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Validation of three dimensional film cooling modeling on convex surface for gas turbine blade ☆

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ABSTRACT

In this study, three dimensional computational predictions on the film cooling performance of single row and simple cylinder on the convex surface have been studied and compared with corresponding experimental data reported in the literature to validate the model. This computational prediction serves as the baseline for future studies of optimization in determining the film cooling effectiveness. Realizable κ–ϵ turbulent model has been employed and energy equation has been solved. Grid independence study has been fulfilled using two kinds of meshing approach for the plenum and the cooling holes. Results of grid independence study showed that fine meshed plenum and cylinders of tetrahedral grids case have provide a good agreement with the related experimental data. Study of temperature ratio between the coolant and mainstream hot gas T_c/T_g has been performed using four values of temperature ratios that are 0.5, 0.6, 0.7, and 0.8. In all of these tests the mainstream duct of the models was generated with multigrid hexahedral mesh. Based on the heat-mass transfer analogy, results of this study showed good agreement of the film cooling effectiveness and temperature distribution in comparison to the related experimental data. The case in which combination of both plenum and cylinders in one volume with tetrahedral fine mesh generation and temperature ratio of $T_c/T_g = 0.6$ was found to be in good agreement with the experimental data among all of the other models. Computational prediction results have found an agreement with the experimental data, thus the approach is verified.

1. Introduction

Gas turbines are widely employed in many applications. The demand for higher overall efficiency and high power output in gas turbine renders the need for increase in turbine entry temperature. However the engine operating temperature is beyond the permissible metal temperature hence reduces the life of turbine blade. In order to maintain an acceptable temperature level of gas turbine blade, cooling is an inevitable issue to provide safe operation under extreme heat load conditions. Film cooling is widely used as a cooling method where the coolant (usually air) is injected onto the surface of the turbine blade to produce a thin protective film so that the adjacent surface temperature is maintained at an acceptable temperature level. This method will consequently rescue the turbine blade from failure.

The heat-mass transfer analogy was used to measure the adiabatic film cooling effectiveness on the blade surface. The adiabatic film cooling effectiveness (η) is an excellent indicator of film cooling performance and defined as:

$$\eta = \frac{T_g - T_{aw}}{T_g - T_c}. \tag{1}$$

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The heat flux ratio (q''/q''_0) according to the recent study by Wang and Zhao [2] defined as:

$$\frac{q''}{q''_0} = \frac{h_{af}}{h_o}\left(1 - \frac{\eta}{\varphi_o}\right) + \frac{h_{af}}{h_o}\cdot\frac{\varphi - \varphi_o}{\varphi_o}. \tag{2}$$

The study of the turbine blade film cooling requires investigation of various flow and geometrical parameters. Wright et al. [3] studied the effect of density ratio on flat plate film cooling. Three separate flat plates containing cylindrical holes, fan shaped holes and laidback fan shaped holes have been employed. The effect of density ratio on the film cooling effectiveness is coupled with varying blowing ratio, freestream turbulence intensity and film hole geometry. The main finding of their study is that in all cases as the freestream turbulence intensity increases the film cooling effectiveness decreases; this effect is reduced as the blowing ratio increases for all three film cooling hole configurations.

Recent study performed by Soe et al. [4] found that antivortex cooling holes have better effectiveness than cylindrical hole because the interaction of side hole vortices leads to reduce the main hole vorticity. Lee and Kim [5] numerically optimized a laidback fan-shaped hole film cooling. Their work has been performed to evaluate the effects of geometric variables of laidback fan-shape hole on film cooling. They evaluated the effects of injection angle of the hole, the