Management of a Longitudinal Vortex for Separation Control

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Solid (fin) type vortex generators are known to be effective on suppressing flow separations and widely used at various fluid mechanical elements such as intakes or airfoils of airplanes. But the solid type generators themselves are the cause of extra flow drag. In this study we designed a blowing jet type vortex generator to realize smart control of flow separation. The present vortex generators are consisted of small jets properly distributed on wall surface. Therefore, the present vortex generators are considered to minimize the extra drag compared to the solid type. The VG was found to be able to generate a single longitudinal vortex near wall, which plays an important role in controlling flow separation.

1. Introduction

Control of flow separation is one of the most important fluid engineering subjects and has been studied by many researchers. To date, however, compact control system, which can be installed in actual elements, such as airfoils, seems to be not yet completed. Recent development in micro-machining, precise flow observation and simulation techniques give us motivation of trying to establish smart flow control system. In this subgroup we consider the separation control system around an airfoil. As a part of establishment of control system, we investigate a new type of actuator for the system.

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 an airfoil. 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, they are the cause of extra flow drag. Further improvement is needed. According to the above situation, the blowing type vortex generators are gathering 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. A device for generating longitudinal vortices have 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 a cross section of 150mm x 150mm. Figure 2 shows the vortex generator with multiple holes (first model). Exit of the jets are mounted flush on the wind tunnel wall. Number of the jet exit (darker area in the left hand side of Fig.2) increases along downstream direction. Right hand side of Fig.2 shows how the small jets issue and resulting vortices. Under the jet exits is a common reservoir connected with a compressor. The blowing air for the jets is provided by the compressor. The jet exit arrangement 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.[4, 5] Figure 3 shows the vortex generator of slit type (second model). The vortex generator is consisted of three slits, and each jet can be separately controlled by regulator. Therefore, it is possible to change shear flow profile by jets. The free stream velocity U_0 was set constant as 0.7 m/sec or 1.0 m/sec. The velocity measurement was conducted by using hot wire anemometry of I-type for boundary layer. For observing the vortex motion, velocities were measured at the downstream positions of x = 50 mm, 100 mm and 200 mm with yz area of 3 mm < y < 30 mm and –20 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 0.5 mm or 1 mm increment in both x and z directions.

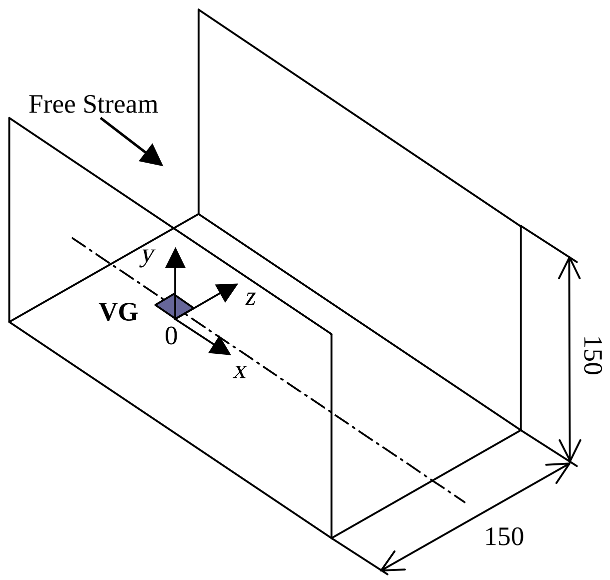

Fig. 1 Test section of the wind tunnel

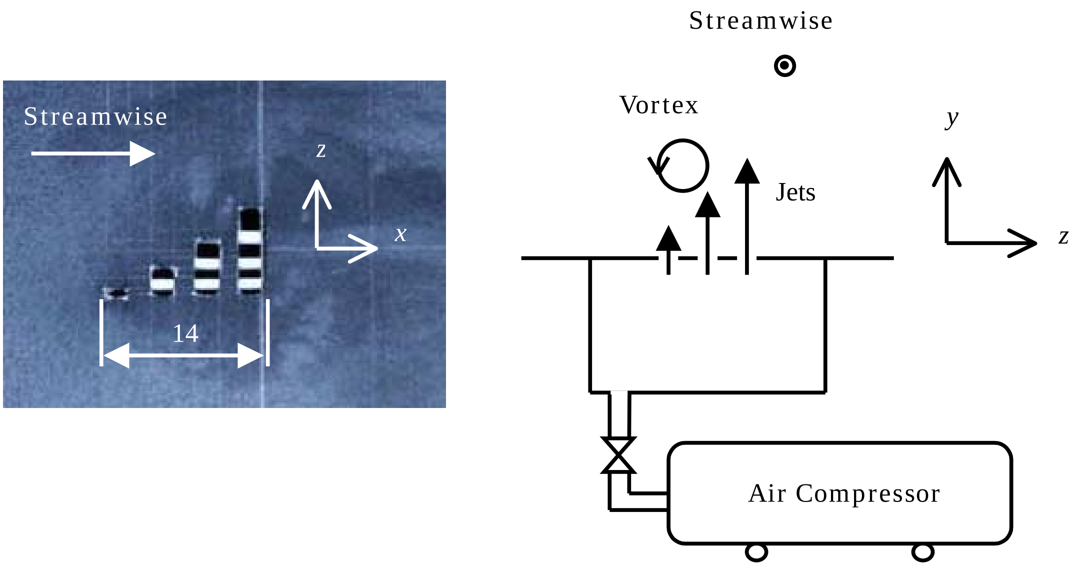

Fig. 2 Vortex generator of multiple hole type

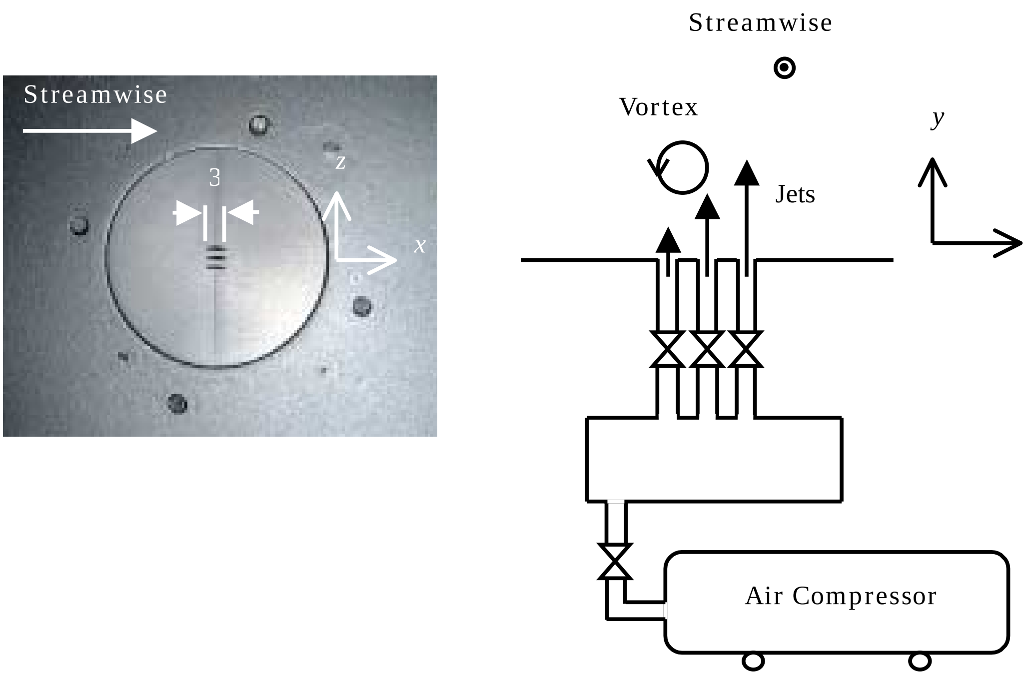

Fig. 3 Vortex generator of slit type

3. Result

3.1 Vortex generator : Multiple hole type (first model)

Figure 4 shows the mean jets velocity distributions on the vortex generator of multiple hole type, and the mean velocity distributions at the cross section of x = 50 mm. The free stream velocity U_0 was 0.7 m/sec. Cross sectional patterns of a longitudinal vortex are clearly observed. They are found to be dependant on the jet velocity distributions controlled by the maximum jet velocity. In the case of the pattern 2 (V_{max} = 1.4 m/sec), a pair of counter rotating vortices appears. That is, the jets velocity distribution of this case seems to work like a single, normal jet. Note that the contours of the vortices are not symmetrical. The left vortex rolls up the right one quickly and the both vortices extend drastically. This implies that left vortex is stronger than the right one. In case of pattern 1 (V_{max} = 0.7 m/sec) and 3 (V_{max} = 2.1 m/sec), the entire velocity gradient in spanwise (z) direction is steeper than pattern 2. A single longitudinal vortex is formed at region with steeper velocity gradient. It is experimentally confirmed that steeper velocity distribution is more preferable to generate a single longitudinal Fig.4, vortex above wall than the distribution with less steep. In Fig.4, patterns 1 and 3 result in a counter clockwise vortex formed at the steeper velocity gradient. However, the vortex structure by the pattern 1 is different from that by pattern 3. Comparing the vortex by the pattern 1 with that by 3, the vortex by pattern 1 moves near wall to down stream, while the vortex of pattern 3 goes up from wall quickly. What should be noticed is that the vortex structure varies on maximum jet velocity. However, in this multiple hole type, precise design of the vortex structure is found to be difficult. Therefore, we tried the next slit with valve type.

3.2 Vortex generator : Slit with valve type (second model)

For this type of vortex generator, we are now making experiment. Therefore, complete data have not yet been obtained. Figure 5 shows mean velocity distributions at the cross sections of x = 50 mm, 100 mm and 200 mm. The free stream velocity U_0 was 1.0 m/sec. The maximum jet velocity was set constant as 8.0 m/sec. However, Figs. (a) to (c) show the pattern 1 of vortex rotates clockwise, and the figures (d) to (f) show the pattern 3 of vortex rotates counter clockwise. Thus, the slit type vortex generator is supposed to generate various vortex patterns easily.

4. Conclusions

We have tried to design a sophisticated blowing type vortex generator to realize smart control of flow separation. The present vortex generators are consisted of multiple holes or three slits on wall surface. These types are considered to be very promising, because no surface obstacles which produce extra drag are not used. In this study the vortex generators were experimentally confirmed to generate a longitudinal vortex. Especially, the slit type was found to be able to control the longitudinal vortex by controlling intensity of individual jet.

References

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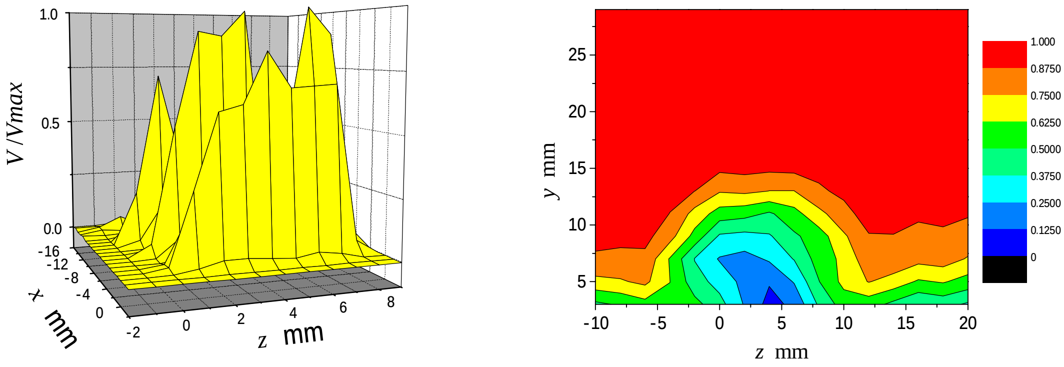
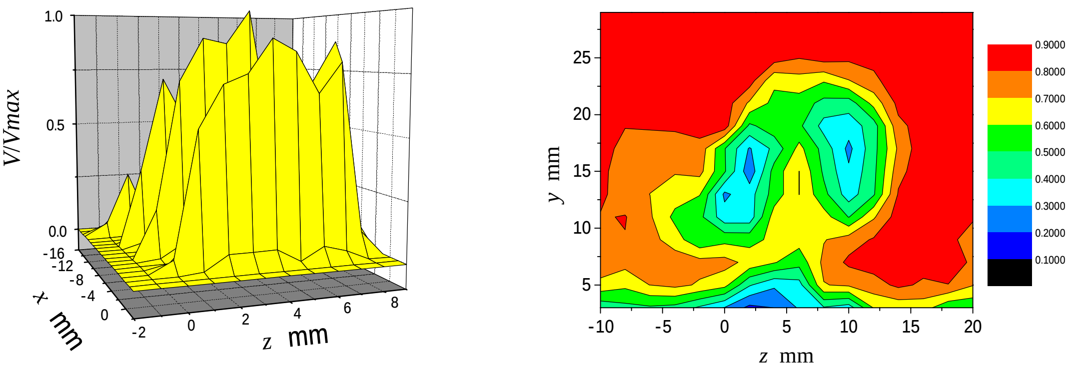
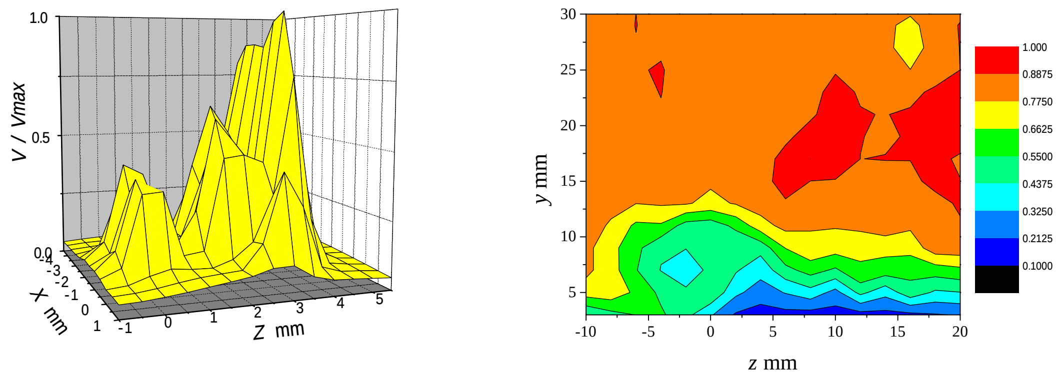


(a) Pattern 1, V_{max} = 0.7 m/sec

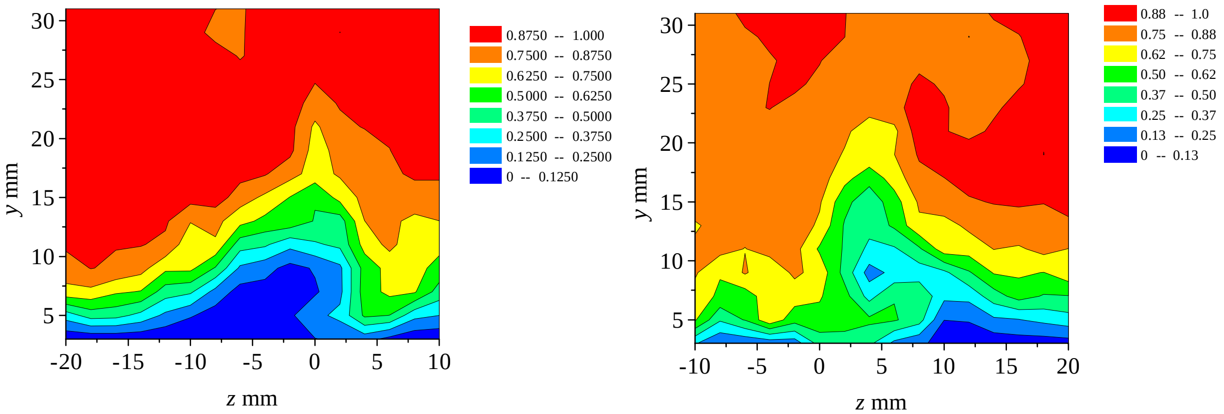


(b) Pattern 2, V_{max} = 1.4 m/sec

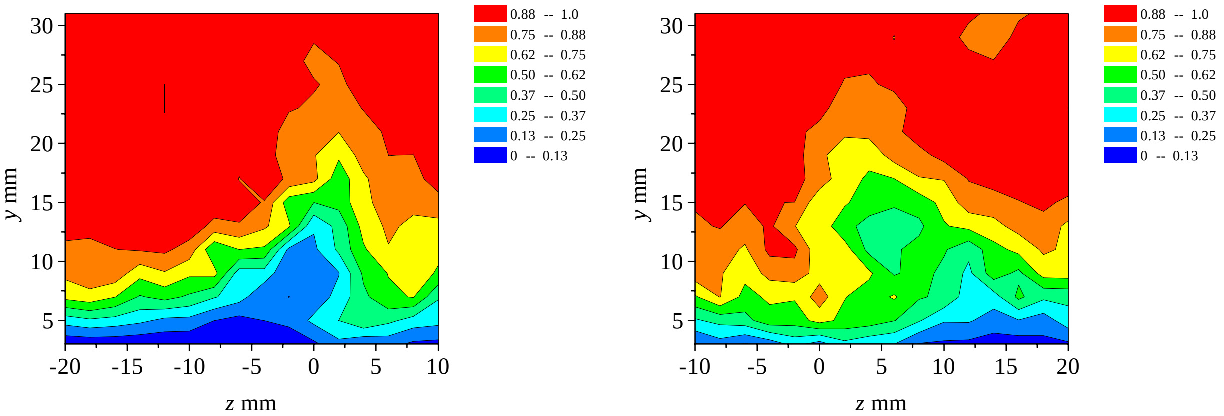


(c) Pattern 3, V_{max} = 2.1 m/sec

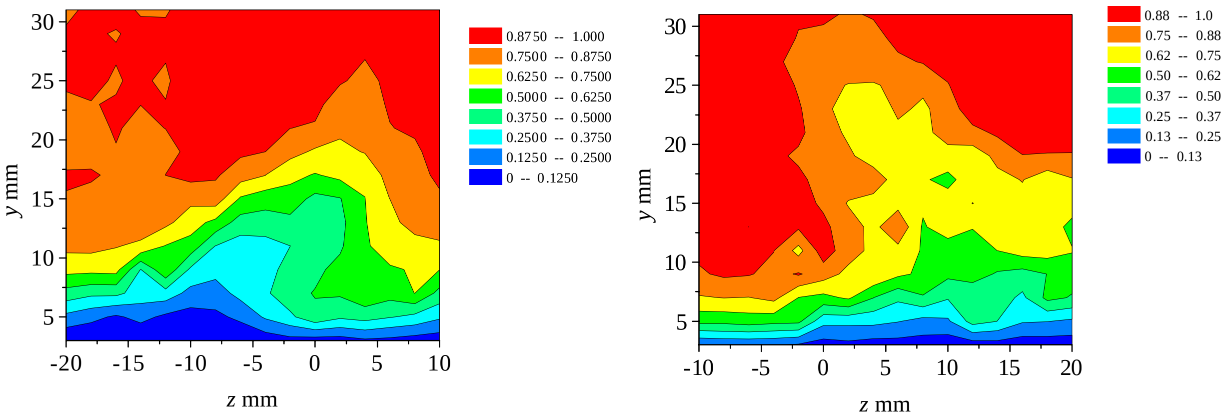
Fig. 4 The mean jets velocity distributions of the vortex generator of multiple hole type (left side), and the mean velocity distributions at a cross section of x = 50 mm (right sade)



(a) x = 50 mm



(b) x = 100 mm



(c) x = 200 mm

Fig. 5 The mean velocity distributions at down stream by the slit type vortex generator

Left figures : clockwise vortex, right figures : counter clockwise vortex