Chapter 6

Conclusion and Outlook

In the dissertation, a numerical study was based on the computation of RANS equations. The influence of a single synthetic jet on controlling the massive separations in airfoil and cascade flows was investigated.

Above of all, the performances of turbulence models were discussed because a reliable model is required before the flows are simulated. A modified k-ε model was proposed as the known turbulence models perform poor in reproducing the flow separated at mid portion or leading edge of the airfoil. The modified turbulence model corrects the production term in the k and ε equations through a dimensionless parameter related to the local pressure gradient, turbulent energy, and dissipation rate. The modification has influence at the leading and trailing edges, and in the near-wall region of the airfoil. In flow field far away from the airfoil, the production term is not corrected. The modified turbulence model was validated for an NACA63_3-018 airfoil at the angles of attack of 14 and 18 degrees at a Reynolds number of 300,000. The computational results from the modified model were compared with those from two other conventional models and the experimental data. Good agreement with the experimental data has been obtained from the results of the modified model in predicting the airfoil lift, drag, pressure, separation, etc. In comparison, the results from other turbulence models showed great deviation from the experimental data. It was made clear that the modified model is capable to reproduce the flow quantities of the airfoil at pre-stall and stall angles of attack. Therefore, the modified model was adopted to simulate the excitation of synthetic jet.

The systematical investigation of the synthetic jet on controlling the massive separation was conducted on the same NACA63_3-018 airfoil at stall angle of attack. The synthetic jet was simulated through a channel perpendicular to the airfoil surface. At the channel entrance, the velocity components were imposed to simulate the expelling and ingesting of the synthetic jet. The influences of jet frequency, jet intensity, and the location of excitation were discussed. Firstly, the frequencies of excitation ranged from 20 to 510Hz, corresponding to Strouhal numbers of 0.1 to 3.1, were simulated. The results showed that the synthetic jet is effective on controlling the massive separation. The response of the main flow to the excitation seems to be continuous. The synthetic jet influences the main flow through the separation region downstream of the orifice. The development of the downstream separation is determined by the frequency of excitation. The size of the separation region decreases with the increase of the frequency. With proper frequencies of excitation, the flow structure can be well rearranged and the flow losses can be reduced, although the large separation region cannot be completely removed by the synthetic jet. The airfoil drag can be reduced by 22% when the frequency of excitation has a value between 1.5 and 2 times the characteristic frequency of $f_c = u_\infty / (C \cos\alpha)$, where u_∞ is the free stream velocity, C the chord, and α the angle of attack. The characteristic frequency f_c relates to a time scale of the main flow passing through the airfoil in flow direction. Secondly, the influence of jet intensity was investigated through prescribing different velocities at the channel entrance. It was shown that with different jet intensities, the responses of the lift and drag of the airfoil to the frequency of excitation are similar in tendency. The jet intensity has little influence on the frequency range of efficient excitation at which the drag of the airfoil can be reduced maximally. However, the scales of the changes of lift and drag are larger with more intensive jet. The airfoil drag can be reduced by 22% from the jet of 15m/s while only by 8% from that of 2.5m/s. Finally, the influence of the location of excitation was studied. The result showed that the best effect (i.e. the maximal drag reduction) can be achieved when the synthetic jet is located at the natural separation point. When the jet is expelled and ingested at a location downstream of the natural separation point, the main flow is not well regulated as many low frequencies in the field are excited up, which leads to extra losses to the flow. It seems that there is certain coupling procedure between the natural instabilities and the disturbance from the synthetic jet. The coupling procedure can be most efficient when the excitation is located at the natural separation point on the airfoil surface. The frequencies of the shear-layer instability of the airfoil flow are difficult to capture because it is usually several hundreds of hertz. However, its average effect can be well obtained.

Like on single stalled airfoil, the massive separation on turbomachine blades may appear. The behavior of a synthetic jet on controlling the massive separation in cascade flow was studied through an unconventional axial stator-rotor arrangement. In the arrangement, the stator and rotor blades were constructed from an NACA63$_3$-018 airfoil with the same stagger angle of 50 degrees but adjusted in opposite directions. The massive separation on the stator blade is characterized by the enormous fluid masses involved in the separation region. The incident flow for the rotor blade is quite unsteady and changes its direction widely because the large separation on the stator blade sheds up periodically. Several small separation regions are on the blade surface. The flow losses are very high in the arrangement, as large pressure and mixing losses exist. The response of the flow to the excitation by the synthetic jet was investigated using a synthetic jet of 15m/s on the stator blade. The synthetic jet located at the natural separation point of 0.1% chord and had a frequency of 120Hz, which was inside the effective frequency range according to the conclusion from the control on the single stalled airfoil. The result showed that the synthetic jet of 120Hz is efficient in controlling the massive separation in the cascade flow. The large separation can be transformed into several small separation bubbles on the blade surface. The turbulent energy of high level exists only inside the separation bubbles. A laminar state in most of the flow field can be obtained with the synthetic jet. Additionally, the stator wake is regulated and stabilized, which forms a favorable inflow condition for the rotor blade. The rotor flow is fully attached. The drags of stator and rotor blades can be reduced by 50% and the loss of total pressure can be reduced to about one-third.

It can be concluded from the investigation in the dissertation that the synthetic jet is effective in controlling the massive separation in airfoil and cascade flows. However, there is still more to know to fully understand the exact mechanism, as not all aspects can be completed in one work. More comprehensive knowledge on the synthetic jet could be obtained if the influences of jet intensity and location of excitation on single stalled airfoil are further investigated. Moreover, the behavior of the synthetic jet in controlling the cascade flow would be another interesting topic for future research.

Also, experimental confirmation of the positive effects of the synthetic jet on stalled cascade flow is needed.