Active Flow Control by Jet Injection on Shock-Boundary Layer Interaction Phenomena

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Improvement of fuel efficiency is an important issue for the development of high-speed transport vehicles. The shock wave-boundary layer interaction (SBLI) phenomena that are encountered when examining fuel efficiency must be considered because the complicated flow features, such as: (i) impinging oblique shock waves and their reflection, (ii) normal shock wave reflection, (iii) ramp flows, and (iv) shock-shock interactions all appear on a high-speed vehicle. Thus, understanding and control of SBLI is a key parameter for efficient combustion. There are two different flow control techniques: passive and active control devices. Passive devices, such as vortex generators and bleed air systems, cannot obtain optimal performance cover of a wide operational range because their performance is reduced at off-design conditions. Active devices, on the other hand, are flexible and can be tuned to various flow conditions. Active flow control devices such as: synthetic jets, plasma generators, and energy deposition mechanisms such as laser and microwaves, enable optimal flow modification. Although plasma generators and energy deposition systems are useful devices, high energy levels are often necessary, whereas, the jet injector can be implemented comparatively easier.

In this study, alternation of flow structures by jet penetration into SBLI regions have been experimentally investigated in an in-draft type supersonic wind tunnel. Three different models: flat plate, three-dimensional contour bump, and an open cavity were tested. Flow diagnostic techniques, such as particle image velocimetry, colour Schlieren, pressure-sensitive paint, and oil flow visualisation, were employed to provide an in-depth understanding of the flow characteristics. Figure 1 shows the typical experimental results which are the velocity field (top figure) and the density field (bottom figures). The flow characteristics are dramatically altered by the jet penetrating into the SBLI region. Jet injection as well as the reflected shock wave caused by SBLI induce a vortical flow, and the jet induced velocity field extends when the jet location moves upstream of the SBLI (top figure). For the cavity model, in the jet off case (bottom right figure), a reflected incident shock wave due to SBLI leads to the generation of a virtual bump at the cavity leading edge, and then a recompression shock wave behind this virtual bump is formed. These induced flow structures disappear when the jet is injected upstream of the cavity leading edge. These jet injections can contribute the enhancement of fuel-air mixing characteristics for propulsion systems. For the three-dimensional contour bump model (bottom left figure), a shear layer appears at the crest of the contour bump which is deflected slightly downwards by the jet induced shock. This deflected shear layer delays the appearance of flow separation at the valley of the contour bump, and the control of flow separation enables drag reduction. These experimental results indicate that the jet injection into SBLI has ability to control the flow structures for improvement of fuel efficiency.

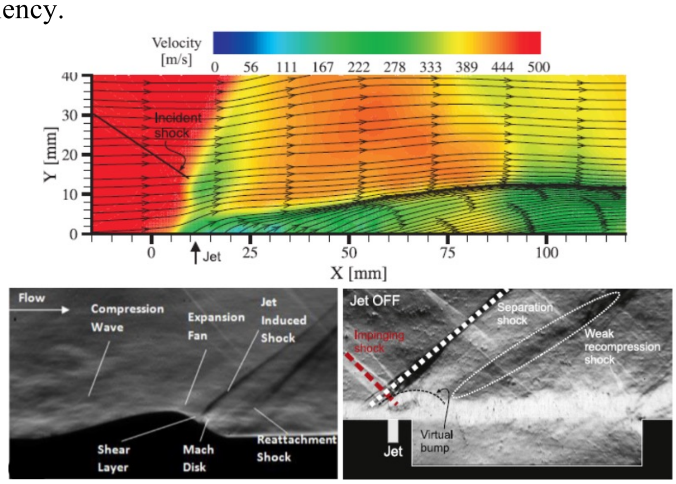

Figure 1, Top figure: the velocity field below the flat plate with jet injection upstream SBLI, bottom left figure: the density field below the three-dimensional contour bump with jet injection, bottom right figure: the density field below the open cavity without jet injection.