

Investigation of Effect of Turbulence Intensity on Cross Injection Film Cooling at the Endwall of a Vane

蔡侁達、吳佩學

E-mail: 9806115@mail.dyu.edu.tw

ABSTRACT

This research concerns with a film cooling technique applicable to the protection of the endwalls of a vane. The way film cooling works is to provide a layer of coolant air which effectively separates the vane and the endwalls from the hot-gas environment so that the wall material can be protected. To better simulate the situation in real engines, turbulence intensity is considered in the present study. In the experiments, cross injection coolant flow with offset centerlines was utilized to form better film cooling effectiveness. The test model is a two-half vane. A computational fluid dynamics (CFD) package was used to simulate the pressure distributions of a linear cascade and a two-half vane counterpart. The opening size of the side gaps in the two-half vane model is determined based on the comparison of the simulation results. The levels of turbulence intensity used in the experiments are T.I. = 1.8%, 7%, and 12%. Other parameters considered in the film cooling experiments include three inlet Reynolds numbers, three blowing ratios (0.5, 1.0, and 2.0), and a forward-facing or a backward-facing endwall step. Thermocromic liquid crystal thermography with steady-state experiments were used for the measurement of the film cooling effectiveness.

Results show that increasing turbulent intensity decreases film cooling effectiveness. The reason for that is the interaction of unsteady, high-turbulence main stream with the injection coolant which disrupts the film coverage, causing the film cooling effectiveness to decrease.

Keywords : cross injection、 film cooling effectiveness、 liquid crystal thermography、 turbulent intensity、 endwall

Table of Contents

封面內頁	
簽名頁	
博碩士論文暨電子檔案上網授權書	iii
中文摘要	iv
英文摘要	v
誌謝	vii
目錄	viii
表目錄	x
圖目錄	xi
符號說明	xviii

第一章 緒論

- 1.1 前言 1
- 1.2 研究動機 2
- 1.3 研究目的 5

第二章 國內外相關研究

第三章 研究方法與進行步驟

- 3.1 實驗系統與測試段 14
 - 3.1.1 雙半葉片模型與膜冷卻孔測試底板設計 14
 - 3.1.2 進口台階設計 15
 - 3.1.3 雙半葉片模型側邊間隙開口大小決定 15
 - 3.1.4 紊流場產生構想與設計 16
- 3.2 實驗儀器及校正 16
 - 3.2.1 熱偶校正 16
 - 3.2.2 熱線風速儀校正 17
 - 3.2.3 風洞品質鑑定 19

3.2.4	紊流場量測系統	20
3.2.5	膜冷卻流體供應系統	21
3.2.6	液晶校正系統	21
3.3	數據化約基本理論	23
3.4	實驗條件與實驗程序	23
3.5	影像擷取系統與影像處理程序	24
3.5.1	影像擷取系統	24
3.5.2	穩態液晶實驗影像處理程序	24
3.6	數據化約流程	25

第四章 結果與討論

4.1	雷諾數對端壁膜冷卻之影響	26
4.2	吹氣比對端壁膜冷卻之影響	27
4.3	台階對端壁膜冷卻之影響	28
4.4	紊流強度對端壁膜冷卻之影響	29

第五章 結論與建議

考文獻 33

表目錄

表3.1	T型(長型)熱偶校正之標準偏差	39
表3.2	T型(表面)熱偶校正之標準偏差	39
表3.3	Hot wire校正之標準偏差	39
表3.4	穩態液晶求解膜冷卻有效性實驗條件	40
表3.5	實驗所有案例與參數表	41

圖目錄

圖2.1	近端壁二次流動模式(Wang et al. 【1】)	43
圖2.2	近端壁二次流動模式(Langston 【2】)	43
圖2.3	近端壁二次流動模式(Sharma and Bulter 【3】)	44
圖2.4	近端壁二次流動模式(Goldstein and Spores 【4】)	44
圖3.1	測試段之雙半葉片模型	45
圖3.2	底板在靜葉片通道內端壁表面膜冷卻孔分佈位置	46
圖3.3	底板膜冷卻孔在靜葉片通道內的噴射方向	46
圖3.4a	台階示意圖：平滑進口台階條件 (S/C= 0%)	47
圖3.4b	台階示意圖：前向進口台階條件 (S/C=+4%)	47
圖3.4c	台階示意圖：背向進口台階條件 (S/C= - 4%)	47
圖3.5	測試段之兩側間隙設計	48
圖3.6	全葉片與雙半葉片CFD模擬壓力分佈圖	48
圖3.7	本研究之測試段模型在CFD模擬下的非結構網格及邊界條件設定	49
圖3.8	文獻之測試段線性串級模型在CFD模擬下的非結構網格及邊界條件設定	49
圖3.9	本研究之測試段模型在CFD模擬下的速度分佈	50
圖3.10	文獻之測試段線性串級模型在CFD模擬下的速度分佈	50
圖3.11	測試段紊流產生器示意圖 (BR=0.36)	51
圖3.12	測試段紊流產生器示意圖 (BR=0.52)	51
圖3.15	T型熱偶校正結果 (#CH3)	53
圖3.16	T型熱偶校正結果 (#CH4)	53
圖3.17	T型熱偶校正結果 (#CH5)	54
圖3.19	T型熱偶校正結果 (#CH7)	55
圖3.21	T型熱偶校正結果 (#CH5)	56
圖3.22	T型熱偶校正結果 (#CH7)	56
圖3.23	T型熱偶校正結果 (#CH8)	57
圖3.24	熱線風速儀實驗校正示意圖	58
圖3.25	boundary layer hot wire校正後電壓與速度曲線回歸圖	58
圖3.26	量測風洞速度場之實驗系統圖	59

- 圖3.27 開放式風洞系統圖 59
- 圖3.28 開放式風洞速度場示意圖 60
- 圖3.29 開放式風洞溫度場示意圖 60
- 圖3.30 開放式風洞速度場不均勻度示意圖 61
- 圖3.31 開放式風洞之紊流強度場 (BR=0) 61
- 圖3.32 開放式風洞之紊流強度場 (BR=0.36) 62
- 圖3.33 開放式風洞之紊流強度場 (BR=0.52) 62
- 圖3.34 膜冷卻流體系統示意圖 63
- 圖3.35 液晶校正系統示意圖 64
- 圖3.36 液晶校正系統測試段影像圖 65
- 圖3.37 液晶校正溫度對位置關係圖 65
- 圖3.38 液晶校正色調值(Hue)對位置(Pixels)關係圖 66
- 圖3.39 液晶校正溫度(Temperature)對色調值(Hue)關係圖 66
- 圖3.40 穩態液晶膜冷卻有效性實驗系統圖 67
- 圖3.41 穩態液晶實驗影像處理流程圖 68
- 圖3.42 穩態液晶實驗數據化約流程圖 69
- 圖4.1 底板膜冷卻有效性方向及範圍 70
- 圖4.2 端壁膜冷卻有效性(S/C=0%,Re=92000,M=0.5,TI=1.8%) 71
- 圖4.3 端壁膜冷卻有效性(S/C=0%,Re=92000,M=1,TI=1.8%) 71
- 圖4.4 端壁膜冷卻有效性(S/C=0%,Re=92000,M=2,TI=1.8%) 72
- 圖4.5 端壁膜冷卻有效性(S/C=0%,Re=124000,M=0.5,TI=1.8%) 72
- 圖4.6 端壁膜冷卻有效性(S/C=0%,Re=124000,M=1,TI=1.8%) 73
- 圖4.7 端壁膜冷卻有效性(S/C=0%,Re=124000,M=2,TI=1.8%) 73
- 圖4.8 端壁膜冷卻有效性(S/C=0%,Re=150000,M=0.5,TI=1.8%) 74
- 圖4.9 端壁膜冷卻有效性(S/C=0%,Re=150000,M=1,TI=1.8%) 74
- 圖4.10 端壁膜冷卻有效性(S/C=0%,Re=150000,M=2,TI=1.8%) 75
- 圖4.11 端壁膜冷卻有效性(S/C=0%,Re=92000,M=0.5,TI=7%) 75
- 圖4.12 端壁膜冷卻有效性(S/C=0%,Re=92000,M=1,TI=7%) 76
- 圖4.13 端壁膜冷卻有效性(S/C=0%,Re=92000,M=2,TI=7%) 76
- 圖4.14 端壁膜冷卻有效性(S/C=0%,Re=124000,M=0.5,TI=7%) 77
- 圖4.15 端壁膜冷卻有效性(S/C=0%,Re=124000,M=1,TI=7%) 77
- 圖4.16 端壁膜冷卻有效性(S/C=0%,Re=124000,M=2,TI=7%) 78
- 圖4.17 端壁膜冷卻有效性(S/C=0%,Re=150000,M=0.5,TI=7%) 78
- 圖4.18 端壁膜冷卻有效性(S/C=0%,Re=150000,M=1,TI=7%) 79
- 圖4.19 端壁膜冷卻有效性(S/C=0%,Re=150000,M=2,TI=7%) 79
- 圖4.20 端壁膜冷卻有效性(S/C=0%,Re=92000,M=0.5,TI=12%) 80
- 圖4.21 端壁膜冷卻有效性(S/C=0%,Re=92000,M=1,TI=12%) 80
- 圖4.22 端壁膜冷卻有效性(S/C=0%,Re=92000,M=2,TI=12%) 81
- 圖4.23 端壁膜冷卻有效性(S/C=0%,Re=124000,M=0.5,TI=12%) 81
- 圖4.24 端壁膜冷卻有效性(S/C=0%,Re=124000,M=1,TI=12%) 82
- 圖4.25 端壁膜冷卻有效性(S/C=0%,Re=124000,M=2,TI=12%) 82
- 圖4.26 端壁膜冷卻有效性(S/C=0%,Re=150000,M=0.5,TI=12%) 83
- 圖4.27 端壁膜冷卻有效性(S/C=0%,Re=150000,M=1,TI=12%) 83
- 圖4.28 端壁膜冷卻有效性(S/C=0%,Re=150000,M=2,TI=12%) 84
- 圖4.29 端壁膜冷卻有效性(S/C=4%,Re=124000,M=0.5,TI=1.8%) 84
- 圖4.30 端壁膜冷卻有效性(S/C=4%,Re=124000,M=1,TI=1.8%) 85
- 圖4.31 端壁膜冷卻有效性(S/C=4%,Re=124000,M=2,TI=1.8%) 85
- 圖4.32 端壁膜冷卻有效性(S/C=-4%,Re=124000,M=0.5,TI=1.8%) 86
- 圖4.33 端壁膜冷卻有效性(S/C=-4%,Re=124000,M=1,TI=1.8%) 86
- 圖4.34 端壁膜冷卻有效性(S/C=-4%,Re=124000,M=2,TI=1.8%) 87
- 圖4.35 端壁膜冷卻有效性(S/C=4%,Re=124000,M=0.5,TI=7%) 87
- 圖4.36 端壁膜冷卻有效性(S/C=4%,Re=124000,M=1,TI=7%) 88
- 圖4.37 端壁膜冷卻有效性(S/C=4%,Re=124000,M=2,TI=7%) 88

- 圖4.38 端壁膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=0.5$, $TI=7\%$) 89
- 圖4.39 端壁膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=1$, $TI=7\%$) 89
- 圖4.40 端壁膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=2$, $TI=7\%$) 90
- 圖4.41 端壁膜冷卻有效性($S/C=4\%$, $Re=124000$, $M=0.5$, $TI=12\%$) 90
- 圖4.42 端壁膜冷卻有效性($S/C=4\%$, $Re=124000$, $M=1$, $TI=12\%$) 91
- 圖4.43 端壁膜冷卻有效性($S/C=4\%$, $Re=124000$, $M=2$, $TI=12\%$) 91
- 圖4.44 端壁膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=0.5$, $TI=12\%$) 92
- 圖4.45 端壁膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=1$, $TI=12\%$) 92
- 圖4.46 端壁膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=2$, $TI=12\%$) 93
- 圖4.47 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=0.5$, $TI=1.8\%$) 93
- 圖4.48 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=1$, $TI=1.8\%$) 94
- 圖4.49 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=2$, $TI=1.8\%$) 94
- 圖4.50 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=0.5$, $TI=7\%$) 95
- 圖4.51 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=1$, $TI=7\%$) 95
- 圖4.52 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=2$, $TI=7\%$) 96
- 圖4.53 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=0.5$, $TI=12\%$) 96
- 圖4.54 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=1$, $TI=12\%$) 97
- 圖4.55 端壁橫向平均膜冷卻有效性($S/C=0\%$, $M=2$, $TI=12\%$) 97
- 圖4.56 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=92000$, $TI=1.8\%$) 98
- 圖4.57 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=124000$, $TI=1.8\%$) 98
- 圖4.58 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=150000$, $TI=1.8\%$) 99
- 圖4.59 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=92000$, $TI=7\%$) 99
- 圖4.60 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=124000$, $TI=7\%$) 100
- 圖4.61 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=150000$, $TI=7\%$) 100
- 圖4.62 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=92000$, $TI=12\%$) 101
- 圖4.63 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=124000$, $TI=12\%$) 101
- 圖4.64 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=150000$, $TI=12\%$) 102
- 圖4.65 端壁橫向平均膜冷卻有效性($Re=124000$, $M=0.5$, $TI=1.8\%$) 102
- 圖4.66 端壁橫向平均膜冷卻有效性($Re=124000$, $M=1$, $TI=1.8\%$) 103
- 圖4.67 端壁橫向平均膜冷卻有效性($Re=124000$, $M=2$, $TI=1.8\%$) 103
- 圖4.68 端壁橫向平均膜冷卻有效性($Re=124000$, $M=0.5$, $TI=7\%$) 104
- 圖4.69 端壁橫向平均膜冷卻有效性($Re=124000$, $M=1$, $TI=7\%$) 104
- 圖4.70 端壁橫向平均膜冷卻有效性($Re=124000$, $M=2$, $TI=7\%$) 105
- 圖4.71 端壁橫向平均膜冷卻有效性($Re=124000$, $M=0.5$, $TI=12\%$) 105
- 圖4.72 端壁橫向平均膜冷卻有效性($Re=124000$, $M=1$, $TI=12\%$) 106
- 圖4.73 端壁橫向平均膜冷卻有效性($Re=124000$, $M=2$, $TI=12\%$) 106
- 圖4.74 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=92000$, $M=0.5$) 107
- 圖4.75 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=92000$, $M=1$) 107
- 圖4.76 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=92000$, $M=2$) 108
- 圖4.77 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=124000$, $M=0.5$) 108
- 圖4.78 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=124000$, $M=1$) 109
- 圖4.79 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=124000$, $M=2$) 109
- 圖4.80 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=150000$, $M=0.5$) 110
- 圖4.81 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=150000$, $M=1$) 110
- 圖4.82 端壁橫向平均膜冷卻有效性($S/C=0\%$, $Re=150000$, $M=2$) 111
- 圖4.83 端壁橫向平均膜冷卻有效性($S/C=4\%$, $Re=124000$, $M=0.5$) 111
- 圖4.84 端壁橫向平均膜冷卻有效性($S/C=4\%$, $Re=124000$, $M=1$) 112
- 圖4.85 端壁橫向平均膜冷卻有效性($S/C=4\%$, $Re=124000$, $M=2$) 112
- 圖4.86 端壁橫向平均膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=0.5$) 113
- 圖4.87 端壁橫向平均膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=1$) 113
- 圖4.88 端壁橫向平均膜冷卻有效性($S/C=-4\%$, $Re=124000$, $M=2$) 114

REFERENCES

【1】 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. 【2】 Langston, L.S., " Crossflow in A turbine Cascade Passage," *ASME Journal of Engineering for Gas Turbines and Power*, Vol. 109, pp. 866-874,1980. 【3】 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. 【4】 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. 【5】 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. 【6】 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. 【7】 Vedula, R.J. and Metzger, D.E, 1991, " A Method for The Simultaneous Determination of Local Effectiveness and Heat Transfer Distributions in Three-Temperature Convection Situations," *ASME 91-GT-345*, pp.1-9. 【8】 Metzger, D.E., Carper, H.J., and Swank, L.R., 1968, " Heat Transfer With Film Cooling Near Nontangential Injection Slot," *Journal of Engineering for Power*, April, 1968, pp. 157-163. 【9】 Dittmar, J., Schulz, A., and Wittig, S., 2003, " Assessment of Various Film-Cooling Configurations Including Shaped and Compound Angle Holes Based on Large-Scale Experiments," *ASME Journal of Turbomachinery*, Vol.125, pp. 57-64. 【10】 Friedrichs, S., Hodson, H.P., and Dawes, W.N., 1995, " Distribution of Film-Cooling Effectiveness on a Turbine Endwall Measured Using the Ammonia and Diazo Technique," presented at the International Gas Turbine and Aeroengine Congress and Exposition, Houston, Texas, USA-June 5-8, 1995. 【11】 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. 【12】 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. 【13】 Goldstein, R.J. and Chen, H.P., 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. 【14】 Wilfert, G. and Fottner, L, 1996, " The Aerodynamic Mixing Effect of Discrete Cooling Jets with Mainstream Flow on A Highly Loaded Turbine Blade," *ASME Journal of Turbomachinery*, Vol. 118, pp. 468-478. 【15】 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. 【16】 Hale, C. A., Plesniak, M. W., and Ramadhyani, S., 2000, " Film Cooling Effectiveness for ShortFilm Cooling Holes Fed by a Narrow Plenum," *ASME Journal of Turbomachinery*, Vol.122, pp.553-557. 【17】 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. 【18】 田智元, 2001, " 液態推進燃?噴注模擬實驗與分析 ", 碩士?文, 大?大學機械工程學系。 【19】 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. 【20】 吳佩學, 2005, " ?用噴注互相衝射形成?卻薄膜之有效性的實驗探討 ", ?政院國家科學委員會專題研究計畫成果報告, 計畫編號: NSC 93 - 2212 - E - 212 - 009 - 【21】 蘇裕傑、王涵威、楊鏡堂, 2001, " 壁面蒸散?對突張?場之效應 ", 中國機械工程學會第十八屆全國學術研討會?文集, 第一冊熱?與能源?文集, pp. 563-571。 【22】 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. 【23】 吳佩學、鐘道雄, 2002, " 具有前向進口台階之氣?機靜?片端壁區域之?場觀察 ", 中國機械工程學會第十九屆全國學術研討會, 熱?與能源?文集, Paper B035. 國科會計畫編號: NSC 90-2212-E-212 - 014 【24】 吳佩學、鐘道雄、謝佳佑, 2003, " 靜?片端壁區域?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?與能源?文集, Paper A02-16. 國科會計畫編號: NSC 90-2212-E-212 - 014 【25】 吳佩學、陳信豪, 2005, " 進口台階對氣?機靜?片端壁前端附近含複合角膜?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?與能源?文集, Paper A8-023.國科會計畫編號: NSC-93-2212-E-212-009- 【26】 Wang, H.P., Goldstein, R.J., and Olson, S.J., 1999, " Effect of High Free-Stream Turbulence With Large Length Scale on Blade Heat/Mass Transfer," *Journal of Turbomachinery*, Vol. 121, pp.217-224. 【27】 Ames, F.E., 1997, " The Influence of Large-Scale High-Intensity Turbulence on Vane Heat Transfer," *Journal of Turbomachinery*, Vol. 119, pp. 23-30. 【28】 Ames, F.E., 1998, " Aspects of Vane Film Cooling With High Turbulence: Part I – Heat Transfer," *Journal of Turbomachinery*, Vol. 120, pp. 768-776. 【29】 Ames, F.E., 1998, " Aspects of Vane Film Cooling With High Turbulence: Part II – Adiabatic Effectiveness," *Journal of Turbomachinery*, Vol. 120, pp. 777-785. 【30】 Krishnamoorthy, V., Pai, B.R., and Sukhatme, S.P., " Influence of Upstream Flow Conditions on the Heat Transfer to Nozzle Guide Vanes," *Journal of Turbomachinery*, Vol. 110, pp. 412-416, 1988 【31】 陳炳輝, 1992, " 在高紊流場內之蓮蓬頭式薄膜冷卻 ", ?政院國家科學委員會專題研究計畫成果報告, 計畫編號: NSC 80 - 0401 - E - 002 - 004 - 【32】 陳建維, 1992, " 高紊流強度下噴射孔及薄膜冷卻對圓柱熱(質)傳之影響 ", 碩士?文, 國立台灣大學機械工程學系。 【33】 陳建維, 1995, " 高紊流強度下蓮蓬頭式薄膜冷卻 ", 碩士?文, 國立台灣大學機械工程學系。 【34】 Maiteh, B.Y., and Jubran, B.A., " Influence of mainstream flow history on film cooling and heat transfer from two rows of simple and compound angle holes in combination," *International Journal of Heat and Fluid Flow* 20 (1999), pp. 158-165. 【35】 Ou, S., and Rivir, R.B., " 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* 22 (2001), pp. 614-623. 【36】 Lebedev, V.P., Lemanov, V.V., Misyura, S.YA. and Terekhov, V.I., 1995, " Effects of flow turbulence on film cooling efficiency," *International Journal Heat Mass Transfer*, Vol. 38, No. 11, pp. 2117-2125. 【37】 AL-Hamadi, A.K., Jubran, B.A. and Theodoridis, G., 1998, " Turbulence intensity effects on film cooling and heat transfer from compound angle holes with particular application to gas turbine blades," *International Journal Heat Mass Transfer*, Vol. 39, No. 14, pp. 1449-1457.