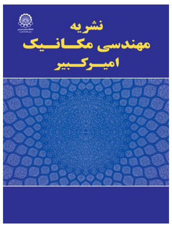


Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(9) (2021) 1141-1144
DOI: 10.22060/mej.2021.19377.7011

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

Dj. Kamari. Kamari, M. Tadjfar*

Turbulence and Multiphase Lab., Department of Aerospace Engineering, Amirkabir University, Tehran, Iran

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, the 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..

Review History:

Received: Jan. 09, 2021
Revised: Apr. 14, 2021
Accepted: Apr. 15, 2021
Available Online: Apr. 18, 2021

Keywords:

Optimization
Active flow control
Synthetic jet
Constant blowing
Genetic algorithms

1- Introduction

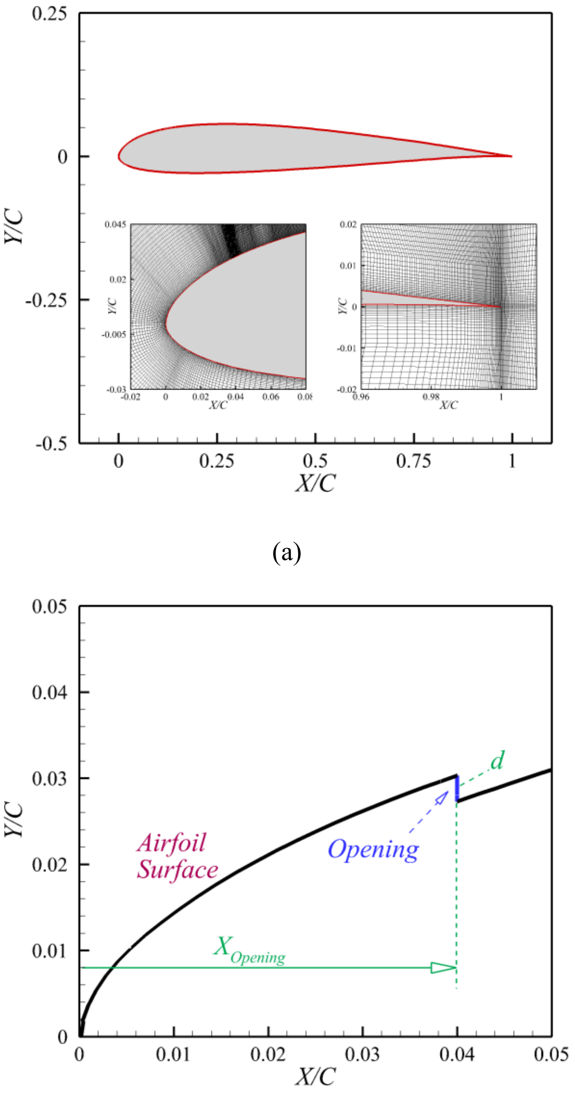
Manipulation of flow pattern to achieve the most desired condition is one of the research interests in fluid mechanics. Different flow control approaches are classified as active or passive methods. Synthetic jets, blowing and suction actuators are categorized as Active Flow Control (AFC) methods while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

Müller-Vahl [1] studied the effectiveness of constant blowing in the 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 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 an 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 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 cycles, 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, the phase difference of the pitching movement, and the 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 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

*Corresponding author's email: mtadjfar@aut.ac.ir



(a)

(b)

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

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 the actuator's performance. The location, the actuation velocity amplitude, the frequency, and the injection angle were considered as design variables.

2- Methodology and Numerical Approach

The optimization algorithm used a 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 Unsteady Reynolds-Averaged Navier-Stokes (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 Computational Fluid Dynamic (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 a suitable convergence was attained.

A 2D Unsteady Reynolds Averaged Navier-Stokes, URANS, accompanied with kω-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 the airfoil to suppress the flow separation. The airfoil geometry, the Tangential to Boundary Layer (TBL) opening configuration, and the structured mesh near the leading and trailing edges were illustrated in Fig. 1.

3- Results and Discussion

An optimization study was performed to control the wide flow separation over an SD7003 airfoil at the incidence of 16° by using both Continuous Blowing Actuator (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 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

1.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 ~ 0.09
L / D	3.697	10.5 ~ 11.4	16.8 ~ 17.6

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 from 2.3 to 4 where the actuator efficiency did not change beyond 2.3.

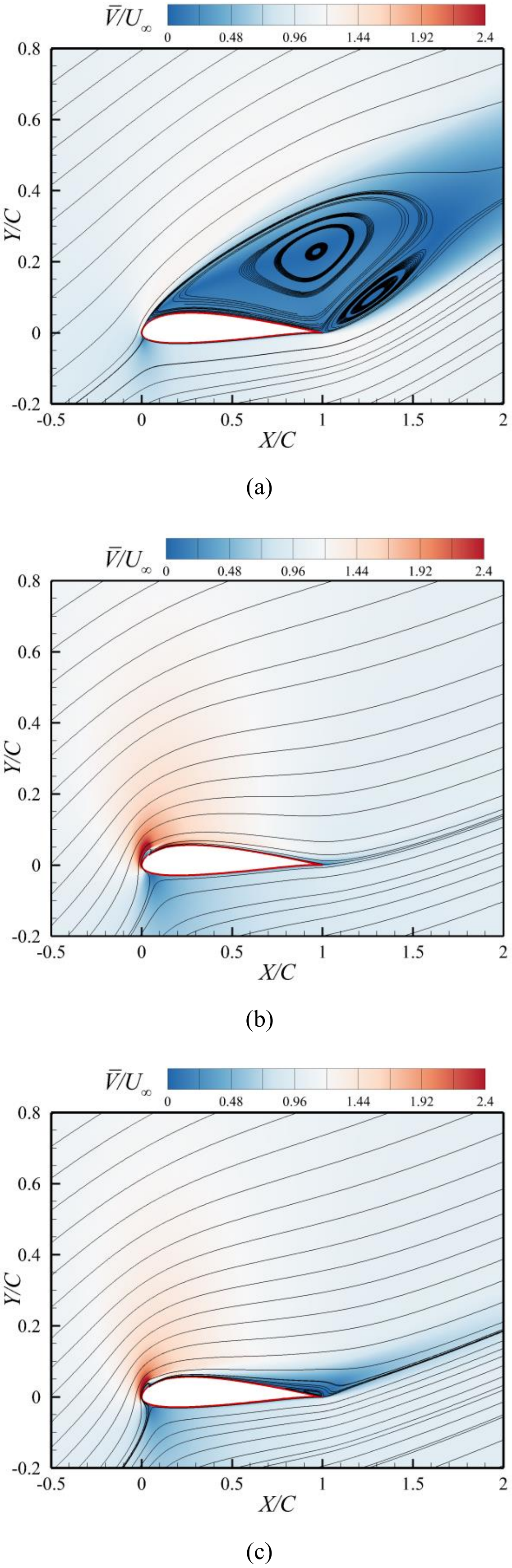
These results implied that the airfoil performance was increased by a factor of 4 in the case of using SJA. Moreover, the CBA is more efficient in lift coefficient increase while SJA is more powerful in drag reduction and performance improvement.

Velocity contours embedded with flow field streamlines are depicted in Fig. 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 a lower blowing momentum coefficient than CBA while it kept the overall performance.

4- Conclusions

An optimization study was conducted to find the optimum operating condition of an airfoil implemented by both CBA and SJA as active flow controllers. These actuators were installed tangentially to the 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 the greater capability in increasing the lift force. Indeed, the required momentum coefficient for preparing the optimum performance using SJA was considerably lower than CBA.



(a)

(b)

(c)

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

References

[1] H.F. Müller-Vahl, C. Strangfeld, C.N. Nayeri, C.O. Paschereit, D. Greenblatt, Control of Thick Airfoil, Deep Dynamic Stall Using Steady Blowing, AIAA Journal, 53(2) (2015) 277-295.

[2] Y. Wang, P. Zhou, J. Yang, Parameters effect of pulsed-blowing over control surface, Aerospace Science and Technology, 58 (2016) 103-115.

[3] S.Z. S. M. Hosseini Baghdad Abadi, M. Rajabi Zargar Abadi, Numerical Investigation of the Effect of Coolant Injection Angle on the Pulsed Film Cooling Effectiveness of Square Wave Flow on Flat, Amirkabir Journal of Mechanical Engineering, 52(64) (2018) 525-532.

[4] M. Tadjfar, E. Asgari, The Role of Frequency and Phase Difference Between the Flow and the Actuation Signal of a Tangential Synthetic Jet on Dynamic Stall Flow Control, Journal of Fluids Engineering, 140(11) (2018) 1-13.

[5] M. Tadjfar, E. Asgari, Active Flow Control of Dynamic Stall by Means of Continuous Jet Flow at Reynolds Number of 1 × 106, Journal of Fluids Engineering, 140(1) (2018) 1-10.

[6] S.H. Kim, C. Kim, Separation control on NACA23012 using synthetic jet, Aerospace Science and Technology, 13(4-5) (2009) 172-182.

[7] R. Duvigneau, M. Visonneau, Simulation and optimization of stall control for an airfoil with a synthetic jet, Aerospace Science and Technology, 10(4) (2006) 279-287.

[8] K. Ekradi, A. Madadi, Performance improvement of a transonic centrifugal compressor impeller with splitter blade by three-dimensional optimization, Energy, 201 (2020) 1-13.

[9] Z.H. Han, K.S. Zhang, W.P. Song, Z.D. Qiao, Optimization of Active Flow Control over an Airfoil Using a Surrogate-Management Framework, Journal of Aircraft, 47(2) (2010) 603-612.

[10] D.J. Zhao, Y.K. Wang, W.W. Cao, P. Zhou, Optimization of Suction Control on an Airfoil Using Multi-island Genetic Algorithm, Procedia Engineering, 99 (2015) 696-702.

HOW TO CITE THIS ARTICLE

D. Kamari, M. Tadjfar, Effect of Start of Injection Timing on Waste Heat Recovery Capacity in a Reactivity Controlled Compression Ignition Engine, Amirkabir J. Mech Eng., 53(9) (2021) 1141-1144.

DOI: 10.22060/mej.2021.19377.7011