A STUDY ON FILM COOLING PERFORMANCE PARAMETERS OF GAS TURBINE BLADES

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Abstract— In pursuit of achieving higher output power and higher efficiency for the gas turbine, various cooling methods have been adopted to maintain the acceptable turbine blade temperature. Film cooling is one such cooling technique most commonly used with high complexity. This paper reports important work previously done on different aspects of film cooling like working phenomena and the dominant factors affecting like hole geometry and configurations, blowing ratio, density ratio, etc. The recent researchers used the CFD simulation practices to obtain the comparable results with experimental data which is focused in the literature review of this paper. The concluding section comprises of the summary from all the researches mentioned in the paper.

Keywords— Gas Turbine, Film Cooling, Heat Transfer, CFD, Anti-vortex, Film Cooling Effectiveness, etc.

I. INTRODUCTION

Gas turbines are widely used in various industrial applications for power producing purposes. There has been a constant effort to increase the power output and efficiency over the years which requires higher turbine inlet temperature. But in pursuit of achieving higher power output and efficiency, the higher turbine inlet temperature causes detrimental effect on the life of the turbine blade and also on its auxiliary components. Hence, providing an efficient cooling system for high performance of the gas turbine has always been the primary concern over the years. Various cooling techniques are used to tackle the mainstream hot gases like liquid cooling, impingement cooling, convective cooling, etc but the most commonly used technique is of the film cooling. Film cooling phenomena reduces the heat transfer from the mainstream hot gases to the blade surface by forming a coolant film layer. There are various parameters affecting film cooling like blowing ratio, density ratio, hole geometry and configuration, mass flux ratio, etc. Different combinations of these parameters give different results in terms of cooling effectiveness. For getting better cooling performance, cooling holes with different configurations can be used.

Fig. no. 1. Branched hole configuration [1]
There has been previous study done mainly on cooling performance using cylindrical holes. But the coolant exiting the main hole generates kidney-shaped vortices which creates turbulence. The branched hole configuration overcomes this obstacle by countering the vortices generated by the main hole and allows better attachment of the coolant layer downstreams.

II. LITERATURE REVIEW

The research work conducted by J. H. Liu et al. [2] aimed at modeling the film cooling flow of a turbine vane with endwall film cooling, showerhead film cooling, and pressure/suction side film cooling simultaneously by using conjugate heat transfer. A method was developed by adding endwall film cooling domain and the film cooling flow was simulated by CFD. The authors made a comparison of the case with or without solid transfer. The results from the study showed highest film cooling effectiveness being achieved immediately downstream the holes. Authors work does not focus on the hole geometry and concentrates on hole rows configuration only. The results are based on only film cooling effectiveness and not on the structural analysis and creep life of blade.

Shane Haydt et al [3], had studied “Cooling Effectiveness For a Shaped Film Cooling Hole at a range of Compound Angles”. The compound angles of holes were varied by 0° to 60° with a regular interval of 15° respectively and additionally two pitchwise spacings of P/D=3 and 6 were tested to examine the effect of hole-to-hole interaction. Higher compound angles enabled higher blowing ratios. For holes with a compound angle less than or equal to 30°, area-averaged effectiveness was decreased with an increasing streamwise component of blowing ratio, defined as the cosine of blowing ratio whereas for 45° and 60° compound angle holes’ area-averaged effectiveness was relatively insensitive to blowing ratio. A hole with a smaller pitch of P/D=3 had higher effectiveness than that same hole with a pitch of P/D=6, and this applies for all compound angles and blowing ratios. The lateral motion of the coolant jet was also quantified, both from the experimental data and the CFD prediction, and as expected, holes with a higher compound angle and higher blowing ratio have greater lateral motion, which generally also promotes hole-to-hole interaction.

Seyed M. Ghoreyshi and Meinhard T. Schobeiri [4] investigated two different approaches in their study to control and reduce the temperature on the stator blade surface of the Ultra- High Efficiency Gas Turbine (UHEGT).The first approach was of indexing the fuel injectors in which the position of the fuel injectors is adjusted with respect to each other and the stator blades. The second approach was of film cooling. Four configurations were studied with the help of CFD. The results showed that the second configuration using indexing approach proves to be the best case for controlling stator blade temperature followed by fourth configuration using film cooling.

Another study of S. Ramesh et al. [5] focused on Film cooling performance of Tripod Antivortex Injection holes over both the pressure and the suction surfaces of Nozzle Guide Vane. The purpose was to testify performance of tripod hole design on suction and pressure sides of GE E3 first stage vane in cascade also the film cooling effectiveness was found at four different blowing ratios. The results showed that tripod holes with and without shaped exits provided much higher film effectiveness than cylindrical and slightly higher effectiveness than shaped exit holes using 50% lesser cooling air while operating at same blowing ratios. Overall, antivortex holes (with shaping) served best design at blowing ratios 1.0 & 2.0.
Stephen A. Hayes et al. [6] experimentally investigated the effectiveness of a multi-hole cooling concept, the anti-vortex hole (AVH) geometry, and analyzed the effects of freestream turbulence on cooling performance at varying blowing ratios. The authors used a transient infrared thermography technique to study the film cooling effectiveness and heat transfer coefficient through the anti-vortex hole geometry. They investigated the AVH geometry for three turbulence intensities of 1, 7.5 and 11.7% at blowing ratios of 0.5, 1.0, 1.5 and 2.0 for a total of twelve different conditions. The results from the study showed that turbulence intensity after a certain amount will result in a higher heat transfer coefficient which directly tends to increase the heat load. The authors suggest that the AVH geometry can be employed in the real gas turbine applications increasing the longevity of the components.

The aim of the research by Timothy W. Repko et al. [7] was to numerically simulate the flat plate film cooling from a multi-exit hole configuration. The effect of freestream turbulence intensity was investigated when analyzing the jet interaction with the cross flow and the corresponding temperatures at the wall. The authors used both steady and unsteady Reynolds Average Navier Stokes (RANS and URANS) Computational Fluid Dynamics (CFD) formulations. The jet interaction with the multi-exit hole was numerically simulated at a high blowing ratio (M=2.0) and density ratio (D.R=2.0). They concluded that as the turbulence intensity is increased, the cooling flow will stay more attached to the wall and the film cooling effectiveness increased in case of the Anti-vortex holes.

Wenjing Gao et al. [8] studied the film cooling performances of the cylindrical film cooling holes with different compound angles on the turbine blade leading edge model. Several numerical simulation results are compared with available experimental data, under different blowing ratios. Five different film cooling hole compound angles in the transverse direction and four different blowing ratios were studied. The results showed that the film cooling effectiveness increased with blowing ratio and then slightly decreased. In this study, a blunt body with semi-cylindrical leading edge and a flat afterbody is used. So the results obtained don't ensure that same results will be obtained in the actual turbine.

The effect of the angle between primary and auxiliary film cooling holes of an anti-vortex hole was analytically...
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studied by Youngii Moon et al. [9] on the film cooling effectiveness. The study also considered the effect of blowing ratio and the mainstream turbulence intensity. The analysis was performed with the help of commercial software CFX. The angle between primary and auxiliary hole was varied from 0 to 75 degrees and the blowing ratio from 0.25 to 2.0. The anti-vortex holes showed better performance than cylindrical holes and the angle between primary and auxiliary hole of AVH strongly affects the film cooling effectiveness.

Another study by Kevin Liu et al. [10] focused on the effect of coolant density on turbine blade film-cooling with axial and compound shaped holes. Film-cooling effectiveness was examined by varying three critical flow parameters: coolant blowing ratio, coolant-to-mainstream density ratio, and freestream turbulence intensity. Coolant density ratios 1.0, 1.5, and 2.0 along with average blowing ratio and the turbulence intensity of 1.5% and 10.5%, respectively has been considered in their study. Overall, the compound angle design performed better film coverage than axial angle. And also it was found that greater coolant-to-mainstream density ratio results in lower coolant-to-mainstream momentum and prevents coolant to lift-off. On the pressure side, significant enhancement of effectiveness was observed as density ratio increased from 1.0 to 1.5 which then decreased when the ratio rose further up to 2.0.

Dhungel et al. [1] had studied film cooling performance for a row of cylindrical holes each supplemented with two symmetrical anti-vortex holes, which branch out from the main holes. The hole design was intended to counteract the detrimental vorticity associated with standard circular cross-section film cooling holes. Detailed film cooling effectiveness and heat transfer coefficients were obtained by performing experiments at a single mainstream Reynolds number of 9683 based on the freestream velocity and film hole diameter at four different coolant-to-mainstream blowing ratios of 0.5, 1, 1.5, and 2 and using the transient IR thermography technique. When the anti-vortex holes are nearer the primary film cooling holes and are developing from the base of the primary holes, better film cooling is accomplished as compared to other anti-vortex hole orientations. When the anti-vortex holes are laid back in the upstream region, film cooling diminishes considerably.

Dorrington et al. [11] investigated film cooling adiabatic effectiveness for various configurations of coolant holes embedded in shallow transverse trenches or circular and elliptical shaped depressions. They conducted various tests on the suction side of a simulated vane at a downstream location where the pressure gradient and curvature effects were small. For the transverse trench, effects of the trench width with varying depths, the trench wall angle, and the pitch between holes within the trench were investigated with trench depths that ranged from 0.5d to 1d. The shallow trench configuration was found to have a critical depth of 0.75d, with relatively improved film effectiveness performance as the trench was increased to this depth. Increasing the trench depth above 0.75d resulted in less increase in performance. The deeper trenches which were greater than 0.75d were less sensitive than the 0.5d trench to increasing trench width when achieved comparable performance for trench widths of 2d and 3d. Comparison of the trench performance with a typical shaped hole configuration showed that film effectiveness for the trench was similar to that of the shaped holes.

Assessment of various film-cooling configurations was studied by J. Dittmar et al. [12] which included shaped and compound angle holes. In total, four different film-cooling hole configurations are investigated: a single row of fanshaped holes with a compound injection angle, a single
row of fanshaped holes without a compound injection angle, a double row of cylindrical holes in staggered arrangement, a double row of discrete slots in staggered arrangement. All holes were inclined 45 deg with respect to the model’s surface. It was found that all configurations showed similar film-cooling effectiveness at low blowing ratios. In case of the fan-shaped holes with compound angle injection, a strong influence of the cooling air crossflow direction has been observed for all blowing rates. Fan-shaped holes provide good effectiveness values even at high blowing rates. The double row of discrete slots showed the best effectiveness results at high blowing rates for all the investigated configurations.

III. CONCLUSIONS

Film cooling technique is an important method which can aid in controlling and reducing the blade surface temperature of a gas turbine. The combination of different parameters affecting film cooling performance like blowing ratio, density ratio, hole geometry and configuration, etc. should be chosen carefully to obtain desired results. Through the studied researches, it can be clearly observed that the operating conditions and the hole geometry must be known precisely to access the cooling performance of a given configuration. A comprehensive study from the previous research studies indicate that the cooling hole geometry and its various configurations played a key role in deciding the cooling effectiveness of the gas turbine blade. Amongst different configurations of cooling holes, the anti-vortex holes proved to be more effective in improving the cooling performance than cylindrical holes.

IV. REFERENCES


