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EXPERIMENTAL ANALYSIS OF FILM HOLE WALL HEAT TRANSFER USING TRANSIENT LIQUID CRYSTALS

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ABSTRACT

Film cooling plays a crucial role in creating effective cooling systems for gas turbine blades, which are necessary to meet thermal protection standards to achieve high thermal efficiency. This study was conducted to experimentally evaluate detailed heat transfer coefficients within a representative geometry, provide contours of internal surface Nusselt number, circumferentially averaged Nusselt number along the entry length of the channels. The Transient Liquid Crystal techniques has been implemented to study the heat transfer distributions over the wall of the film hole. The test section representing the film cooling hole was a cylindrical channel and it had a length of 5 jet diameters. The experimental tests have been conducted at wide range of Reynolds numbers (30,000–60,000), inclination angle (0^o-135^o) and rotation angle (0^o-135^o). The effect of channel entry configuration was also varied between sharp, filleted, and chamfered. Results showed that the sharpness of the nozzle was directly related to the magnitude of the entry length separation and reattachment heat transfer enhancement. When inclination angle was introduced, it was discovered that there was a reduction of the reattachment heat transfer enhancement, but an overall increase in heat transfer could be achieved, with most enhancement shown for inclination angle of 45°. While varying the rotation angle illustrated that the most significant impact was within one diameter in length from the channel entry, with overall reductions in heat transfer when varied by more than 90°.

1. INTRODUCTION

Film cooling is a commonly used technique, and whilst the downstream film effectiveness is well understood, the internal heat sink effect, caused by heat transfer coefficients within the entry length to the cylinder are often not well understood. This study was conducted to experimentally evaluate detailed heat transfer coefficients within a representative geometry, provide contours of internal surface Nusselt number, circumferentially averaged Nusselt number along the entry length of the channels, and provide discharge coefficient data. The test section representing the film cooling hole is a cylindrical channel with an inclination angle (α) between the cooling plenum and 'hot-gas' plenum wall, and rotation angle (β) relative to the axial/radial direction angle as shown in Figure 1.

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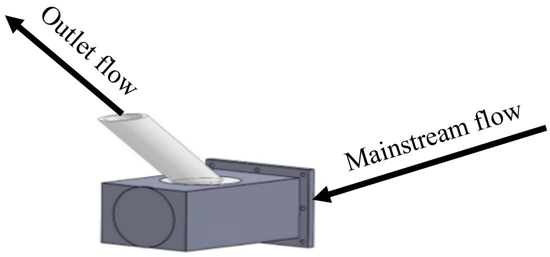

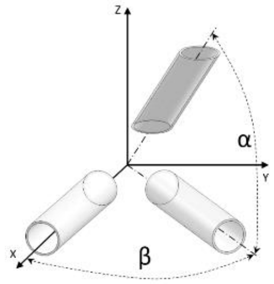

(x-axis represents the mainstream flow direction)

Figure 1: Scheme variation of inclination and rotation angles

2. METHDOLOGY

The experimental work has been conducted using the Thermochromic Liquid Crystal (TLC) transient technique. Convection heat transfer coefficients from a heated jet to an impingement plate can be deduced by monitoring the time wise temperature rise of the model surface when subjected to a transient convective heating as shown in the below Figure 2. During a transient test, the coating layer colour change time at every pixel on the heat transfer surface is recorded by using an image processing technique. Based on the obtained time responses of these TLC coating, the local distribution of Nusselt number could be estimated by solving the Fourier's equation.

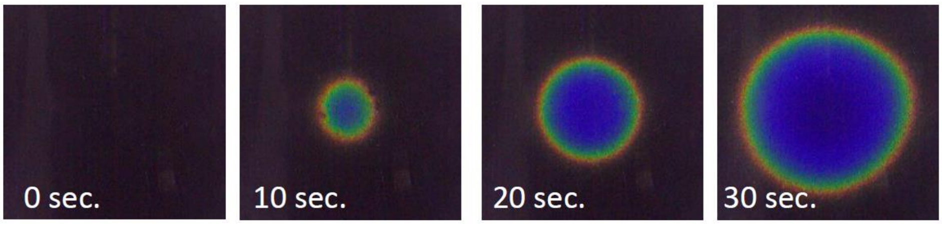

Figure 2: Representative development of jet impingement target liquid crystal

The test condition is assumed to be one dimensional transient conduction through a semi-infinite solid with constant surface heat transfer coefficient. The transient solution of the Fourier's equation is as shown in the following equation[1].

$$\theta = \frac{T_w - T_i}{T_{inlet} - T_i} = 1 - \exp\left(\frac{h^2 t}{\rho c k}\right) erfc\left(\frac{h\sqrt{t}}{\sqrt{\rho c k}}\right)$$

where θ is the non-dimensional temperature ratio. T_w, T_i and T_{inlet} are wall surface temperature at time t, initial temperature and the inlet air temperature. ρ; c and k are the density, specific heat and thermal conductivity of the model, respectively. h and t are the activation time of liquid crystals and the local heat transfer.

3. RESULTS

The inlet configuration was varied between a sharp entry, a filleted entry, and a chamfered entry at 45,000 Reynolds number. Nu distributions for each are shown in Figure 3. Enhancement can be seen to be more significant in the sharper entry, due to a larger disruption and mixing in the boundary layer. All cases show an initial area of low Nusselt number, as the flow separates followed by reattachment. The severity of the Nusselt number variation is proportional to the sharpness of the entry condition.

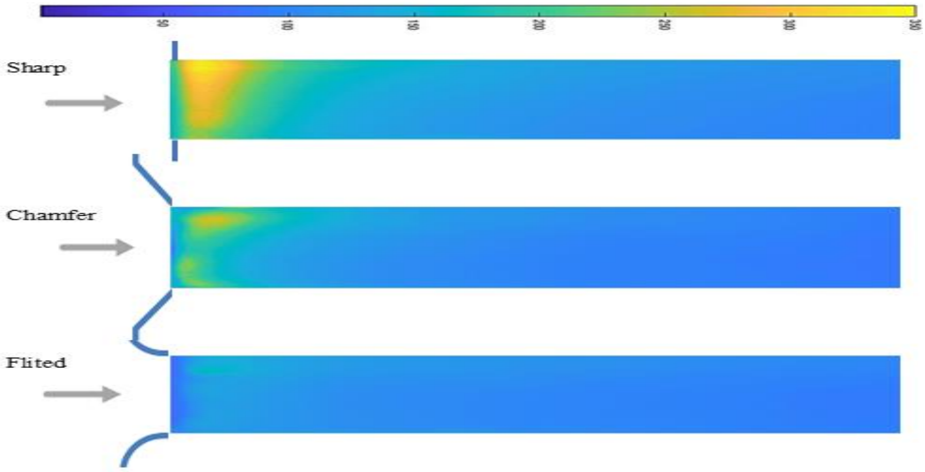

Figure 3: Inlet configuration influence on local Nu distribution at $\alpha = 0^o$, $\beta = 0^o$

When assessing the circumferentially averaged entry length effects for variation in rotation angle, Figure 4 demonstrates that only the 0° case shows an initial area of sufficient separation, this is likely due to the existing impact of the 45° inclination angle, and that the biased enhancement against the right face compensates for the average initial separation. All rotation angles otherwise follow a similar trend, with the highest overall rates of heat transfer in the 0° rotation angle case.

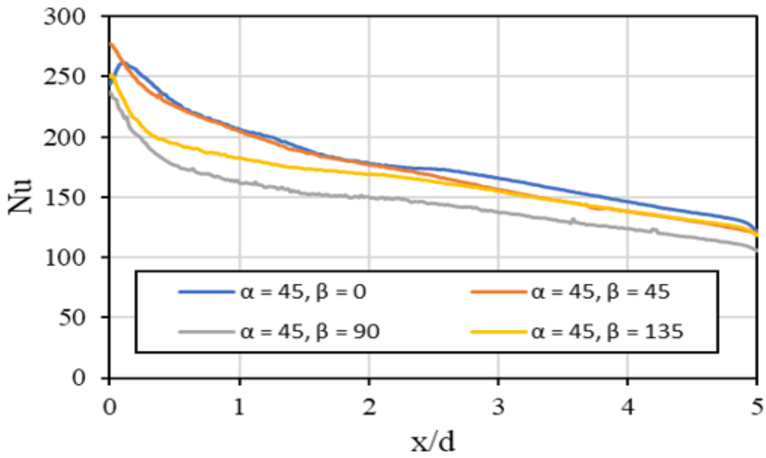

Figure 4**:** Influence of β angle on total average Nu distribution at $\alpha = 45^o$, Re=45,000

4. CONCLUSIONS

A comprehensive experimental evaluation was conducted to investigate heat transfer characteristics within a scaled cylindrical cooling channel featuring consistent diameter. This research aimed to understand the complex relationship between geometric configurations and heat transfer efficiency. Increasing the sharpness of the inlet, enhance the heat transfer because of increasing the flow turbulence at the entry region. Inclination angles, ranging from 0 to 135 degrees, were observed to diminish the enhancement of reattachment heat transfer, while simultaneously leading to an increase in overall heat transfer.

REFERENCE

[1] T. L. Bergman, A. S. Lavine, F. P. Incropera and D. P. DeWitt, Fundamentals of Heat and Mass Transfer, 8th ed., Wiley, 2017.