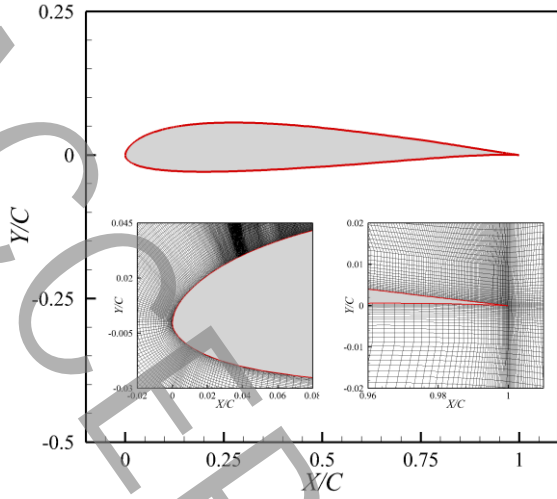
A 2D Unsteady Reynolds Averaged Navier-Stokes, URANS, accompanied with $k\omega$ -SST as turbulence model for the CFD section. The uncontrolled SD7003 airfoil experiences a full deep stall condition and forms a widespread separation area at the Reynolds number of 60,000 based on the chord length and angle of attack of 16° . Two different AFC methods were applied over the suction surface of airfoil to suppress the flow separation. The airfoil geometry, the TBL opening configuration and the structured mesh near the leading and trailing edges were illustrated in Figure 1.

Results and Discussion

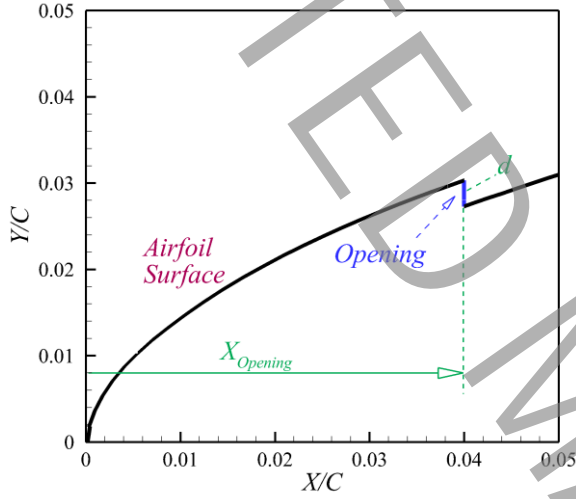
An optimization study performed to control the wide flow separation over a SD7003 airfoil at incidence of 16° by using both CBA and SJA. The installation location, actuation velocity amplitude, opening height and actuation frequency were considered as design variables. The varying ranges of these variables are presented in Table 1.

The optimum ranges of design variables are given in Table 2. It can be seen that the opening location was moved to upstream in the proximity of the leading edge. This means that the optimum location is placed at a location close to natural separation onset. Also, both velocity ratio and opening length had reached the maximum value of their ranges. As a result, the maximum feasible momentum coefficient is required to control the vast flow separation occurred in uncontrolled condition. Furthermore, the range of non-dimensional frequency showed that there is a large interval of F^+ from 2.3 to 4 where the actuator efficiency did not change beyond the 2.3.

These results implied that the airfoil performance was increased by a factor of 4 in the case of using SJA. Moreover, the CBA is more efficient in lift coefficient increase while SJA is more powerful in drag reduction and performance improvement.



(a)



(b)

Figure 1. (a) SD7003 geometry and structured computational domain (b) TBL opening configuration and the computational grid close to opening

Table 1. Range of Design Variables

Design Variable	Range
Install Location (X_o)	4 ~ 16 [%C]
Velocity Amplitude (U_A / U_∞)	0.1 ~ 5
Opening Height / Diameter (d)	0.05 ~ 0.30 [%C]
Non-Dimensional Frequency (F^+)	0.1 ~ 4

Table 2. Optimum design variables ranges

Design Variable	Uncontrolled	CBA	SJA
X_o [%C]	-	4 ~ 4.2	4.00 ~ 4.01
d [%C]	-	0.27 ~ 0.3	0.288 ~ 0.30
U_A / U_∞	-	4.76 ~ 5	4.87 ~ 5.00
F^+	-	-	2.30 ~ 4.00
C_μ	-	14 ~ 15	5.98 ~ 6.08
C_l	0.8205	1.76 ~ 1.86	1.61 ~ 1.64
C_d	0.233	0.16 ~ 0.17	0.093 ~ 0.097
L / D	3.697	10.5 ~ 11.4	16.8 ~ 17.6

Velocity contours embedded with flow field streamlines are depicted in Figure 2 for both controlled and uncontrolled conditions. The results showed that the AFC methods considerably suppressed the vast separation formed over the suction surface. Also, the aerodynamic characteristics were improved by enhancing the lift and reducing the drag force, especially pressure drag. Moreover, the results revealed that SJA had lower blowing momentum coefficient than CBA while it kept the overall performance.

Conclusions

An optimization study was conducted to find the optimum operational condition of an airfoil implemented by both CBA and SJA as active flow controllers. These actuators were installed tangential to boundary layer. Both flow controller methods could suppress the extensive separation area formed over the fully stalled airfoil, significantly.

The SJA was more efficient in performance improvement and drag reduction, while CBA had greater capability in increasing the lift force. Indeed, the required momentum coefficient for preparing the optimum performance using SJA was considerably lower than CBA.

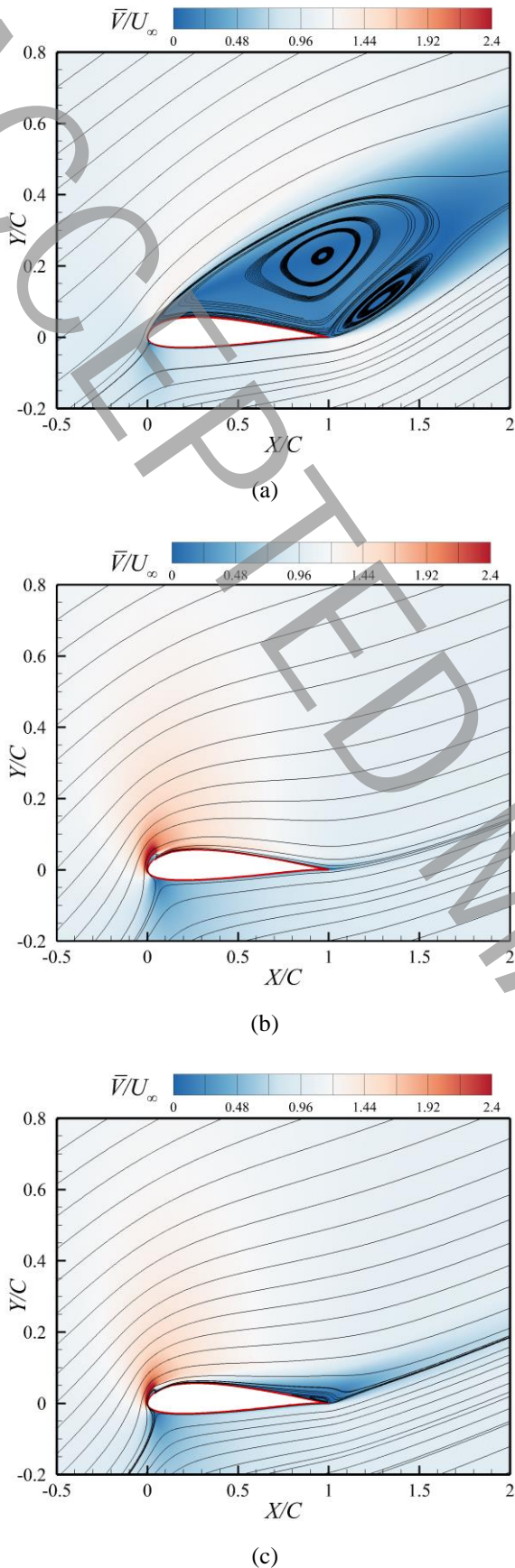


Figure 2. Velocity magnitude contour and streamlines (a) Uncontrolled (b) CBA (c) SJA at Reynolds number of 60,000 and incidence angle of 16°

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