Vortex Generator Composed of Micro Jet Array for Flow Separation Control

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We have designed a blowing type vortex generator to realize smart control of flow separation. The vortex generator is consisted of small jets properly distributed on wall surface. Therefore, the vortex generator is considered to minimize the extra drag compared to a solid type. The vortex generator was found to be able to generate a single longitudinal vortex near wall, which plays an important role in controlling flow separation.

1. Introduction

A blowing type vortex generator using small jets instead of a fixed solid vortex generator has been investigated aiming at a smart control of flow separation around airfoils. The solid type is known to be effective on suppressing flow separations and widely used at the intakes or airfoils of the airplane. However, we must remind the following fact: Even if usefulness of the solid type is emphasized, the themselves are the cause of extra flow drag. In other words, there is still a room for further improvement of the solid type. According to the above situation, the blowing type vortex generator begin to gather attention. Johnston et al. [1] showed that the vortex generator jets (VGJs) actually produced the longitudinal streamwise vortices. Compton et al.[2] found out the optimum skew angle of the jet. Scale of the vortices in their experiment was taken as the same as the thickness of the boundary layer for the purpose of simulating momentum exchange between the free stream and the boundary layer. Therefore, the mass flow rate of the jet was not necessarily small. Pulsed VGJs is a method to enhance the mixing process further. McManus et al.[3] indicated that the pulsed VGJs for separation control actually reduced the mass flow as compared with steady jets.

Since it is known that transition flow is greatly influenced by the vortices, in this study we have tried to elucidate behavior of the near wall longitudinal vortices in the boundary layer. Understanding the interaction between the longitudinal vortices and the boundary layer is inevitable for achieving smart, active control of flow separation around airfoils. As a first step a multiple micro jet system for generating longitudinal vortices are examined using low speed wind tunnel.

2. Method of Experiment

Figure 1 shows the test section of an open-circuit blower wind tunnel used for the measurements. The test section has cross section of 150mm x 150mm and length of 600 mm. Top view of the vortex generator consisting of multiple micro jets is shown in Figure 2. Exit of the jets are mounted flush on the wind tunnel wall. Number of the micro jet exit (darker area) increases along downstream direction, i.e. 1 exit at x = -13 mm and 4 exits at x = -1 mm. Under the jet exits is a common reservoir, which connects with a compressor. The blowing air from the jets is, therefore, provided by the compressor. The jet exit arrangement in Fig.2 was decided empirically to generate effectively the small, longitudinal vortices. Single micro jet arrays placed along the spanwise or the downstream directions were found to be hardly useful to generate the longitudinal vortices. Intensity of the generator jets are defined at the position x = -1.5mm, y = 3 mm, z = 5.75 mm, where the maximum jet velocity V_0 is achieved at this position (see Figure 3). The free stream velocity U_0 was set constant as 0.7 m/sec. The velocity measurement was conducted by using hot wire anemometry of I-type. For observing the vortex motion, velocities were measured at the downstream positions of x = 10 mm, 50mm and 100 mm with yz area of 3 mm < y < 29 mm and –10 mm< z < 20 mm. Each yz area was scanned at every 2 mm increment in both y and z directions. On the other hand, for observing the jet velocity profile, y coordinate was fixed at 3 mm with xz area of –16 mm < x < 2 mm and –1 mm < z < 9 mm. The xz area was scanned at every 1 mm increment in both x and z directions. Without the vortex generator operation the boundary layer thickness was 11 mm at x = 0 mm and z = 0 mm.

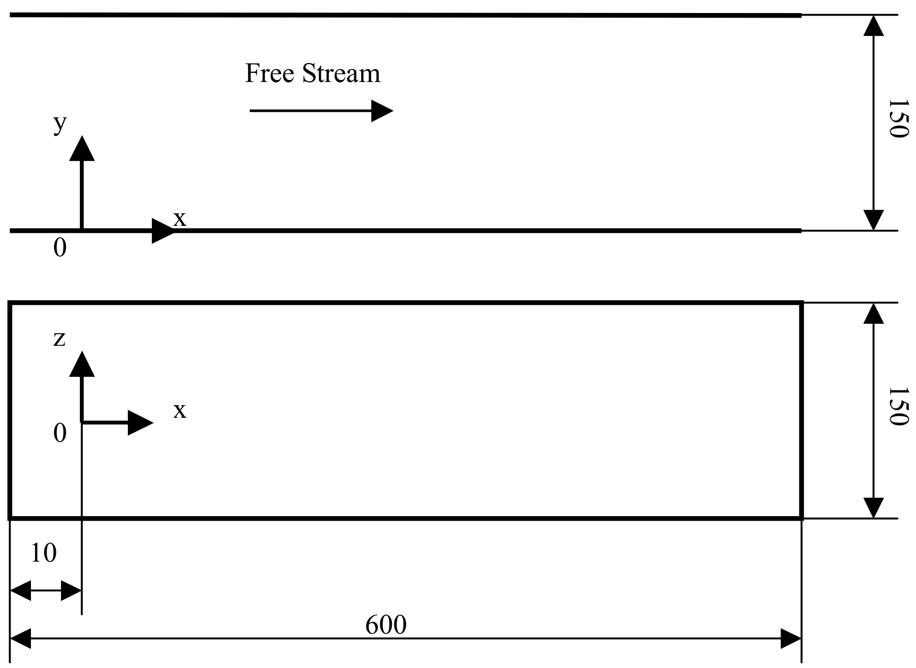

Fig. 1 Test section of the wind tunnel

3. Result

3.1 Jet velocity profile of vortex generator

Figure 3 shows the mean velocity contours (left) and the mean velocity distribution (right) generated by the four micro jet arrays under the condition of no free stream. In this case micro jet arrays form four separate contours or islands corresponding to them. For the case of jet velocity of V_0 = 0.7 m/sec, velocity gradient in spanwise (z) direction at x = -1 mm is steep. It is experimentally confirmed that steeper distribution is more preferable to generate the longitudinal vortices than less steep one.

3.2 Contours of velocity

Figure 4 shows mean velocity and figure 5 shows turbulence intensity at x = 10mm and 100 mm. The jet velocity was set V_0 = 0.7 m/sec. In this figure the free stream flows from behind to front of this sheet. Cross sectional patterns of the single longitudinal vortex are clearly observed at downstream of the vortex generator. Although the I-type hot wire probe is not necessarily suitable for the measurement of three dimensional flow field, formation of the vortex is still recognizable by the contours as shown in Figure 4. Low velocity region appears at the central part of the vortex. On the other hand, high turbulence intensity region appears on the vortex-free stream boundary due to flow interaction. In the left hand area of $z < 0$, high velocity region tends to near to the wall, while in the right hand area of 5 mm < z, the high velocity region does not come close to the wall compared to the left hand area. This means that the vortex rotates counter clockwise. The direction of the rotation was also confirmed by the flow visualization using the smoke wire. The vortex is found to be conveyed downstream keeping the same pattern.

4. Conclusions

The vortex generator consists of small jets, which are arranged 2-dimensionally on the wall surface. This type is considered to be very promising, because no surface obstacles which produce extra drag are not used. In this study we experimentally confirmed that the present vortex generator actually generated a single longitudinal vortex in the boundary layer. In the next step we will make more quantitative examination on the present vortex generator and try to optimize the system for the application to airfoils.

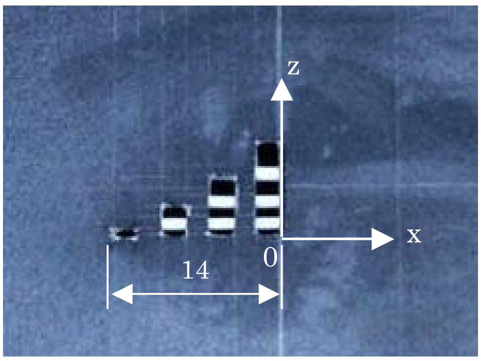

Fig. 2 Vortex generator

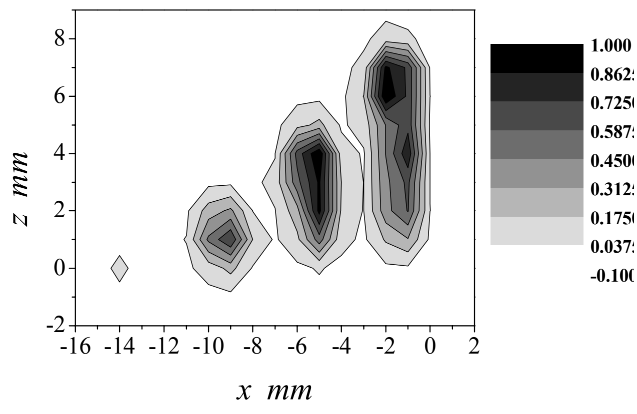

Fig. 3 Jet velocity profile of vortex generator

References

1. Johnston, J. P. and Nishi M., “Vortex Generator Jets-Means for Flow Separation Control,” AIAA Journal, Vol. 28, No. 6, Jun 1990, pp. 989-994.
2. Compton, D. A. and Johnston, J. P., “Streamwise Vortex Production by Pitched and Skewed Jets in a Turbulent Boundary Layer,” AIAA Journal, Vol. 30, No. 3, March 1992, pp. 640-647.
3. McManus, K. R., Legner, H. H. and Davis, S. J., “Pulsed Vortex Generator Jets for Active Control of Flow Separation,” AIAA Paper 94-2218, Jun 1994.

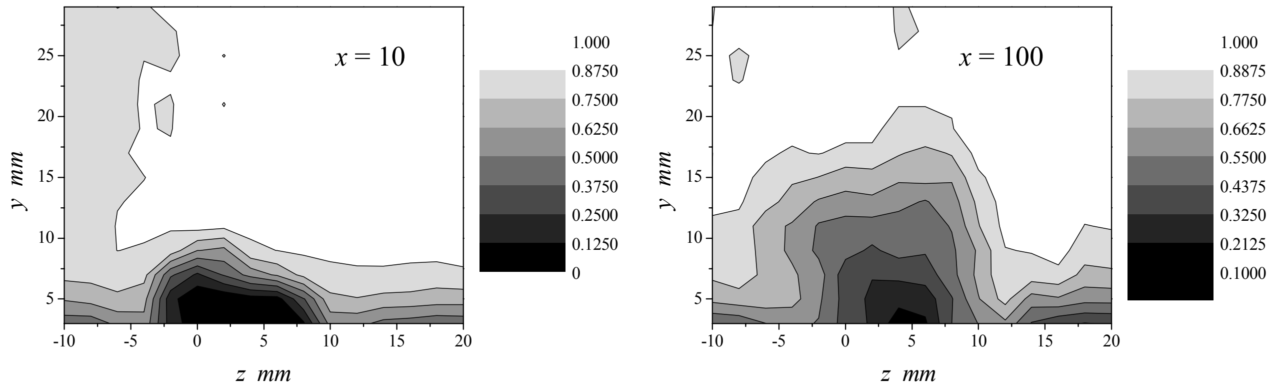

Fig. 4 Contours of mean velocity U/U_0

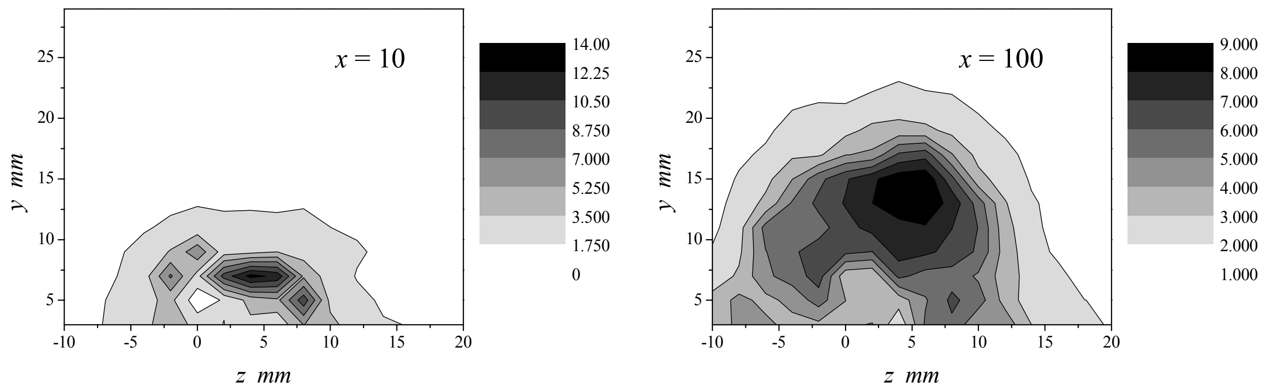

Fig. 5 Contours of turbulence intensity %