The Effects of a Backward-Facing Entrance Step on Heat Transfer and Film Cooling in the Endwall Region of a Vane

邱耀俊、吳佩學

E-mail: 9419540@mail.dyu.edu.tw

ABSTRACT

This article is concerned with a practical problem regarding external heat transfer at the endwall of a vane in a gas turbine. A downward step in the flow direction normally occurs at the exit of the combustion gas duct which connects the combustion chamber and the first stage guide vanes. For a flow passage in between any two adjacent vanes, this is a backward-facing entrance step. Due to thermal expansion of different materials, the size of the step, and thus the downstream thermal and flow fields, may also change with the load of the gas turbine. Based on the smooth endwall condition, the effects of the entrance step on heat transfer coefficient and film cooling effectiveness of the endwall inside the vane passage are investigated in this study. A two-half vane with side bleeding gaps is used as the test model. The downward step size, S, is taken as 4% of the chord length. Film coolant injects into the main flow at an angle of 45 degrees with the endwall. All the film cooling holes do not include any compound angle. The main flow Reynolds number is kept at Rec = while the blowing rate of the film coolant is either 0.5 or 2.0. Experimental results using thermochromic liquid crystal technique show that a backward-facing entrance step causes a remarkable increase in the heat transfer coefficient at the endwall. Although most of the endwall surface has higher film cooling effectiveness for the case with a downward step, it does not help much to eliminate the hot spot near the flow reattachment point. Keywords： downward step, endwall, film cooling, heat transfer coefficient

Keywords : Backward ; Vane ; Film

Table of Contents

REFERENCES

【1】 Takeishi, K., Matsuura, M., Aoki, S., Sato, T, 1990,“ An Experimental Study of Heat Transfer and Film Cooling on Low Aspect Ratio Turbine Nozzles, ”ASME Journal of Turbomachinery, Vol. 112, pp.488-496. 【2】 Ekkad, S. V., Zapata, D., Han, J. C., 1997,“ Film Effectiveness Over a Flat Surface With Air and CO2 Injection Through Compound Angle Holes Using a Transient Liquid Crystal Image Method, ”ASME Journal of Turbomachinery, Vol. 119, pp.587-593. 【3】 Ekkad, S. V., Zapata, D., Han, J. C., 1997,“ Heat Transfer Coefficients Over a Flat Surface With Air and CO2 Injection Through Compound Angle Holes Using a Transient Liquid Crystal Image Method, ”ASME Journal of Turbomachinery, Vol. 119, pp.580-586. 【4】 Ekkad, S. V., Zapata, D., Han, J. C., 1997,“ Heat Transfer Coefficients Over a Flat Surface With Air and CO2 Injection Through Compound Angle Holes Using a Transient Liquid Crystal Image Method, ”ASME Journal of Turbomachinery, Vol. 119, pp.580-586. 【5】 Vedula, R. J., Metzger, D. E., 1991,“ A Method for the Simultaneous Determination of Local Effectiveness and Heat Trandfer Distributions in Three-Temperature Convection Situations, ”International Gas Turbine and Aeroengine Congress, pp.1-9. 【6】 Du, H., Ekkad, S., Han, J. – C., 1997,“ Effect of Unsteady Wake With Trailing Edge Coolant Ejection on Detailed Heat Transfer Coefficient Distributions for a Gas Turbine Blade, ”ASME Journal of Turbomachinery, Vol. 119, pp.242-248. 【7】 Yu, Y., Chyu, M. K., 1998,“ Influence of Gap Leakage Downstream of the Injection Holes on Film Cooling Performance, ”ASME Journal of Turbomachinery, Vol. 120, pp.541-547. 【8】 Nasir, H., Ekked, S., Acharya, S., 2003,“ Flat Surface Film Cooling from Cylindrical Holes with Discrete Tabs, ”Journal of thermophysics and heat transfer, Vol. 17, pp.304-312. 【9】 Drost, U., Bolcs, A., Hoffs, A.,“ Utilization of the Transient Liquid Crystal Technique for Film Cooling Effectiveness and Heat Transfer Investigations on a Flat Plate and a Turbine Airfoil, ”pp.1-9. 【10】 Kim,

Y. W., Metzger, D. E., 1995, “ Heat Transfer and Effectiveness on Film Cooled Turbine Blade Tip Models, ” ASME Journal of Turbomachinery, Vol.117, pp.12-21. 【11】 Kim, Y. W., Downs, J. P., Soechting, F. O., Abdel-Messeh, W., Steuber, G. D., Tanrikut, S.,1995, “ A Summary of the Cooled Turbine Blade Tip Heat Transfer and Film Effectiveness Investigations Performed by Dr. D. E. Metzger, ” ASME Journal of Turbomachinery, Vol.117, pp.1-10. 【12】 Ou, S., Rivir, R. B., 2001, “ Leading edge film cooling heat transfer with high free stream turbulence using a transient liquid crystal image method, ” International Journal of Heat and Fluid Flow, Vol. 22, pp.614-623. 【13】 Yu, Y., Yen, C. – H., Shih, T. I. – P., Chyu, M. K., Gogineni, S., 2002, “ Film Cooling Effectiveness and Heat Transfer Coefficient Distributions Around Diffusion Shaped Holes, ” ASME Journal of Heat Transfer, Vol.124, pp.820-827. 【14】 Wanda Jiang, H., Han, J. – C., 1996, “ Effect of Film Hole Row Location on Film Effectiveness on a Gas Turbine Blade, ” ASME Journal of Heat Transfer, Vol. 118, pp.327-333. 【15】 Goldstein, R. J., Chen, H. P., 1985, “ Film Cooling on a Gas Turbine Blade Near the End Wall, ” ASME Journal of Engineering for Gas Turbines and Power, Vol. 107, pp.117-122. 【16】 Jin, P., Goldstein, R. J., 2003, “ Local Mass and Heat Transfer on a Turbine Blade Tip, ” International Journal of Rotating Machinery, Vol. 9, pp.81-95. 【17】 Kwak, J. S., Han J. C., 2003, “ Heat-Transfer Coefficients of a Turbine Blade-Tip and Near-Tip Regions, ” Journal of Thermophysics and Heat Transfer, Vol. 17, pp.297-303. 【18】 Friedrichs, S., Hodson, H. P., Dawes, W. N., 1995, “ Distribution of Film-cooling Effectiveness on a Turbine Endwall Measured Using the Ammonia and Diazo Technique, ” International Gas Turbine and Aeroengine Congress, pp.1-10. 【19】 Wagner, G., Vogel, G., Chanteloup, D., Bolcs, A., 2002, “ Pressure sensitive paint (PSP) and transient liquid crystal technique (TLC) for measurements of film cooling performances, ” The 16th Symposium on Measuring Techniques in Transonic and Supersonic Flow in Cascades and Turbomachines, pp.1-9. 【20】 Du, H., Han, J. C., 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. 【21】 Lindgren, B., Johansson, A. V., 2002, “ Design and Evaluation of a Low-Speed Wind-Tunnel with Expanding Corners, Royal Institute od Technology Department of Mechanics. 【22】 Drost, U., Bolcs, A., 1999, “ Investigation of Detailed Film Cooling Effectiveness and Heat Transfer Distributions on a Gas Turbine Airfoil, ” ASME Journal of Turbomachinery, Vol. 121, pp.233-242. 【23】 Shih, T. I-P., Lin, Y. – L., 2003, “ Controlling Secondary-Flow Strucyure by Leading-Edge Airfoil Fillet and Inlet Swirl to Reduce Aerodynamic Loss and Surface Heat Transfer, ” ASME Journal of Turbomachinery, Vol. 125, pp.48-56. 【24】 Ahn, J., Jung, I. S., 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. 【25】 Badran, O.O. and Bruun, H.H., 1998, “ The Effect of Inlet Conditions on Flow over Backward Facing Step, ” Journal of Wind Engineering and Industrial Aerodynamics 74-76, pp. 495-509. 【26】 Abu-Hijleh, B.A/K, 2000, “ Heat Transfer from a 2D Backward Facing Step with Isotropic Porous Floor Segments, ” International Journal of Heat and Mass Transfer, Vol. 43, pp. 2727-2737. 【27】 Fitt, A.D., Ockendon, J.R., and Jones, T.V., 1985, “ Aerodynamics of Slot-Film Cooling Theory and Experiment, ” J. Fluid Mech, Vol. 160, pp. 15-27. 【28】 Garg, V.K. and Rigby, D.L., 1999, “ Heat Transfer on a Film-Cooled Blade – Effect of Hole Physics, ” International Journal of Heat and Fluid Flow, Vol. 20, pp. 10-25. 【29】 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. 【30】 P.S. Wu, and T.Y. Lin, “ Effects of a Forward-Facing Entrance Step on Film Cooling Effectiveness in the Endwall Region of a Vane, ” Recent Progress in Transport Phenomena, pp. 573-578, 2003. 【31】 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 【32】 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， Paper 10659. 【33】 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. 【34】 Langston, L.S., “ Crossflows in A turbine Cascade Passage, ” ASME Journal of Engineering for Gas Turbines and Power, Vol. 109,pp.866-874,1980. 【35】 Goldstein, R.J., and Spores, R.A., “ Turbulent Transport on the Endwall in the Region Between Adjacent Turbine Blades, ” Journal of Heat Transfer, Vol. 110, pp. 862-869,1988. 【36】 Krishnamoorthy, V., Pai, B.R., and Sukhatme, S.P., “ Influence of Upstrean Flow Conditions on the Heat Transfer to nozzle Guide Vanes, ” Journal of Turbomachinery, Vol. 110, pp. 412-416, 1988.