THE SUMMARY OF Ph. D. DISSERTATION

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Title

Control of Turbulent Separated Flow over a Backward-facing Step by Periodic Forcing

Abstract

The flow separation brings increasing of drag and decreasing of pressure recovery, which turn out to decrease the performance of fluid machineries. For this reason, the development of the flow control techniques to prevent or delay separation, and promote reattachment is desired. The objective of the present study is to promote the reattachment of separated flow by applying the periodic forcing. This control technique has been applied to separated flows over an aerofoil and bluff body. They commonly reported that there is a most effective frequency range for the periodic forcing. However, why the effect of forcing varies with the forcing frequency and why the most effective frequency exists are still unclear. This study aims to discover these issues by examining the detailed mechanism of the reattachment promotion by the forcing, and based on it, propose appropriate scaling law for the reattachment promotion to predict the most effective frequency. The flow configuration chosen for the test case was turbulent flow over a backward-facing step, a typical separated flow geometry with the fixed separation point, and periodic suction and injection was applied from the step edge. It was considered from the preliminary flow visualization experiments that the mechanism of the reattachment promotion concerned with the large-scale vortical structures induced by the forcing. To capture this vortical motion, two-dimensional particle image velocimetry (PIV) was employed for the flow-field measurement.

The relationship between the forcing frequency and reattachment length at fixed perturbation amplitude was first evaluated and confirmed that the reattachment length varied with the forcing frequency, and there existed a most effective frequency for the reattachment promotion. To clarify the effect of the perturbation on the momentum transfer enhancement, that realizes the reattachment promotion,

the Reynolds stress distribution was then investigated at the most effective frequency and surrounding two frequency cases. The results showed that the Reynolds stress was increased behind the step in any frequency cases tested. The region where the Reynolds stress was remarkably increased was, however, different among the frequencies. This region was observed in the recirculating and the reattachment region in the most-effective frequency case. On the other hand, in the lower frequency case, this region shifted to downstream. In the higher frequency case, the increase of the Reynolds stress was observed limited in the region immediately behind the step. Based on above observation, it was found that the necessary condition for the reattachment promotion is to increase the Reynolds stress in the region upstream of the reattachment zone. Moreover, it was revealed that the increase of the Reynolds stress is obtained from the turbulent motion produced by the periodic motion (indirect effect), rather than the induced periodic motion itself (direct effect).

The reason why the most effective frequency forcing realized this condition was investigated next, in terms of vortical structure. Based on the evaluation of the phase-averaged velocity and vorticity distribution synchronized with the forcing, it was revealed that the large-scale spanwise vortices, that direction of rotation was the same, are successively introduced. The phase-averaged vorticity and Reynolds stress distribution showed that the Reynolds stress was increased in the region between adjacent these large-scale vortices. This is the Reynolds stress produced by the vortical structure and corresponds to the indirect effect. In the most effective frequency case, two vortices always existed in the recirculating region. The number of vortices in the recirculating region was reduced in the lower frequency case because the size of the vortices were larger. In the higher frequency case on the other hand, the number of induced vortices increased but they disappeared immediately behind the step. From above observation, it was found that the necessary condition for the increase of the Reynolds stress in the upstream region of the reattachment zone is to introduce large number of strong vortices there.

Finally, the scaling law for the reattachment promotion was discussed. Since the induced large-scale vortical structures play a major role on the reattachment promotion, the most effective frequency should be expressed by the length scale and velocity scale of these vortices. The Strouhal number was therefore defined with the height of the separation bubble and convection velocity of these vortices. Using this Strouhal number, the most effective frequency of the present study and other back-step results was expressed by almost universal value even the expansion ratio, inlet flow condition and Reynolds number differ.