Investigation of effectiveness of applying cross-injection film cooling technique to curved surfaces

陳坤佑、吳佩學

E-mail: 322046@mail.dyu.edu.tw

ABSTRACT

In this thesis, liquid crystal thermography with steady-state experimental method is used to investigate the effectiveness of cross-injection film cooling technique as applied to convex surfaces. Based on a comparison with flat plate case, the feasibility of applying this cooling technique to the curved surfaces of gas turbine blades is understood. In order to produce the secondary flow phenomena in the endwall region of a turbine blade, one leg of vortices of a delta wing is used in the experiments to realize the interaction mechanism between the vortex generated by the cross-injection coolant and the secondary vortex of the main flow. In the experiments, the cooling hole diameter（7min）, hole-to-hole distances, and an included angle（120 degrees）are fixed. The main flow velocities are 6 m/s, 8 m/s, and 10 m/s, corresponding to the Reynolds numbers of 9.2x104,, 1.24x105,and 1.5x105, respectively, for a turbine blade/vane with a chord length of 241 mm. The blowing ratios are 0.5,1,and 2. The delta-wing vortex generator is used to generate secondary flow with upwash vortex or downwash vortex. Experimental results show that the influence trends of Reynolds number and the blowing ratio on flat plate cases agree with the literature. When the blowing ratio increases from 0.5 to 1, the film cooling effectiveness may increase. However, when the blowing ratio further increases up to 2, flow separation may occur at the coolant hole exit, causing the effectiveness to decrease in that region. This situation is the most remarkable for the concave surface. Because the cross-injection coolant generates a counter-clockwise marching vortex（viewed from upstream toward downstream）, the upwash vortex in the main flow helps enhance the cross-injection vortex, hence, increase the effectiveness. On the other hand, the downwash vortex weakens the cross-injection vortex and decreases the effectiveness. Both the convex and concave curvatures hamper the attachment of cross-injection coolant to the surface, resulting in a reduction in film cooling effectiveness. The effect is also the most influential for the concave surface.

Keywords : liquid crystal thermography, cross-injection, film cooling, curved surfaces, upwash vortex, downwash vortex, Reynolds number, blowing ratio, delta-wing vortex

Table of Contents

REFERENCES

【1】 Hale, C.A., Plesniak, M. W., and Ramadhyani, S., 2000, ” Film Cooling Effectiveness for Short Film Cooling Holes Fed by a Narrow Plenum, ” ASME Journal of Turbomachinery, Vol.122, pp.553-557. 【2】 Goldstein, R.J., 1971, “ Film Cooling ” in Advances in Heat Transfer, Academic Press, eds. T. F. Irvine, Jr. and J. P. Hartnett, Vol. 7, pp. 321-379. 【3】 Wang, H.P., Olson, S.J., Goldstein., R.J., and Eckert

E.R.G.,“ Flow Visualization in a Linear Turbine Cascade of High Performance Turbine Blades,” Journal of Turbomachinery, Vol. 119, pp.1-8, 1997. 【4】 Langston, L.S.,“ Crossflow in A turbine Cascade Passage,” ASME Journal of Engineering for Gas Turbines and Power, Vol. 109, pp. 866-874,1980. 【5】 Sharma, O.P., and Butler, T.L.“ Predictions of Endwall Losses and Secondary Flows in Axial Flow Turbine Cascades,” Journal of Turbomachinery, Vol. 109, pp.229-236,1987. 【6】 Goldstein, R.J.,and Spores,R.A.,1988,“ Turbulent Transport on the Endwall in the Region Between Adjacent Turbine Blades,” ASME Journal of Heat Transfer,Vol. 110,pp.862-869. 【7】 Wanda Jiang, H. and Han, J.C., 1996, ” Effect of Film Hole Row Location on Film Effectiveness on a Gas Turbine Blade,” Journal of Heat Transfer, Vol. 118, pp. 327-333. 【8】 Gillespie, D.R.H., Byerley, A.R., Ireland, P.T., and Topy Kohler, S., 1994,“ Detailed Measurement of Local Heat Transfer Coefficient in The Entrance to Normal and Inclined Film Cooling Holes,” ASME 94-GT-1, pp. 1-8. 【9】 Cho, H.H. and Goldstein, R.J., 1995, ” Heat (Mass) Transfer and Film Cooling Effectiveness With Injection Through Discrete Holes: Part I – Within Holes and on the Back Surface,” Journal of Turbomachinery, Vol. 117, pp.440-450. 【10】 Cho, H.H. and Goldstein, R.J., 1995, ” Heat (Mass) Transfer and Film Cooling Effectiveness With Injection Through Discrete Holes: Part II – On the Exposed Surface,” Journal of Turbomachinery, Vol. 117, pp.451-460. 【11】 Spencer, M.C., Jones, T.V. and Lock G.D.,1996,“ Endwall Heat Transfer Measurements in an Annular Cascade of Nozzle Guide Vanes at Engine Representative Reynolds and Mach Numbers,” International Journal of Heat and Fluid Flow,Vol. 17,pp.139-147. 【12】 Chung, J.T. and Simon, T.W. ,1990,“ Three-Dimensional Flow Near the Blade/Endwall Junction of a Gas Turbine: Visualization in a Large-Scale Cascade Simulator,” ASME 90-WA/HT-4. 【13】 Takeishi, K., Matsuura, M., Aoki, S., Sato, T., 1990,“ An Experimental Study of Heat Transfer and Film Coolong on Low Aspect Ratio Turbine Nozzles,” ASME Journal of Turbomachinery, Vol. 112, pp. 488-496. 【14】 Metzger, D.E., Carper, H.J., and Swank, L.R., 1968, ” Heat Transfer With Film Cooling Near Nontangential Injection Slots,” Journal of Engineering for Power, pp. 157-163. 【15】 Dittmar, J., Schulz, A., Witting, S., 2003,“ Assessment of Various Film-Cooling Configurations Including Shaped and Compound Angle Holes Based on Large-Scale Experiments,” Journal of turbomachinery, Vol. 125, pp. 57-64. 【16】 Chambers, A.C., Gillespie, D.R.H., Ireland, P.T., Dailey, G.M., 2003,“ A Novel Transient Liquid Crystal Technique to Determine Heat Transfer Cofficient Distributions and Adiabatic Wall Temperature in a Three-Temperature Problem,” ASME Journal of Turbomachinery, Vol. 125, pp. 538-546. 【17】 Du, H., Han, J.C.and Ekkad, S.V., 1998,“ Effect of Unsteady Wake on Detailed Heat Transfer Coefficient and Film Effectiveness Distributions for a Gas Turbine Blade,” ASME Journal of Turbomachinery,Vol. 120, pp.808-817. 【18】 Goldstein, R.J. and Chen, H.P., 1985,“ Film Cooling on A Gas Turbine Blade Near The End Wall,” ASME Journal of Engineering for Gas Turbine and Power, Vol. 107, pp. 117-120. 【19】 Goldstein, R.J., Chen, P.H.,1987,“ Film Cooling of A Turbine Blade with Injection Through Two Rows of Holes in The Near-Endwall Region, ” ASME Journal of Turbomachinery, Vol. 109,pp.588-593. 【20】 Yu, Y. and Chyu, M. K., 1998, ” Influence of Gap Leakage Downstream of the Injection Holes on Film Cooling Performance,” ASME Journal of Turbomachinery, Vol.120, pp. 541-548. 【21】 Wang, H.P., Goldstein, R.J., Olson, S.J.,1999,“ Effect of High Free-Stream Turbulence with Large Length Scale on Blade Heat/Mass Transfer,” ASME Journal of Turbomachinery,Vol. 121, pp. 217-224. 【22】 Ames, F.E., 1997,“ The Influence of Large-Scale High-Intensity Turbulence on Vane Heat Transfer,” Journal of Turbomachinery, Vol. 119, pp. 23-30. 【23】 Sieverding, C.H., 1985,“ Recent Progress in The Understanding of Basic Aspects of Secondary Flows in Turbine Blade Passages,” ASME, Journal of Engineering for Gas Turbines and Power, Vol. 107, pp. 248-257. 【24】 Yamamoto, A., 1987,“ Production and Development of Secondary Flows and Losses in TwoTypes of Straight Turbine Cascades: Part 1 - A Stator Case,” J. of Turbomachinery, Vol. 109,pp.186-193. 【25】 Chung, J.T., Simon, T.W., 1991,“ Three-Dimensional Flow Near the Blade/Endwall Junction of a Gas Turbine: Application of a Boundary Layer Fence,” ASME paper 91-GT-45. 【26】 Ahn, J., Jung, I.S., and Lee, J.S., 2003,“ Film Cooling From Two Rows of Holes with Opposite Orientation Angles: Injectant Behavior and Adiabatic Film Cooling Effectiveness,” International Journal of Heat and Fluid Flow, Vol. 24, pp. 91-99. 【27】 田智元，2001， ”液態推進燃料噴注模擬實驗與分析”，碩士論文，大葉大學機械工程學系。 【28】 蘇裕傑、王涵威、楊鏡堂，2001， ”壁面蒸散率對突張流場之效應”，中國機械工程學會第十八屆全國學術研討會論文集，第一冊熱流與能源論文集，pp. 563-571. 【29】 吳佩學、鐘道雄，2002， ”具有前向進口台階之氣輪機靜葉片端壁區域之流場觀察”， 中國機械工程學會第十九屆全國學術研討會，熱流與能源論文集，Paper B035. 國科會計畫編號: NSC 90-2212-E-212 –014. 【30】 吳佩學、鐘道雄、謝佳佑，2003， ”靜葉片端壁區域流場受背向進口台階影響之可視化觀察”，中國機械工程學會第二十屆全國學術研討會，熱流與能源論文集，Paper A02-16. 國科會計畫編號: NSC 90-2212-E-212 –014. 【31】 吳佩學、陳信豪，2005， ”進口台階對氣輪機靜葉片端壁前端附近含複合角膜冷卻孔性能之影響”， 中國機械工程學會第二十二屆全國學術研討會，熱流與能源論文集，Paper A8-023.國科會計畫編號: NSC-93-2212-E-212-009- 【32】 Joon Ahn,In Sung Jung, and Joon Sik Lee,2003 ” Film cooling from two rows of holes with opposite orientation angles : injectant behavior and adiabatic film cooling effectiveness, ” International Journal of Heat and Fluid Flow, PP.91-99. 【33】 陳榮良，2008，“交叉噴流膜冷卻技術對直線與彎曲流道端壁之有效性的數值探討”，碩士論文，私立大葉大學機械系。 【34】 Ireland, P.T., Wang, Z., And Jones, T.V., 1995,“ Measurement Techniques: Liquid Crystal Heat Transfer Measurements,” von Karman Institute for Fluid Dynamics Lecture Series 1995-01, pp. 1-67. 【35】 Gursul, I., Allan, M.R, Badcock, K.J.,2005,“ Opportunities for the Integrated Use of Measurements and Computations for the Understanding of Delta Wing Aerodynamics” International Journal of Aerospace Science and Technology, pp.181-189. 【36】 吳政憲，2006，“76度-40度雙三角翼模型之靜態與動態高攻角氣動力特性研究”，碩士論文，國立中興大學機械系。 【37】 郭光輝、朱錦洲，1991， ”三角翼前緣渦漩之實驗研究”，中國機械工程學會第二十二屆全國學術研討會力學會議，pp. 163-170 【38】 黃漢生，2001，“三角翼類型渦流產生器對加熱管道內流場結構及熱傳效益之實驗研究”，碩士論文，私立淡江大學機械系。