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Parameter Optimization Research on Lift-enhancing of Multi-element Airfoil Using Air-blowing

Yuqin Jiao*, Yan Lu

National Key Laboratory of Science and Technology on Aerodynamic Design and Research, Northwestern Polytechnical University, Xi’an 710072, China

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Abstract

Based on the response surface methodology and the grid method combining with numerical simulation of Reynolds-averaged Navier-Stokes equations, the lift-enhancing optimizations of three-element airfoil parameters and its air-blowing flow control parameters are carried out. The finite volume method is adopted to discretize the Reynolds-averaged Navier-Stokes equations in space, the second-order upwind scheme is used in time advance, and SST $k-\omega$ turbulence model is used to compute turbulence viscosity. The objective function is obtained with the response surface methodology, and the optimal solution is made using nonlinear programming with the grid method. On the base of multi-element airfoil parameter optimization, the influencing parameters of air-blowing effect are analyzed and selected, the optimization design variables are determined as the air-blowing slot locations, angles and air-blowing momentum coefficients, and lift-enhancing aerodynamic optimization of air-blowing flow control parameters on multi-element airfoil is completed. It is shown from the results that the optimization method combining response surface methodology with the grid method is fit for parameter optimization of multi-element airfoil and its flow control with air-blowing on the flap for lift-enhancing; the flow around the multi-element airfoil can be well controlled and its aerodynamic performance is greatly improved, then the maximum lift coefficient achieves 4.9589 which is usually the maximum lift coefficient of the five-element airfoil; after optimization the air-blowing slot angles are of about 20° on the trailing edge flaps and the air-blowing momentum coefficients of slots exist an optimum value.

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Keywords: multi-element airfoil; air-blowing; flow control; numerical simulation; response surface methodology

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* Corresponding author. Tel.: +86-29-88493775-6303; fax: +86-29-88491242.
E-mail address: jiaoyuqin@nwpu.edu.cn

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1. Introduction

The mechanical lift-enhancing device of aircraft is usually constituted of the multi-element airfoil stretching along the span. In order to satisfy the request of the lift coefficient when the aircraft take off or land, the high lift devices of some large aircrafts even use the five-element airfoil, which make the control mechanism so complex that the no load weight of the aircraft rises. The surface air-blowing control is a kind of the active flow control (abbreviate: AFC). The use of AFC in improving the multi-element airfoil flow can reduce the no load weight through reducing the number of the element of the multi-element airfoil and simplifying the control mechanism, which has very important engineering application prospects. Shmilovich and Yadlin [1]，Meunier and Dandois [2]， Meunier [3] ，DeSalvo, Whalen and Glezer [4] studied the lift-enhancing and flow of airfoil with the no slot hinged drooped leading edge and the no slot hinged trailing edge flap using air-blowing flow control. Some studies include the relevant control parameter optimization. It is prove that the lift coefficient of airfoil with the no slop hinged drooped leading edge and the no slot hinged trailing edge flap under the air-blowing control can achieve the value of the reference initial multi-element airfoil. Shmilovich and Yadlin [5] found that the zero mass jet active flow control used in upper surface of the traditional multi-element high-lift device can well improve the aerodynamic performance of the device, the linear section lift coefficient approaches the inviscid value and the maximum lift coefficient has greatly improved. Jiao et al [6] studied the mechanism that the jet flow control can further improve the lift in the two-element airfoil high lift device by experiments. Tong et al [7] carried out the preliminary exploration of blowing control methods of the multi-element airfoil flow with numerical simulation. These studies also demonstrated the air-blowing flow control is very promising for application.

Response surface methodology (RSM) has the following advantages compared with some other direct optimization methods. Firstly, response surface methodology can be expected to get the global approximate optimal solution. Secondly, because the form of response surface method in use is invariable with the idiographic problem, the optimization design process for different objective functions and constraints needn't additional computation. Thirdly, response surface methodology is fit for multi-disciplinary multi-objective multi-constrained optimization design. By selecting the regression model, the complex response relationship can be fitted. Many scholars have successfully used response surface methodology in the airfoil and wing aerodynamic optimization design and aerodynamic/ structural integrated optimization design [8-10].

Previous studies have shown that the air-blowing control can well improve the aerodynamic lift-enhancing effect of the multi-element airfoil. In this paper, on the base of the multi-element airfoil parameter optimization, the influencing parameters of air-blowing control effect are analyzed, the optimization design variables are determined and the aerodynamic lift-enhancing optimization of air-blowing flow control parameters on multi-element airfoil is completed using response surface methodology.

2. Numerical simulation and optimization method

2.1. Governing equations and numerical simulation

The governing equations of the steady flow of the multi-element airfoil are the integral conservation form of two-dimensional Reynolds average Navier-Stokes equations:

$$\frac{\partial}{\partial t}\iiint_V \mathbf{W}dV + \iint_{\partial V}\mathbf{H}\bullet\mathbf{n}dS = \iint_{\partial V}\mathbf{H}_\mathbf{V}\bullet\mathbf{n}dS \tag{1}$$

where V is an arbitrary control unit, ∂V is the control unit boundary, $\mathbf{n}$ is a unit vector normal to the surface of control unit, the other variables are described in the relevant references. The finite volume method [11] is adopted to discretize the governing equations in space and the second-order upwind scheme is used in time advance. SST $k-\omega$ turbulence model is used to compute turbulence viscosity. This model is applicable to solid wall turbulent flow with laminar flow simultaneously, because it can well deal with the near-wall flow problem under low Reynolds number [12]. For boundary conditions, the velocity on object surface satisfy no-slip condition, that is,