TOWARD SMART CONTROL OF SEPARATION AROUND A WING
- Active Control Device part 2 -

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In order to establish smart control system for wing separation, micro jet vortex generator (MJVG) was developed. By using MEL001 wing section, effect of MJVG on the lift was confirmed. Under a certain condition, MJVG appreciably enhance the lift performance. Those results give us valuable hints to improve control strategy. Simultaneously, piston type (suction / blowing) magnetic actuator was developed successfully. Moreover, new cantilever sensor with higher robustness is under development. Those control devices will be assembled to establish a smart control system for the separation.

1.Introduction

Control of flow separation is one of the most important fluid engineering subjects and has been studied by various researchers. To date, however, compact, self-contained control system, which can be installed in actual fluid engineering elements seems to be not yet completed. Recent development in the fields of micro-machining, precise flow observation and simulation techniques gives us motivation of trying to establish smart flow control system. We consider the separation control system around airfoil. The system should be useful to not only improve aerodynamic performance of the wing but also to suppress aerodynamic noises. As a part of establishment of control system, we have been investigated micro jet vortex generator (hereafter, MJVG).

A blowing type vortex generator (hereafter, VG) using small jets instead of a fixed solid vortex generator has been studied for smart control of flow separation around an airfoil. The solid type is known to be effective on suppressing flow separation and widely used at the intakes or airfoils of the airplane. However, we must remind that the solid type VG is always accompanied by the extra flow drags. According to this situation, the blowing type VGs are gathering attention. Johnston et al.[1] showed that the VG jets actually produced the longitudinal streamwise vortices. Compton et al.[2] found out the optimum skew angle of the jets. 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 VG jets are a method to enhance the mixing process. McManus et al.[3] indicated that the pulsed VG jets for separation control actually reduced the mass flow as compared with the steady jets.

In this paper, we will introduce our results obtained in this fiscal year.

2. Vortex Generator

Figure 1 shows a concept of the vortex generator. Exit of the jets are mounted flush on the wind tunnel wall (or airfoil surface). The each jet can be separately controlled by regulator valve. Therefore, it is possible to control shear flow profile over the jet holes. The distribution of jet velocity was decided empirically to generate effectively the single longitudinal vortex. Here we note that VG with single jet hole was found to be hardly useful to generate the longitudinal vortices.[4, 5]

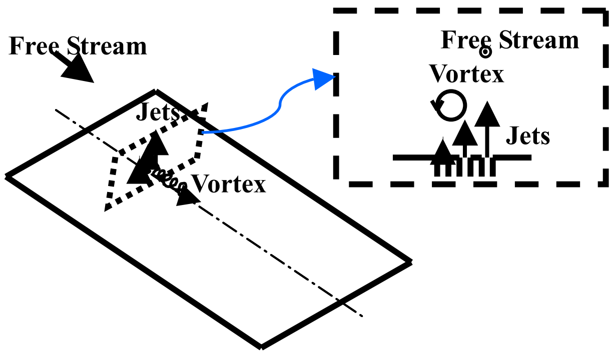

Fig.1 Concept of MJVG for producing arbitrary longitudinal vortices.

3. Pressure Fluctuation Around Separation Points at High Attack Angle

In order to obtain clues for improving control strategy, we measured pressure fluctuation around the short bubble by using piezo-pressure sensors. Figure 2 shows normalized frequency F of the pressure fluctuation as a function fo chord-Reynolds number Re at separation point on the airfoil, MEL001, which was designed for a windmill. The airfoil has chord length of 300 mm, span length of 500 mm. Though the aspect ratio is not enough because of space of installed pressure transducer at every 10 mm to chord-wise, the boundary layer fences were fitted around each edge of the airfoil to keep two dimensions flow. Some pressure transducers were installed around the separation points at high attack angles, and especially we analyzed short bubble at attack angle of 13 degree and position of x/c = 0.10, and turbulence separation point at attack angle of 16 degree and position of x/c = 0.57. Where, x is coordinate axis of chord-wise and c is chord length. In case of short bubble, the normalized frequency F increases slowly with the chord-Reynolds number Re. On the other hand in the case of turbulence separation, F varies as Re. F for each separation is characteristic of changing to Re, therefore we can separate their separations and we can guess formation of separations. There shows us that the pressure transducer must be installed points within error of 10 mm to chord-wise, and it need to catch the signal of turbulence separation that we must watch the signal in wide range of frequency [6].

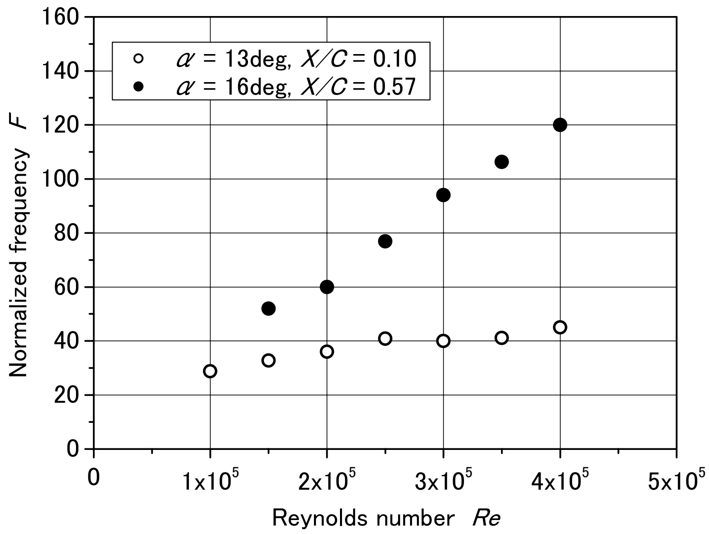

Fig.2 Pressure fluctuation as a function of chord Reynolds number *Re*

$F = f \cdot c / U$, $Re = U \cdot c / v$, f : frequency, c : chord length, U : velocity of free stream, v: viscosity

4. Effect of MJVG on the Lift of MEL001

Figure 3 shows MEL001, chord length of 300 mm, installed the vortex generator system. The airfoil is consisted of the vortex generator VG located on suction surface to span-wise at (a) x/c = 0, (b) x/c = 0.3, air tanks and some sensors. The airfoil is supported by cantilever connected a load cell. Compressed air for the vortex generator is supplied from outer. Figure 4 shows coefficient of lift C_L to attack angle α obtained this airfoil. *Va* is maximum velocity of jet on VG at x/c = 0, and *Vb* is maximum velocity of jet on VG at x/c = 0.3. The jet velocity was measured by a single hot-wire at height of 5 mm on surface of the airfoil. In case of without VG, C_L decreases as decreasing *Re* in low α because of laminar separation at near x/c = 0.4, and in high α because laminar separation at leading edge. These tendencies are appeared on an airfoil in low *Re*. This time, we tried VG at 6 degree as low attack angle and 20 degree as high attack angle in low *Re* of 1.0×10^5. As a result, it is sure that VG has an effect on improvement of C_L, if VG is controlled at optimum position to a separation type on the airfoil.

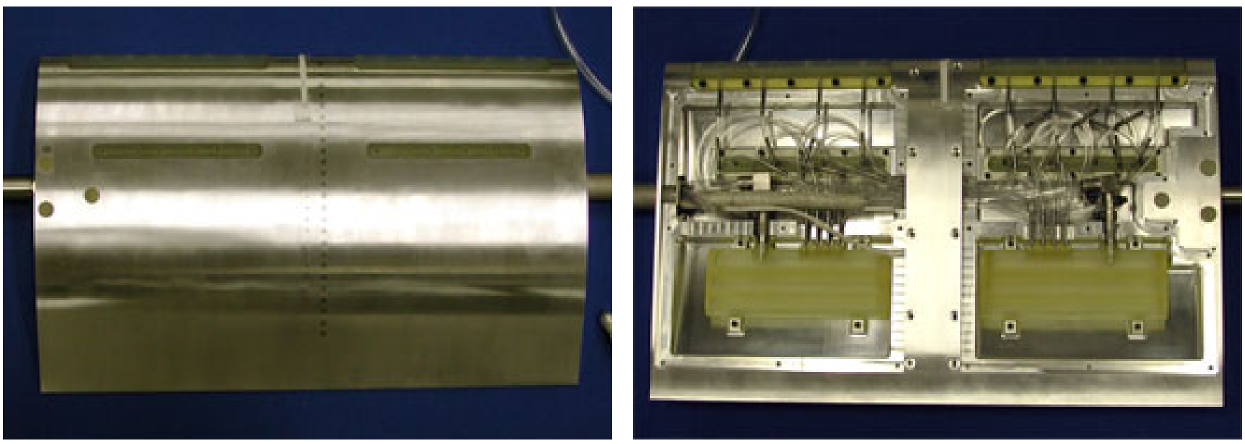

Fig. 3 MEL001 wing section installed MJVG.

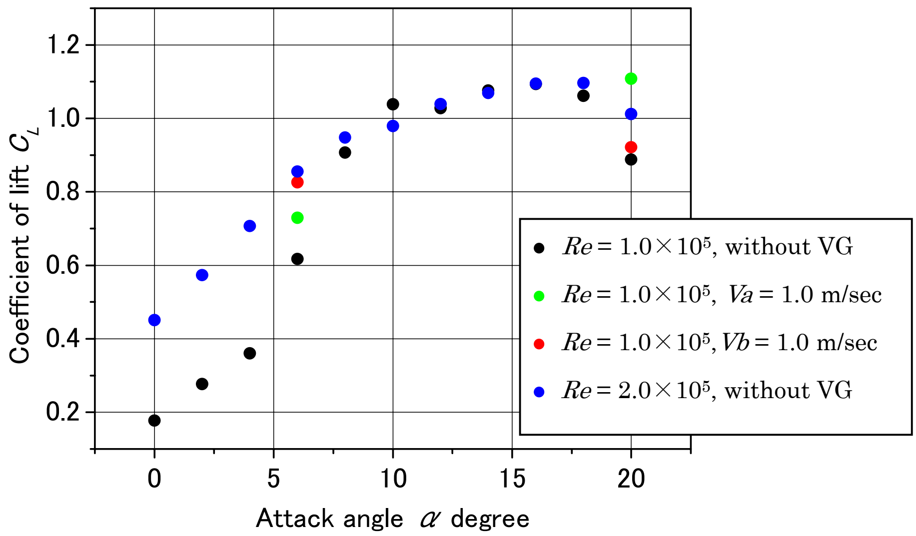

Fig.4 Effect of the MJVG on the lift coefficient of MEL001 airfoil.

5. Small Piston Type Actuator

In addition to the MJVG, small piston type, suction / blowing, actuator is developed simultaneously. The driving principle and geometry are shown in Fig.5. A pair of magnets, each one is 9 mm diameter, 3 mm thick and 2 g weigh, is placed at the neutral position. The magnets are connected by cylindrical spring rubbers in the both sides. Winding directions of the coils in the both sides of the magnet are opposite so as to generate forces, which tend to bring the magnet towards the neutral position. Jet cross section is 1mm X 2 mm. Figure 6 shows the time variation of the jet velocity generated by the actuator. The velocity was measured by a hot wire anemometry at 5 mm above the jet exit. As can be seen from the figure, the maximum velocity of 7 m sec^{-1} was observed at 40 Hz oscillation. The actuator will be installed in the MEL001 wing section and its control effect will be confirmed soon.

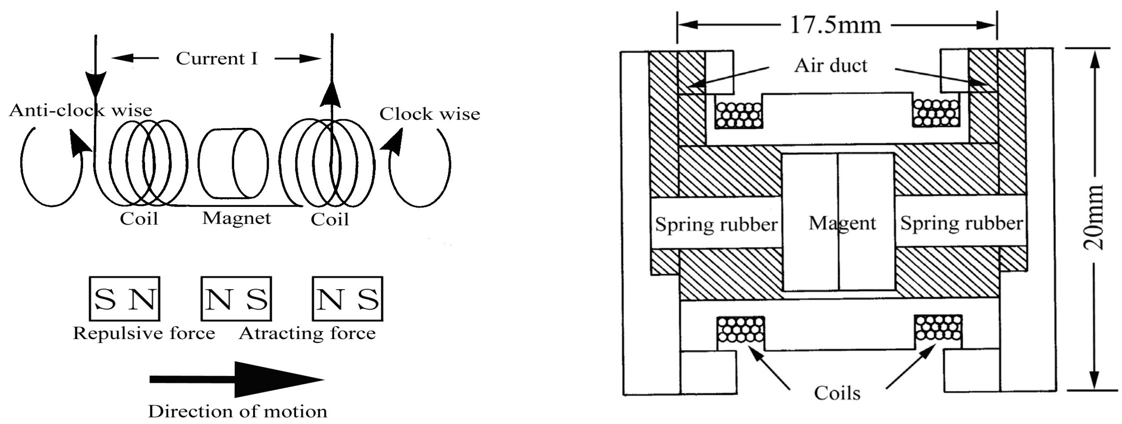

Fig.5 Magnetic suction/blowing actuator developed.

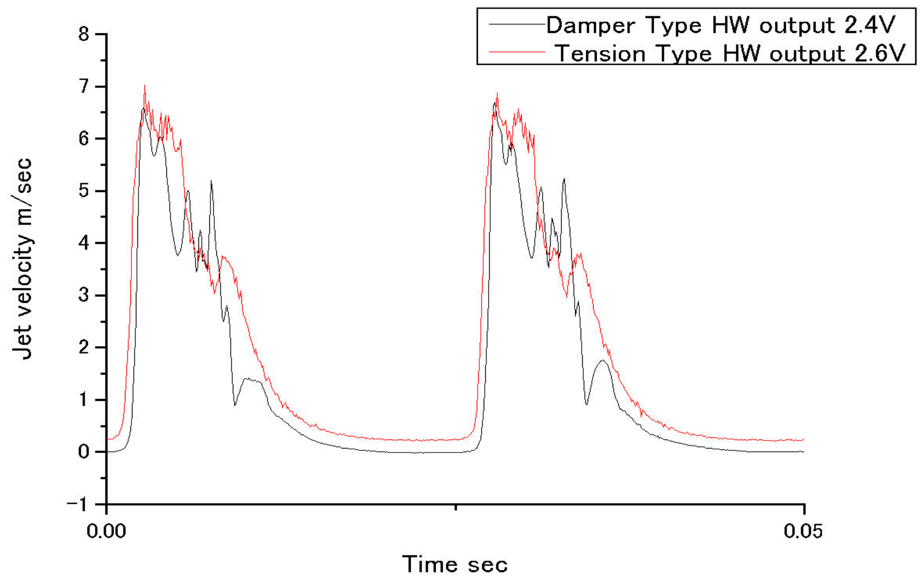

Fig.6 Jet issued by the actuator. Velocity was measured by a hot wire at 5 mm above the jet exit. Driven at 40 Hz frequency.

6. New Cantilever Sensor

So far the Ozaki and Shimoyama's cantilever sensor[7] has found to be very useful for discriminating flow direction as reported by Nishizawa et al. [8] in the last Symposium. However, in the former type sensor the thin cantilever is directly exposed in the flow without any protection. Thus we are fabricating new cantilever sensors with high robustness and functions at MEMS foundry in AIST.[9]

It is considered that when the separation appears somewhere on the suction surface of the wing and moves to and fro, the circulation around the wing varies due to the variation of the separation point. As a result the stagnation point near the leading edge also varies according to the variation of the separation point. In other words, flow direction near the leading edge varies by the location of the separation. This means that the flow direction discriminator like the cantilever sensor should be installed around the leading edge in order to detect information on the separation. Related figures are not shown here, because of the patent process.

7. Conclusion

We have developed a sophisticated blowing type vortex generator, i.e. micro jet vortex generator (MJVG)[10] , which consists of multiple holes. Each micro jet from the hole can be regulated independently. Since MJVG does not have any extruding part unlike conventional solid type vortex generator, extra flow drags by VG can be minimized. By installing MJVG in MEL001 wing section, preliminary test was carried out. It was found that MJVG appreciably improve the lift behavior of the MEL001 wing section under certain conditions. Those results give us valuable hints for designing active control strategy.

Moreover, we successfully developed a piston type, suction / blowing, actuator for other candidate of the control actuators. Also a new type of the cantilever sensor with high robustness is now under development In the next step, we will construct an active control system using devices developed so far and install them in MEL001 wing section to verify the control effect.

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