Flowfield Measurement for an Array of Film Cooling Holes

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1. Introduction

Film cooling has been a common feature in modern gas turbine and can be achieved by injecting the coolant fluid through the blade surface into the external boundary [1]. The injected cold air will form a buffer layer of relatively cool air between the surface and the hot gases contained within the turbine flow path [2]. From a flow field perspective, minimal penetration of the coolant is necessary to ensure the coolant remains attached to the blade surface [3] which can be achieved at low coolant mass flowrate, but yet it must be high enough to enable covers for the whole blade area. The film cooling benefit will gradually decay as the distance from the cooling hole increased [2] and to provide continuous cooling protection to the blade, cooling holes can be arranged to be in a row to ensure the continuity of the coolant protective layer along the film cooling line.

Early studies have highlighted the important to understand the complicated flowfield involve in film cooling to have physical interpretation of film cooling performance. Previous researchers [4-7] reported the flowfield that occurs includes intense shear regions, longitudinal vortices and counter rotating vortices. Base on these flowfield characteristics, it was the intent of the present study to determine the effect of BR in an array of cooling holes. This paper presents center line flow field measurement for an array of cooling holes for a blowing ratios, BR=1.0 and 2.0 at Reynolds number base on hole diameter, $Re_0=6.2\times10^5$.

2. Experiments

Experiments discussed in this paper were carried out in a close circuit wind tunnel with the secondary air was supplied through a separate blower. The test model consists of total 20 holes with an arrangement of 5 holes in a row. Fig. 1 shows the holes arrangement together with measurement location involved.

The film hole considered is a normal cylindrical hole with a diameter, $D=10$mm with inclination angle, $\Theta=20^\circ$. The thickness of the test plate is set to provide the hole length to diameter ratio, $L/D=6$. The pitch to diameter ratio in the streamwise and spanwise direction is assigned to be at $x/D=10$ and $z/D=6$ respectively. The test plate was made from acrylic plate and has been applied with the black paint on the inner test surface to reduce the measurement noise cause by laser reflection.

Two experimental conditions have been considered. Both conditions were set at $Re_0=6.2\times10^5$ with two different BR=1.0 and 2.0. The aims of the experiments are to capture blowing ratio and cumulative effects on the flowfield downstream of the cooling hole.

3. Measurement Technique

A three-component, coincident, fiber optic commercial Laser Doppler Velocimeter (LDV) from DANTEC was used to measured the velocity fields. The probes where aligned to inclined at $25^\circ$ from the center line to right and left directions. As the result of the alignment, the measured velocities will need to go through a transformation process to represent the actual experimental axis. The transformation and other data analyses were done through BSA Flow Software supplied together with processor; Dantec's BS F60 Processor and 3-D Traversing System by Dantec. Both the primary and secondary air was seeded with fog generated by the Fog Generator through the fog tank. The velocity were measured at 9 different locations in streamwise direction as shown in Fig. 1 with measurement points yield from $y/D=0.3$ to 3.0 on the direction perpendicular to the test plate surface.

4. Results

Three velocity components have been measured namely $u$, $v$ and $w$ at determined locations. Fig. 2 shows normalize mean velocities vectors measured for BR=1.0 and 2.0 together with the locations of the holes.

Different in terms of velocity magnitude can be clearly seen between the two BR. Previous study by Thole [3] reported a significant deceleration of the streamwise velocity in the near wall region at the leading edge of the hole. This was explained as results of blockage effect of the secondary air as it penetrates into the freestream which is cannot be seen clearly in the present study. Absence of such event could possibly due to the different of hole angle between the past and present study; 30° and 20° respectively. As the hole angle is steeper, the blockage effects were reduces along with vertical velocity component of the secondary air in the present study.

The distortion of streamwise velocity can clearly be seen at BR=2.0 as compared to 1.0. Negative gradient of the streamwise velocity captured at both BR at all locations indicates the formation of a shear layer cause by penetration of the secondary air into the freestream region [3]. The negative velocity gradient indicates the intensity of the shear layer formation in the flowfield. Obviously, higher BR will result in more intense shear layer formation compare to the lower BR as been shown in Fig. 2.

Note that the peak value of streamwise velocity, $u_{\max}$ at $x/D=27.0$ and 28.5 respectively as shown in Fig. 3 and 4 at $x/D=37$. The peak $u_{\max}$ value for BR=1.0 is greater than unity could be explained by the temperature different between the secondary air, 45.2°C and main stream air, 19.9°C.
which later differentiate the velocity between the secondary air and the main stream even at BR = 1.0.

![Normalize Streamwise Velocity for BR = 1.0](image1)

![Normalize Streamwise Velocity for BR = 2.0](image2)

The location of where the maximum $u/U_\infty$ was captured could be explained by the cumulative effects due to the hole arrangement involved in the study. As we are moving further downstream the magnitude of $u/U_\infty$ increases as shown in both Fig. 3 and Fig. 4. The figures also show that the captured $u/U_\infty$ at $x/D = 7.0$ is going below unity and has not been the case at other locations. This is another example of the cumulative effect cause by the hole arrangement applied in the present study.

In terms of penetration wise, the penetration depth can be indicated by existent of vertical component away from the wall. In Fig. 2 at both BR the minimum penetration depth can be seen at $x/D = 7.0$ with the vertical velocity component can only be seen up to $y/D = 1.5$ at BR = 1.0 and $y/D = 2.5$ at BR = 2.0. The penetration depth of BR = 1.0 increases as we move further downstream but recorded at most $y/D = 2.0$ at $x/D = 37.0$. As for BR = 2.0, the penetration depth can already be seen exceeding $y/D = 3.0$ at $x/D = 17.0$ and expected to increases as we are moving downstream of the measurement line.

5. Conclusion

Flowfield of two different BR have been presented in the present study. The results of mean normalize velocity vector, normalize streamwise velocity and normalize vertical velocity have been discussed. The effects of BR can be clearly seen in all presented results. The negative gradient of the streamwise velocity which indicates the formation of shear layer is a clear evidence especially at BR = 2.0 with peak value $u/U_\infty = 1.77$ compared to BR = 1.0 with $u/U_\infty = 1.19$. Both of the values have been measured at $x/D = 37$ which indicates the cumulative effects due to the hole arrangement involved. The cumulative effects can also be seen in all normalize streamwise velocity and normalize vertical velocity results presented in Fig. 5 and Fig. 6 as the most downstream velocity profile showing higher magnitudes compared to the others.

References