

## 9. SUMMARY AND RECOMMENDATIONS

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### 9.1 Summary of Results and Conclusions

An experimental study about an active separation control using vortex generator jets was conducted. The interaction of wall-jet flows with a freestream generates longitudinal vortices that persist further downstream and enhance mixing between a boundary layer and the freestream. For the flow field derived longitudinal vortices, the streamwise velocity, streamwise vorticity, and pressure recovery were measured. Moreover, flow visualization was used as a diagnostic technique to observe the flow condition. These data sets were used to investigate the effect of boundary layer condition and a jet pitch angle on separation control, and the mechanism for suppressing flow separation. Furthermore, we tried to develop an active separation control feedback system utilizing these results. Summarizing our results on the active separation control using vortex generator jets, the following conclusions could be drawn:

1. For the vortex generator jet method, separation control can be achieved without surveying boundary layer conditions before jets are issued.
2. The suppression of flow separation is achieved by the secondary flow of longitudinal vortices which transports high momentum fluid of the freestream toward the lower wall. The effective separation control is accomplished by keeping the location of

longitudinal vortices near the lower wall.

3. In order to suppress the upward movement of longitudinal vortices, it is desirable to produce no counter-rotating vortex pair of nearly equal strength.
4. For the suppression of generating the counter-rotating vortex pair of nearly equal strength, it is available 1) to derive the pulsed jet flow and 2) to adjust the jet pitch angle. These promote the interaction between positive and negative vortices, and as a results the generation of a vortex pair is prevented to be produced in the downstream direction.
5. Both the strength and the vertical position of longitudinal vortices are affected by a jet pitch angle and an optimal jet pitch angle may be less than 60 degrees.
6. If we can issue jets near the location where the flow separation occurs, the pulsed jet method is desirable. Longitudinal vortices generated by pulsed jets make effective separation control because the boundary layer thickness is not distorted in the spanwise direction. However, it should be noted that longitudinal vortices do not persist further downstream in comparison with the steady jet case.
7. If we cannot issue jets near the location where the flow separation occurs, the steady jet method is desirable. Longitudinal vortices generated by steady jets persist further downstream because the vorticity becomes stronger in comparison with the pulsed jet case. However, it should be noted that the boundary layer thickness is strongly distorted in the spanwise direction at some downstream locations.
8. An active separation control feedback system which has the ability to control adaptively the flow field of a diffuser caused by the change of flow situation (e.g., freestream velocity and

diffuser's divergence angle) is developed. Separation control of this system was made in reference to the static pressure only at two measurement points, in the upstream of the divergent portion and in the divergent portion.

## **9.2 Recommendations for Future Work**

Several observations made in this study could be more fully justified with measurements extending them to a region closer to the wall. In particular it would be helpful that the vortices in the boundary layer are investigated. These measurements would help in gaining a better understanding of the suppression mechanism of longitudinal vortices.

Our active separation control system is justified to be useful for suppressing flow separation in our wind tunnel tests. However, for the actual use of this system it is necessary to apply our system to a different freestream velocity range.

Lastly, it is greatly to be hoped that computational studies for finding the relationship between various parameters of vortex generator jets and the characteristics of longitudinal vortices (e.g., strength and downstream development) will be pursued.