EFFECTS OF BULK FLOW PULSATIONS ON FILM COOLING WITH SHAPED HOLES

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Experimental results are presented describing the effects of bulk flow pulsations on flow and film cooling characteristics around shaped holes with compound angle orientations. The study consists of injectant flow visualization and measurements of adiabatic effectiveness distributions and heat transfer coefficient. The current shaped holes have a 15° forward expansion with a fixed inclination angle of 35° and three different orientation angles of 0°, 30° and 60° (Figure 1). Static pressure pulsations are produced by rotating vanes made of an array of six shutter blades, which are extended across the span of the exit of the wind tunnel test section. The free-stream velocity is in the form of near-sinusoidal variation and peak-to-peak amplitude is about 10%. Changing two parameters which are time-averaged blowing ratio ($\overline{M}$ = 0.5, 1.0, 1.5 and 2.0) and pulsation frequency (f = 0, 8 and 32 Hz) gives the corresponding coolant Strouhal numbers (St_c) ranging from 0 to 2.4.

Flow visualization is conducted using a single shaped hole with 30 mm in diameter to investigate the interaction between free-stream boundary layer flow and injectant at the hole exit plane. The injectant mixed with oil aerosol particles is illuminated at the hole exit plane and the image is captured by a high speed camera (Figure 2). Figure 3 shows that in the case of 60° orientation injection, free-stream fluid penetrates into the film hole at the hole exit plane even with no pulsations. This result supports the possibility of free-stream ingestion into the hole, which was predicted by the numerical simulation (McGrath and Leylek[1]). Figure 4 shows the pulsation effect on the interaction between free-stream and injectant. It is clearly observed that static pressure pulsations in the free-stream result in periodic variation of injectant mass flow rate, which causes dramatic alterations in film coolant distributions, trajectories and corresponding adiabatic film cooling effectiveness distributions downstream of injection holes.

The adiabatic film cooling effectiveness and heat transfer coefficient are measured on a single row of four shaped holes with 15 mm in diameter using the thermochromic liquid crystal technique (Figure 5). Spanwise-averaged adiabatic effectiveness distributions are shown in Figure 6 together with round hole results (Jung[2]) for comparison. Although static pressure pulsations cause drastic decrease in the adiabatic film cooling effectiveness, shaped holes show still higher effectiveness near the hole than round holes do.

REFERENCES

1. McGrath, E. L. and Leylek, J. H., Physics of Hot Crossflow Ingestion in Film Cooling, *ASME Paper,* No. 98-GT-191, 1998.

2. Jung, I. S., Effects of Bulk Flow Pulsations on Film Cooling with Compound Angle Injection Holes, *Ph.D. Thesis*, Seoul National University, 1998.

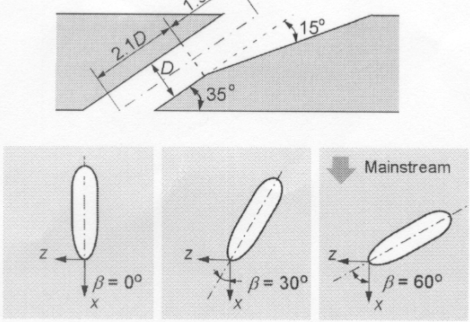


Figure 1. Shaped hole geometry and orientation angle (β)

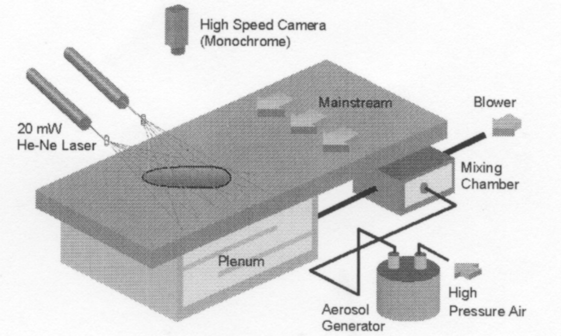
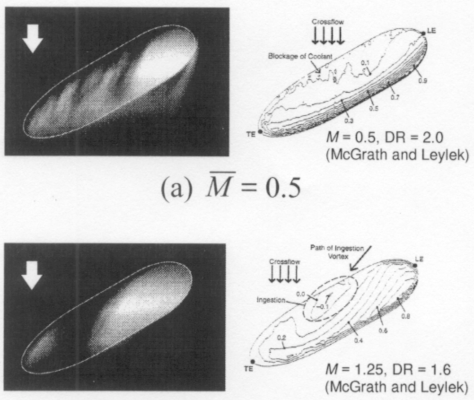


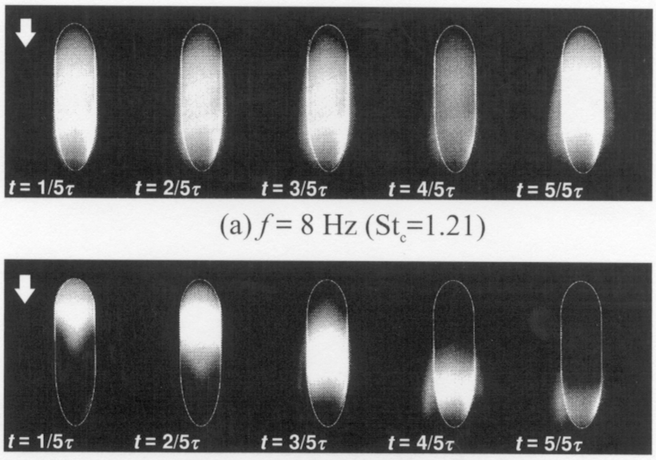
Figure 2. Experimental setup for visualization



(a) $\overline{M} = 0.5$

(b) $\overline{M} = 1.0$

Figure 3. Comparison with computational results (McGrath and Leylek[1]) at $\beta = 60^\circ$ with no pulsations



(a) f = 8 Hz (St_c=1.21)

(b) f = 32 Hz (St_c=4.83)

Figure 4. Phase-averaged images at the hole exit plane at $\overline{M} = 0.5$ and $\beta = 0^\circ$

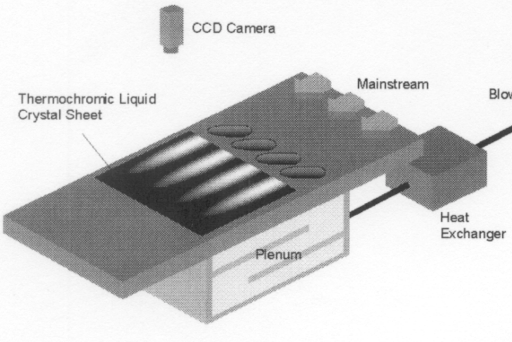


Figure 5. Experimental setup for film cooling performance

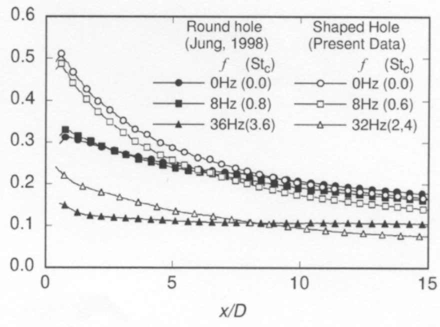


Figure 6. Comparison of spanwise-averaged adiabatic effectiveness with round hole results (Jung[2]) at $\beta = 60^\circ$ and $\overline{M} = 0.5$