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Compound Cooling Holes for Film Cooling of Combustor Simulator: A Review

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Abstract – *Gas turbine cooling can be classified into two different schemes; internal and external cooling. In the internal cooling method, the coolant provided by compressor is forced into the cooling flow circuits inside turbine components. Meanwhile, for the external cooling method, the injected coolant is directly perfused from coolant manifold to save downstream components from hot gases. Furthermore, in the latter coolant scheme, coolant is used to quell the heat transfer from hot gas stream to a component. There are several ways in external cooling. Film cooling is one of the best cooling systems for the application on gas turbine blades. This study concentrates on the comparison of experimental, computational and numerical investigations of advanced film cooling performance for cylindrical holes at different angles and different blowing ratios in modern gas turbines.*

Keywords: Film cooling, Compound cooling holes, Dilution holes, Combustor end wall, Cylindrical cooling holes

1.0 INTRODUCTION

Continuous improvements in the performance of film cooling, as well as various internal and external cooling techniques, are utilized to reduce the temperature of blade material below its melting point. One of the best cooling techniques to protect critical components of gas turbine is called film cooling with compound angle. According to Yiping [1], the compound angle injection hole has two injection angles as shown in Fig. 1. Inclination angle (α) is defined as the angle between injection vector and its projection on the x–z plane, whereas orientation angle (β) is defined as the angle between stream wise direction and the projection of injection vector on the x–z plane. In a compound angle orientation system, coolant is injected with a span wise momentum, which provides more uniform film coverage and shows higher heat transfer coefficient enhancement.

2.0 INLINE AND STAGGERED ARRANGEMENT MODELS

The effect of using various injection holes arrangements clearly shows that the location of compound cooling angle on the performance of film cooling is noticeable. Inline and staggered arrangement models are some of the best methods to enhance the performance. Following to this paper the results of several investigations over film cooling effectiveness and heat transfer characteristics of compound angle holes are cited.

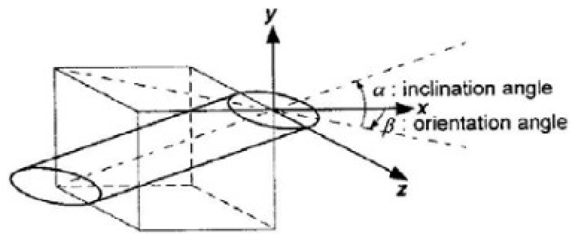

Figure 1: Compound Hole Configuration

Jurban et al. [2] presented the influence of two staggered rows of cooling holes on film cooling effectiveness and heat transfer. Fig. 2 shows that the first scheme (a) includes a combination of one row of simple holes and one row of compound holes, and the second scheme (b) consists of staggered compound cooling holes. The results declared that the best film cooling effectiveness was achieved by using the staggered compound holes, and it was much better than inline compound angle holes and simple angle holes. This was also confirmed by Maiteh and Jubran [3]. The effect of the pattern which included a combination of one row compound holes and one row axial holes was completely related to the placement of the rows.

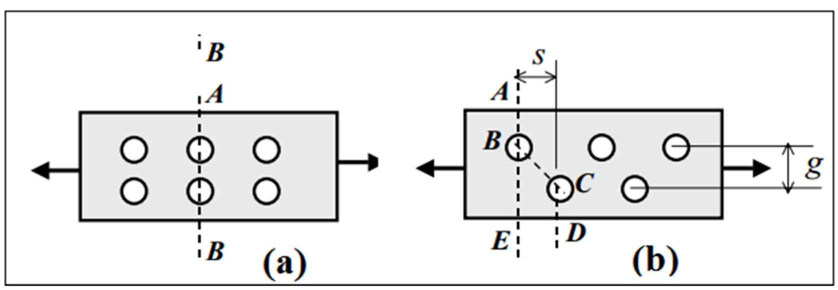

Figure 2: Two-dimensional inline and staggered arrangements models

Maiteh et al. [3] investigated the effect of pressure gradient on film cooling performance. It was observed that the two staggered rows arrangement of compound angle injection holes tended to provide better and more uniform cooling protection than that of the two inline rows of compound angle injection holes. The effect of the pattern, which included a combination of one row compound holes and one row axial holes, was completely related to the placement of the rows.

Ligrani et al. [4, 5] studied the effect of compound angle injection for a single row and two staggered rows of holes to provide the first data related to compound angle holes injection. They indicated that compound angle injection improved film cooling protection significantly compared to the simple angle hole while keeping all other parameters constant.

3.0 EXPERIMENTAL PROCEDURE

This section presented the results of some investigation on film cooling effectiveness and heat transfer characteristics of compound angle holes performance with different orientation angle holes of injected jet over a flat surface. Aga et al. [6], Jubran et al. [7], Han et al. [8] and I-Chien et al. [9] investigated the effects of lateral angle, blowing ratio and density ratio on the blade leading edge film cooling. The major finding from this study was that at elevated compound angles of 60º and 90º, the average adiabatic film cooling effectiveness was two times higher than that of streamwise injection, especially at high blowing ratios. In addition, increasing high compound angles enhanced the jet free stream interaction and as a result, raised the normalized heat transfer coefficient. Nasir et al. [10] stated that increasing compound angle holes affect both heat transfer and film cooling effectiveness.

Sang et al. [11] determined the thermal field at the aft position of a row compound injection holes under different orientation angles and blowing ratios. The results showed that orientation angle increased for a prepared uniform spanwise field and thus modified film cooling. Furthermore, the effect of compound angle holes was more noticeable especially at an orientation angle of higher than 60º and blowing ratio more than unity.

Shine et al. [12] investigated the effects of different coolant configuration as the length of cooling holes and the uniformity of film cooling depend on the liquid or gaseous coolants on cooling performance. The results declared that at low blowing ratios, there was no difference between the effects of different coolants on cooling. At high blowing ratios, the compound angle had a noticeable effect on cooling compared to the case without compound holes. The maximum film cooling effectiveness was achieved at compound angles of 30°-10°, while the effect of compound angle of 45°-10° was not remarkable.

Using the liquid crystal technique, Nasir et al. [13] studied the effects of parallel tabs, -45 oriented downward tabs and +45 oriented upward tabs on the film cooling performance from one row cylindrical holes. They showed that the upward oriented tabs had no significant effect and reduced the film cooling performance. To enhance the tab effectiveness, tabs should interact with the coolant injected from the cooling holes rather than cross flow. Using horizontal and downward oriented tabs increased the heat transfer coefficient, but the increased value of film cooling effectiveness was more than the heat transfer enhancement.

Goldstein et al. [14] constructed a test plate simulator which contained one row of short holes with an inclination angle of 35º and compound angle of 45º. They noticed the effects of wide range of blowing ratios from M=0.50 to M=2.0 and fixed density ratio of 1.0. The main finding of this study was for compound cooling holes, the injected flow attached to the surface at small blowing ratios due to the high mixing between the main flow and the jets on the +Z side, thereby reduced the liftoff effect particularly at high blowing rates in comparison with the jet liftoff for streamwise injection at small blowing ratios.

Gritsch et al. [15] took discharge coefficient measurements of traditional injection holes at inclination angles of 30º, 45º and 90º and orientation angles of 0º, 45º and 90º. The results indicated that the orientation or inclination angle variation was dominated on the losses at the inlet of holes compared to injection holes exit. The increase of orientation or inclination angle enhanced losses at the inlet of cooling holes and reduced discharge coefficient. At the end of injection holes, the moderate inclination or orientation angle enhancement caused flow losses.

4.0 NUMERICAL PROCEDURE

Zhang et al. [16] considered computational results of flow behavior in different parts of a stationary gas turbine vane at blowing ratio of 1.50 and compound holes application at the leading edge by using the LES model. The results declared that the suitable arrangement of compound angle holes produced the best cooling condition in both pressure and suction sides of turbine vane. Stitzel et al. [17] showed that a pair of counter-rotating vortexes was produced sooner than that on the suction side. On the pressure surface, the central part of vortex was away from blade wall. In addition, the area influence of vortex was noticeable as well. Furthermore, compound angle holes enhanced the total pressure in comparison with axial holes. Lin and Shih [18] showed that a combination of shear layer vortexes, horseshoe vortexes and a pair of counter-rotating vortexes was developed due to the reciprocity among mainstream flow and coolant from turbine cooling holes.

Graf et al. [19] used a specific LES model to simulate different arrangement of cooling holes to prepare higher film cooling performance. They used Navier-Stokes equation to simulate the compressible flow and Synthetic-Eddy technique for modeling of turbulent reflection production. The film-cooling simulation presented that the plenum inflow condition provided a mean steady state at the coolant ejection positions, and a good match of the key quantity of film cooling (i.e. cooling effectiveness) was obtained between simulation and experiment.

Jung and Young [20] found that for compound angle of 0º, the maximum film cooling effectiveness was observed at the center point (Z/D=0), and for compound angle of 60º, the best film cooling performance was identified on the right side of the vortex.

By using TDM (three-dimensional volume methods) and multi-block methods, Azzi and Jurban [21] studied the adiabatic film cooling effectiveness under four different lateral angles. They found that the optimum film cooling performance was achieved at an inclined injection angle of 25º.

5.0 CONCLUSSION

Based on the investigations done by three different methods i.e., experimental, numerical and computational, it can be concluded that the effectiveness of configuration cooling holes on film cooling performance is very important and compound angle cooling holes provide better protection compared when simple angle cooling holes were used for injection. Using staggered rows arrangement of compound angle injection cooling holes tended to provide better and more uniform cooling than when inline compound angle holes were used and at high blowing ratios and angles, compound angle had a noticeable effect on cooling compared to the case without compound holes.

REFERENCES

[1] Y. Lu, Effect of hole configurations on film cooling from cylindrical inclined holes for the application to gas turbine blades, PhD thesis, Louisiana State University, 2007.

[2] B.A. Jubran, B.Y. Maiteh, Film cooling and heat transfer from a combination of two rows of simple and/or compound angle holes in inline and/or staggered configuration, Heat Mass Transfer 34 (1999) 495-502.

[3] B.Y. Maiteh, B.A. Jubran, Effects of pressure gradient on film cooling effectiveness from two rows of simple and compound angle holes in combination, Energy Conversion and Management 45 (2004) 1457-1469.

[4] P.M. Ligrani, J.M. Wigle, S. Ciriello, S.W. Jackson, Film-cooling from holes with compound angle orientations: part 1- results downstream of two staggered rows of holes with 3D spanwise spacing, ASME Journal of Heat Transfer 116 (1994) 341-352.

[5] P.M. Ligrani, J.M. Wigle, S.W. Jackson, Film-cooling from holes with compound angle orientations: part 2- results downstream of a single row of holes with 6d spanwise spacing, ASME Journal of Heat Transfer 116 (1994) 353-362.

[6] V. Aga, R.S. Abhari, Influence of flow structure on compound angled film cooling effectiveness and heat transfer, Journal of Turbomachinery 133 (2011) 31029-31041.

[7] B.A. Jubran, A.K. Al-Hamadi, G. Theodoridis, Film cooling and heat transfer with air injection through two rows of compound angle holes, Heat Mass Transfer 33 (1997) 93-100.

[8] B. Han, D.K. Sohn, J.S. Lee, Flow and heat transfer measurements of film injectant from a row of holes with compound angle orientations, KSME International Journal 16 (2002) 1137-1146.

[9] L. I-Chien, C. Yun-Chung, D. Pei-Pei, C. Ping-Hei, Film cooling over a concave surface through two staggered rows of compound angle holes, Journal of the Chinese Institute of Engineers 28 (2005) 827-836.

[10] H. Nasir, S.V. Ekkad, S. Acharya, Effect of compound angle injection on flat surface film cooling with large streamwise injection angle, Experimental Thermal and Fluid Science 25 (2001) 23-29.

[11] W.L. Sang, R.B. Jong, S.L. Dae, Measurements of temperature fields within film-cooling jets injected from a row of compound angle holes, KSME International Journal 12 (1998) 301-309.

[12] S.R. Shine, S.S. Kumar, B.N. Suresh, Influence of coolant injector configuration on film cooling effectiveness for gaseous and liquid film coolants, Journal of Heat Mass Transfer 48 (2012) 849-861.

[13] H. Nasir, S. Acharya, S. Ekkad, Improved film cooling from cylindrical angled holes with triangular tabs: effect of tab orientations, International Journal of Heat and Fluid Flow 24 (2003) 657-668.

[14] R.J. Goldstein, P. Jin, Film cooling downstream of a row of discrete holes with compound angle, Journal of Turbomachinery 123 (2001) 222-230.

[15] M. Gritsch, A. Schulz, S. Wittig, Effect of cross flows on the discharge coefficient of film cooling holes with varying angles of inclination and orientation, Journal of Turbomachinery 123 (2001) 781-787.

[16] L. Zhang, G. Wen, Large eddy simulation on compound angle film cooling of turbine blades, 10th International Conference on Electronic Measurement & Instruments (2011) 282-287.

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[17] S. Stitzel, K.A. Thole, Flow field computations of combustor-turbine interactions relevant to a gas turbine engine, Journal of Turbomachinery 126, (2004) 122-129.

[18] Y.L. Lin, T.I.P. Shih, Film cooling of a cylindrical leading edge with injection through rows of compound-angle holes, Journal of Heat Transfer 123 (2001) 645-654.

[19] L. Graf, L. Kleiser, Eddy simulation of double-row compound-angle film cooling: setup and validation, Computers & Fluids Journal 43 (2011) 58-67.

[20] H.L. Jung, K.C.A. Young, numerical study on flow and heat transfer characteristics of film cooling with a compound angle hole, KSME International Journal 12 (1998) 963-971.

[21] A. Azzi, B.A. Jubran, Influence of leading-edge lateral injection angles on the film cooling effectiveness of a gas turbine blade, Heat Mass Transfer 40 (2004) 501-508.