PIV measurements of supersonic slot-film cooling
with shock/cooling-film interaction

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HIGHLIGHTS

• High-speed PIV measurements of shock/cooling-film interaction
• Laminar supersonic cooling film injected in a supersonic turbulent boundary layer
• Varying injection Mach number and shock intensity
• Great impact of the injection Mach number on the flow structure. Reduced injection Mach number leads to a thick subsonic layer with increased turbulent mixing
• Increased shock intensity induces a large separation bubble with intense turbulent transport

ABSTRACT

Supersonic slot-film cooling is a promising cooling concept for surface temperature reduction of engine components that experience high thermal loads. If shocks are present in these components, their interaction with the cooling film may change the fundamental structure of the flow field in the vicinity of the surfaces that require cooling, which in turn can reduce the cooling effectiveness. The scope of this study is to analyze the influence of the injection Mach number of the cooling film and the shock strength on the shock/cooling-film interaction. Two different cooling films with injection Mach numbers of $Ma_i = 1.2$ and 1.8 are injected beneath a turbulent boundary layer through a two-dimensional slot nozzle at a freestream Mach number of $Ma_\infty = 2.45$. Flow deflections of either $\beta = 5^\circ$ or $8^\circ$ generate shock waves with different strength which impinge upon the cooling film. The flow field of the shock/cooling-film interaction is investigated by means of high-speed particle-image velocimetry, and the time-averaged velocity fields and the Reynolds stress distributions are analyzed for three flow configurations. A high injection Mach number in combination with a low shock intensity shows moderate influence of the shock impingement on the cooling film. Lowering the injection Mach number or increasing the shock intensity leads to a highly disturbed flow with large separation bubbles. In these cases, the turbulent transport of heat and momentum between the cooling film and the outer flow is greatly increased. The results of the low shock strength cases are compared with large-eddy simulations. There is a reasonable agreement between the present study and the simulations with respect to the flow structure in the vicinity of the shock impingement position, the shock-induced transition of the laminar slot boundary layer, and the increase in turbulent transport.

Fig. 1 Mean streamwise velocity $\bar{u}/u_0$ on the centerplane for an injection Mach number of $Ma_i = 1.8$ and $8^\circ$ flow deflection.