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Numerical Investigation of The Effect of Plasma Actuator on Film Cooling Effectiveness

S. Dolati, N. Amanifard, H. Mohaddes Deylami*

Faculty of Technology and Engineering, Guilan University, Guilan, Iran

ABSTRACT: In this paper, a 2-D numerical approach was conducted for analyzing incompressible, turbulent and steady flow and thermal fields of the film cooling through using plasma actuator over a flat plate model. Simulations were implemented using non uniform structured grid and low-Re k-ε turbulence model. The present study was analyzed at 35 degree injection angle, hole length-to-diameter ratio (*L/D*) 5 and density ratio (DR) 1.2, with the present of plasma actuator. The flow and temperature fields were investigated with different blowing ratios and applied voltages. In addition, the effect of geometry parameters and position of plasma actuator has been studied on the adiabatic film cooling effectiveness. Based on the numerical analysis results, the effect of plasma actuator on film cooling effectiveness is better in lower blowing ratios and higher applied voltages and positions near the film hole. Unlike other similar works in this filed, this study has examined geometry parameters of plasma actuator and their effect on adiabatic film cooling effectiveness. These parameters include electrode gap distance and dielectric thickness. The results show that higher thickness has low effect on improving of film cooling effectiveness. But when electrode gap distance decreases, the performance of plasma actuator and average effectiveness enhances.

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1- Introduction

Thermal efficiency and power output of modern gas turbine engines can be increased through higher combustor exit temperatures. To achieve at the aim of protecting blade material from the extreme temperatures, development of materials and efficient cooling methods are required which leads to maximum component life. Among different cooling methods, film cooling is an advanced technology which can be applied to gas turbines in order to protect the surface of blades from thermal stresses resultant of hot gases arriving from the combustion chamber. The coolant air forms a thin, insulating protective layer of coolant gas between the hot mainstream gas and the turbine blade. This technique reduces the heat transfer amount and increases the turbine overall efficiency as a consequence [1-3]. Flow control techniques play an important role as they can balance the contradiction between keeping the quality of flow field and improving cooling effectiveness, in contrast with common configuration design [4]. The plasma actuators are a new type which consist of an asymmetric electrode arrangement (one exposed and one encapsulated) separated by a dielectric medium [5-7].

The goal of this paper is to study film cooling performance for a cylindrical hole with plasma aerodynamic actuator. The present study was analyzed at 35 degree injection angle, hole length-to-diameter ratio (*L/D*) 5 and density ratio (*DR*) 1.2, with the present of plasma actuator. The flow and temperature fields were investigated with different blowing ratios, applied voltages and position of plasma actuator. Unlike other researches, the effect of geometry parameters of plasma actuator as electrode gap distance and dielectric thickness has been studied on the adiabatic film cooling effectiveness.

Corresponding author, E-mail: hmohaddesd@guilan.ac.ir

2- Geometry

Fig. 1 shows the computational domain. The geometry was built up and meshed using GAMBIT software.

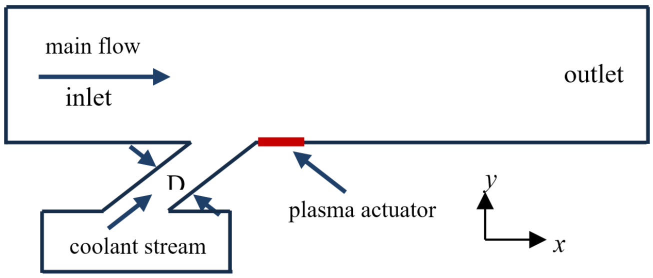

Figure 1. Computational domain geometry

3- Governing Equations and Turbulence Modeling

In this research, the Launder-Sharma Low-*Re* *k-ε* model is adopted for all case studies. System of equations governing the flow and thermal fields including continuity, momentum and energy equations and also transport equations of k and ε, are as follows:

$$\frac{\partial(\rho u_i)}{\partial x_i}=0 \quad (1)$$

$$\frac{\partial(\rho u_i u_j)}{\partial x_i}=-\frac{\partial P}{\partial x_j}+\frac{\partial}{\partial x_i}\left[(\mu+\mu_t)\frac{\partial u_j}{\partial x_i}\right]+\vec{f}_b \quad (2)$$

$$\frac{\partial(\rho u_i T)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\frac{\mu}{\Pr}+\frac{\mu_t}{\Pr_t}\right)\frac{\partial T}{\partial x_j}\right] \quad (3)$$

$$\frac{\partial}{\partial x_i}\left[\rho k u_i - \left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] = P - \rho\varepsilon - \rho D \tag{4}$$

$$\frac{\partial}{\partial x_i}\left[\rho \varepsilon u_i - \left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] = \left(C_{\varepsilon 1} f_1 p - C_{\varepsilon 2} f_2 \rho\varepsilon\right)\frac{\varepsilon}{k} - \rho E \tag{5}$$

The effect of the plasma actuator on the external flow is incorporated into momentum equation as a body force vector.

4- Results and Discussion

Fig. 2 shows the flow field of secondary stream before and after using plasma actuator. The secondary flow field is changed significantly when actuator is exerted at the exit downstream of the film hole. Because of the nearby air is ionized and produced a plasma layer.

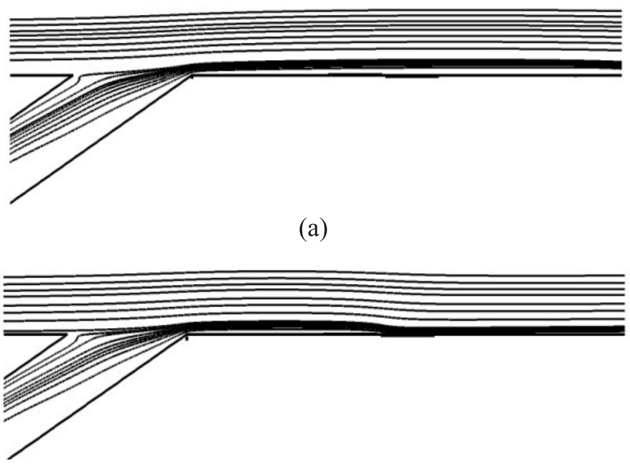

Figure 2. Stream lines from the film hole, (a) without plasma actuator, (b) with plasma actuator

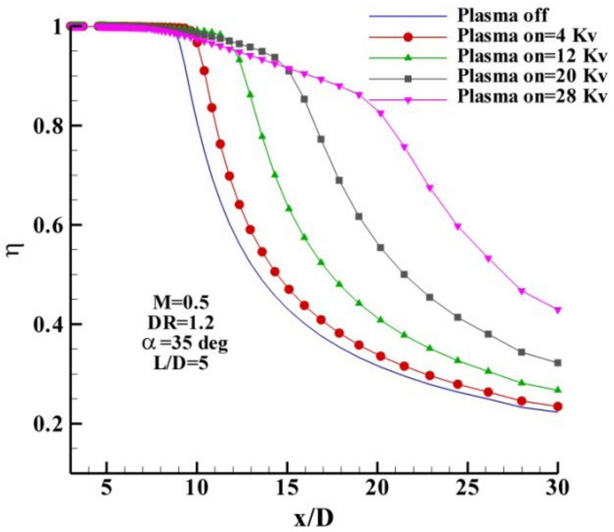

Figure 3. Film cooling effectiveness under different voltages

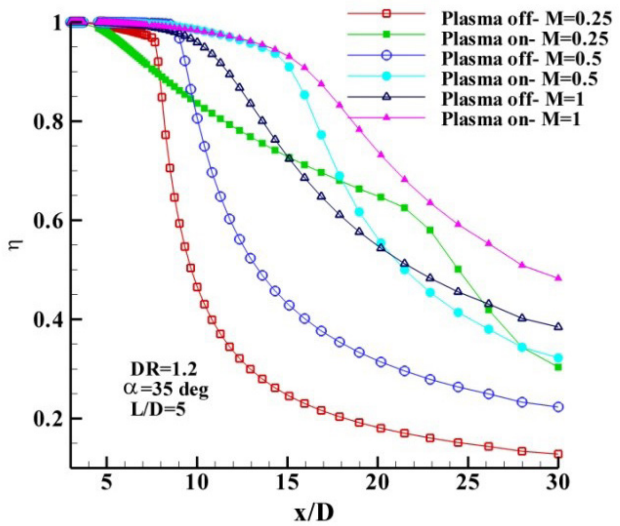

Figure 4. Film cooling effectiveness in different blowing ratios

Fig. 3 shows film cooling effectiveness with different applied voltage into the plasma actuator at the downstream exit of the film hole. In higher voltages, film cooling effectiveness increases. But, because of the heating effect of plasma near the hole, effectiveness has a significant drop. Plasma actuator as shown in Fig. 4 can improve film cooling effect in different blowing ratios. At the blowing ratio 0.25, 0.5 and 1, the increment of average film cooling effectiveness is from 91.32, 94.51 and 96.82 %, to 95.21, 97.44 and 98.17 % respectively. To investigate the best actuator position for higher effectiveness, plasma actuator set at different positions *X/D*=0, 2 and 7 along the wall was simulated. Based on results, the position of the actuator has great effect on the film cooling effectiveness and for near and *X/D*=2, effectiveness is better. The effect of dielectric thickness was investigated for values 0.01, 0.005, 0.02 and 0.1*D*. In thicker dielectric, film cooling effectiveness increases slowly. Also gap distance influences generated body force. The measurements for gap distance=0.1, 0.5, 1, 1.5 and 2mm shown in Fig. 5. Maximum effectiveness occurs for a small gap distance.

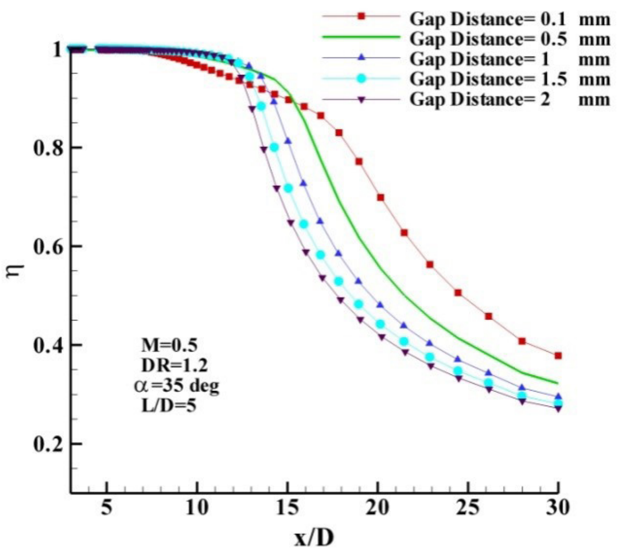

Figure 5. Film cooling effectiveness with different positions of actuator

5- Conclusions

A detailed study on the effects of plasma aerodynamic actuator on improving film cooling effectiveness under different conditions and parameters was presented. With actuator, the cooling effectiveness is better than without. In lower blowing ratio and higher voltage input, better film cooling effectiveness is acquired. Also thicker dielectric and less gap distance improve effectiveness.

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