Comparison of film cooling in the presence of various mainstream pressure gradients

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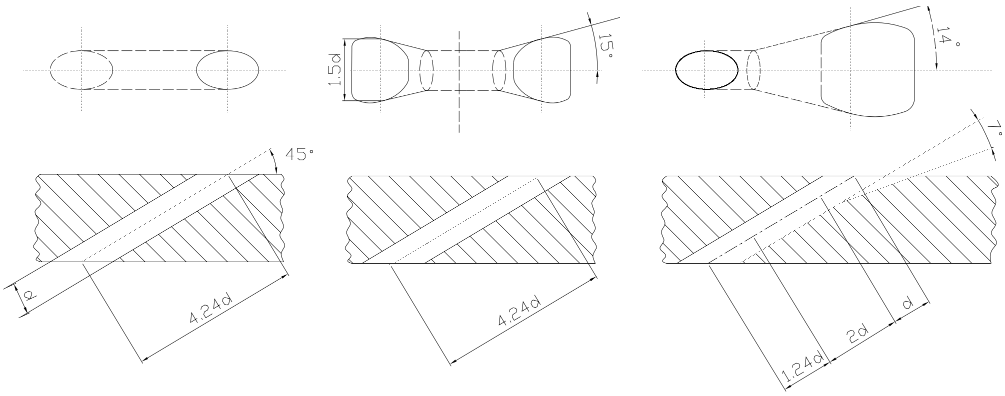
In an attempt to improve the cooling process, attention has been paid to contouring the hole geometry recently. Film cooling holes with a diffuser-shaped expansion at the exit portion of the hole are believed to improve cooling performance. The increased cross-sectional area at the hole exit compared to a standard cylindrical hole leads to a reduction of the momentum flux of the jet exiting the hole. Therefore, the length of penetration of the jet into the main flow is reduced, resulting in an increased cooling efficiency. Furthermore, lateral expansion of the hole provides an improved lateral spreading of the jet, leading to a better coverage of the airfoil in lateral direction and a higher laterally averaged film-cooling effectiveness. In order to get better understanding of film cooling characteristics with various hole geometrics in the presence of mainstream pressure gradients, investigation program was carried out in the Heat Transfer Laboratory of Northwestern Polytechnical University. Measurements were conducted in a large-scaled closed-loop wind tunnel with a secondary flow system for film cooling. The cylindrical hole, fanned hole and 3-in-1 hole are tested in simulating film cooling on the flat plat in the presence of various mainstream pressure gradients. Each hole has a diameter of 7.5 mm at their cylindrical section. Fig.1 shows the sketch of the 3 kinds of holes with the inclined angle of 45 deg.

The normalized heat transfer coefficient h/h_0 of the cylindrical holes under favorable mainstream pressure gradient is significantly higher than those under zero pressure gradient and adverse pressure gradient. For the double-fan shaped holes and the fan shaped holes, The h/h_0 under favorable pressure gradient is also the highest.

The film cooling effectiveness of the cylindrical holes increases significantly in the presence of the mainstream adverse pressure gradients. The cooling effectiveness under zero pressure gradient and adverse pressure gradient is very close. The effect of pressure gradients on film cooling effectiveness by numerical simulation is similar to that of the experimental result. The coolant of the adverse pressure gradient has a good coverage on the surface, resulting in the high dimensionless temperature in the vicinity of the surface. The coolant of the zero pressure gradient has a significant separation from the surface, resulting in the lowest film cooling effectiveness. The lateral spread of the adverse pressure gradient is better than that of the favorable pressure gradient. The effect of pressure gradients on film cooling effectiveness of double-fan shaped holes with small inclined angle $\alpha=20^\circ$ is very weak. The coolants under various pressure gradients have good attachment on the surface due to the very small injection angle. The effect of pressure gradients on film cooling effectiveness of double-fan shaped holes with larger inclined angle $\alpha=45^\circ$ is larger. The film cooling effectiveness under adverse pressure gradient is the highest and the film cooling effectiveness under zero pressure gradient is the lowest. And the effect of pressure gradient becomes increasingly significant when the momentum flux ratios increase. But the effect of pressure gradient on film cooling effectiveness of $\alpha=90^\circ$ is different from that of $\alpha=45^\circ$. The film cooling effectiveness under favorable pressure gradient is the highest for the $\alpha=90^\circ$ case. The numerical results are different from the experimental results for the double-fan shaped holes. The effect of pressure gradient on film cooling effectiveness of the fan shaped holes is weak because of the good attachment on the wall of the coolants of the fan shaped holes. The film cooling effectiveness under zero pressure gradient is the highest in the vicinity of the holes and is the lowest at x/d>10. The film cooling effectiveness under favorable pressure and adverse pressure is very close in the whole measured region.



(a) Cylindrical Hole (b) double-fan shaped Hole (c) Fan shaped Hole

Fig.1 Sketch of Film Cooling Holes