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IMPROVING AIRFOIL PERFORMANCE BY DESIGNED BLOWING

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Abstract

Modern trends in the development of urban air vehicles and small-scale unmanned air vehicles require them to be as efficient as possible. One option is to improve their aerodynamic performance by semi-active boundary layer control (BLC) techniques, which are more economic and accessible through 3D printing, such as injection/blowing. Flow control generally serves to reduce BL thickness and friction drag, as well as to delay transition and separation. This computational study investigates and quantifies the change in lift and drag coefficients of NACA 23012 airfoil at the critical angle-of-attack (AoA) at M = 0.18 and Re = 1.8 million. Flow simulations are performed using the finite volume method in ANSYS Fluent. Clean and controlled flows are considered steady, incompressible, and viscous. Equations governing the flow are closed by *k-ω* SST turbulence model. The adopted numerical set-up is validated by available experimental data. Main observations on the possible improvements of aerodynamic performance at a higher angle-of-attack are presented and discussed.

Keywords: NACA 23012, lift, drag, turbulence, blowing.

1. Introduction

Airfoils, main constituents of lifting surfaces, affect the overall aerodynamic performance of flying vehicles. Resulting flows can be controlled to increase aerodynamic efficiency by reducing BL thickness and friction drag, delaying laminar-turbulent transition and preventing or postponing its separation. Numerous flow control techniques have been tried [1]. A relatively reasonable and economic methods are continuous injection or suction (or their combination) that locally change velocity profile and energize the boundary layer [1, 2]. Nowadays, with the advancement of novel production practices, it is possible to design and incorporate a BLC that is structurally simple, does not require any additional moving parts, only locally influences the flow field, and does not significantly increase the total manufacturing and maintenance costs. This work proposes a BLC appropriate for airfoils at higher AoAs. The idea is to suck in the slower flow from the airfoil pressure side, accelerate it through a variable-area passage and blow it along the rear part of the airfoil suction side. This simple solution should be designed for a particular airfoil and flow regime. A well proven NACA 23012 airfoil is chosen as baseline for its reasonably high maximum lift and low profile drag. This paper describes the initial computational study of flows with and without flow control that can be further improved in the future.

2. Methodology

Computational domains around the airfoils are 3D, cylindrical and stretch 10 in radial, and 0.2 chord lengths in spanwise direction. Grids are unstructured with fine resolution near the airfoil walls numbering 8-9 million control volumes for the cases with and without flow control, respectively. All flow simulations are realized by finite volume method in ANSYS Fluent. The flow is considered spatial (2.5D), steady, incompressible, and viscous. Reynolds-averaged Navier-Stokes equations are closed by k-ω SST turbulence model. Velocity of the undisturbed flow is assigned to the inlet boundaries, two sides form a periodic boundary, while no-slip boundary conditions are assumed along the airfoil walls. Pressure-based solver with SIMPLE coupling schemes for pressure and velocity fields are employed. All spatial derivatives are approximated by 2nd order schemes. Computations were performed until reaching the converged values of aerodynamic coefficients (3000 iterations).

3. Results and Discussion

The adopted computational set-up was first validated on the clean configuration through comparison with available experimental data [3, 4]. Although some discrepancies between the two data sets are observed, the trends of aerodynamic coefficients are well captured. Afterwards, some qualitative results were post-processed. Here, only critical AoA $\alpha = 14.4°$ is considered. Figure 1 illustrates the obtained velocity fields around the airfoil without and with semi-active flow control, respectively. It can be observed that the existence of variable-area channel leads to the enlarged zone of accelerated flow near the leading edge, an obvious reduction of the separated zone near the trailing edge as well as considerably narrowed wake. Quantitatively, the values of lift and drag coefficients computed on the clean airfoil are $C_L = 1.36$ and $C_D = 0.0364$, respectively, resulting in lift-to-drag ratio $L/D = 37.2$. On the other hand, the corresponding values obtained on the modified airfoil are $C_L = 1.46$ (7.5% increase), $C_D = 0.0333$ (8.5% decrease) and $L/D = 43.7$, i.e., an increase of nearly 17.5% in lift-to-drag ratio is achieved.

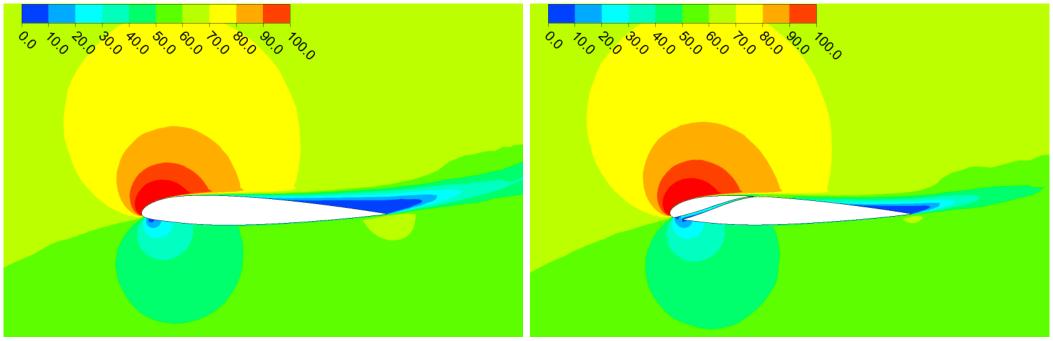

Fig. 1. Velocity contours around airfoils without (left) and with (right) flow control at AoA = 14.4°.

4. Conclusions

Possible changes of airfoil lift and drag coefficients by semi-active boundary layer control are quantified and interesting flow visualizations are presented. Although investigated flow fields are simplified, they provide an insight into the complex flow phenomena occurring in the boundary layer and justify further research studies as well as exploration of different channel geometries.

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