TOWARD SMART CONTROL OF SEPARATION AROUND A WING

S. Takagi, N. Tokugawa, A. Nishizawa,
National Aerospace Laboratory of Japan, Chofu, Tokyo, 182-8522
H. Abe, Y. Kikushima, R. Maeda, H. Yoshida,
National Institute of Advanced Industrial Science & Technology, Namiki, Tsukuba, 305-8564

Abstract

In order to establish basis of a smart control system for separation around wing, two kinds of experiments were performed. The first attempt was made to detect separation flow in use of a new receptor sensor on the slope simulating upper wing surface. It was shown that the output of the sensor in sign works well as flow-direction discriminator. In the second attempt, it was confirmed that laminar boundary layer is sensitive to separation, while turbulent flow is tolerable to separation. In the present study separation was prevented by using a static, roughness element. Results of the separation prevention experiment gave us important hints regarding specification of electrically activated devices, which, in place of static element, are indispensable to an integration system of smart separation control

1. INTRODUCTION

Control of flow separation has been obviously one of the most noticeable fluid engineering subjects. It has great impact on the performance of air, land, and sea vehicles; turbomachines; diffusers; and a variety of other technologically important systems involving fluid flow (Gad-el-Hak 2000). To date various actuation methods of control of flow separation have been attempted. For example, Ahuja and Burrin (1984) and Hsiao et al (1990) used acoustic excitation for control. Neuburger and Wygnanski (1987) used vibrating ribbon to delay separation. By using synthetic jet technique, Glezer’s group (1999, 2001) has carried out separation control and virtual-shaping of airfoils. So far, experience and knowledge on the active flow control have been accumulated though, as pointed out by McCormick et at (2001), packaging of a self-contained actuator inside the confined leading edge of the airfoil is a significant challenge. In other word, establishing a compact control system, which can be installed in a small wing, is an important subject.

One of the goals in the MEMS subgroup is to establish the basis of smart, i.e. feedback and/or feedforward, control system of flow separation around wings. So far, this subgroup has investigated the possibility of thermal multi-sensors as separation detector on circular cylinder body and airfoil (Takagi et al. 2001). Prior to an integration of separation detection-prevention system, the present study is focusing on independent establishment of separation-detection and separation-prevention techniques with the use of a new small surface sensor (Ozaki et al. 2000), which has been originally developed for a model of wind receptor hairs of insects. Regarding actuators for smart control of separation, Abe et al (2001a,b) are developing integrated micro jet vortex generator (MJVG), which is considered to be more sophisticated than the former solid fin type VGs.

2. EXPERIMENTAL APPARATUS

2.1 Wind Tunnel

A small wind tunnel as shown in Fig.1 was prepared for the present experiment. This tunnel has a cross section of 40mm by 40mm at the exit following the nozzle with a contraction ratio 6.25 in area. The velocity at the nozzle exit was set approximately 8m/s for the present study. In a test section, as a false floor a test plate made of 0.1mm thick steel was installed 5mm above the exit wall in order to avoid oncoming boundary layer. New laminar boundary layer developing on the plate encounters adverse pressure gradient downstream and separates somewhere on the constant slope region with an angle of 16° except the corner region. A 2mm diameter two-dimensional cylindrical roughness element was adhered on the test plate at 5mm from the leading edge in order to force laminar boundary layer to be turbulent.

2.2 Separation detector

A new reverse-flow detector was installed at the entrance of the slope, where flow separation apparently occurs according to preliminary hot-wire anemometer measurements when boundary layer is laminar. This sensor made use of MEMS technology consists of five independent cantilevers in line, which are perpendicularly extruded from the test plate, but three sensors are active with a length of 0.4, 0.8 and 1.2mm, a width of 0.23mm and a thickness of 0.01mm. Each element has a strain gauge at the root near the base so as to interpret flow direction: the sensor output for reverse flow indicates the negative sign, and verse versa. In this experiment, the longest cantilever in three was used together with an amplifier (TEAC Model SA-59) with an excitation voltage of 10V and a DC gain of 400. More details on the gauge are given in Ref. 5.

2.3 Hot-wire anemometer and data reduction

Profiles of the mean and fluctuating velocities in boundary layers developing on the plate were measured by means of a conventional constant-temperature hot-wire anemometer. The anemometer output was analogously linearized using a high sensitive pressure transducer (Sayama Trading Model S130-250P-DG) connected to a Pitot static tube in uniform flow. The hot-wire sensor mounted on a 2-D traversing mechanism was manually moved. The outputs from the anemometer and the separation detector were acquired and reduced by an FFT analyzer (Ono Sokki Model CF-5210).

3. RESULTS AND DISCUSSION

3.1 Characteristics of basic flow

Figure 2 shows profiles of mean and fluctuating velocities above the plate measured at three locations 70mm, 90mm and 110mm from the leading edge of the plate. The boundary layer at 70mm is laminar and turbulent fluctuation intensity is about 1% free-stream velocity except for the near wall. The boundary layer at 90mm in the vicinity of the entrance of the slope is still kept laminar but nearly separated. Further downstream at 110mm, complete separation is observed. At the same time, velocity fluctuation is suddenly increased near the wall. At this location, instantaneous velocity waveform at the maximum position on the fluctuation profile and its corresponding power spectrum are illustrated in Fig.3. Waveform is found to be dominant due to periodic component at the center frequency of about 500Hz in the spectrum. This component is certainly amplified due to instability of inflectional shear layer on the separation bubble. Although it is judged from the mean and fluctuating velocity profiles that the flow at 110mm is separated, it is noteworthy to note that it is hard to interpret the flow direction from one instantaneous hot-wire signal captured at 110mm very near the wall (Fig. 4). This is the reason why hot-wire anemometer does not indicate the flow direction but the magnitude of velocity.

On the other hand, once a 2-D rod placed near the leading edge of the plate disturbs the boundary layer, behavior of the turbulent boundary layer is completely different as shown in Fig. 5. It seems that separated flow is swept away and eventually forward flow is dominant.

3.2 Detection of reverse flow

In order to make sure of the results from hot-wire anemometer, a separation detector was installed at 110mm. The outputs of the sensor are shown in Fig. 6(a) and (b) for laminar flow and in Fig. 6(d) and (e) for turbulent flow. For laminar case, the averaged sensor output is negative, which means that the flow is reverse, while the sensor output becomes positive for the case disturbed by the roughness element near the leading edge. It turns out that this observation is consistent with the hot-wire measurement. It is also interesting to point out that the sensor detects the same periodic component as the aforementioned result. In reality, a spectral analysis of waveform as shown in Fig. 6(c) peaks at a frequency component of 500Hz. Such a frequency is not due to the resonance of the cantilever, because if the uniform flow is decreased, the frequency is also decreased. This documents that the new sensor responds to fluid motions up to a frequency of 500Hz. It is found that the new sensor as direct indicator of flow direction has excellent characteristics unlike a single hot-wire anemometer.

4. CONCLUDING REMARKS AND NEAR FUTURE PLAN

In the present study, two kinds of experiments have been performed. The first attempt was made to detect separation flow in use of a new receptor sensor on the slope simulating upper wing surface. It was shown that the output of the sensor in sign works well as flow-direction discriminator.

The second showed that laminar boundary layer is sensitive to separation, while turbulent flow is tolerable to separation. In the present experiment, separation was prevented by using a static, roughness element though, results of this attempt gave us great hints to develop electrically activated devices, which are indispensable to an integration system of smart separation control as aforementioned in the Introduction. Based on those results, characteristics of several devices such as micro vortex generator, electrostrictive actuators and so forth are being investigated simultaneously.

Acknowledgements

An air-flow sensor used as separation detector in this study was given by courtesy of Professor Shimoyama, Department of Mechano-Informatics, the University of Tokyo. The authors would like to express their sincere appreciation.

References

Abe, H., Segawa, T., Matsunuma, T., Yoshida, H., 2001, "Vortex generator composed of micro jet array for flow separation control", *Proc. 2nd Symp. Smart Control of Turbulence*, Univ. Tokyo, March 4-6, pp.117-120.

Abe, H., Segawa, T., Matsunuma, T., Yoshida, H., 2001, "Micro jet vortex generator for active control of flow separation", *Proc. International Conference on Power Engineering, ICOPE*, Oct.8-12, 2001, Xi'an China.

Ahuja, K.K., Burrin, R.H., 1984, "Control of flow separation by sound", *AIAA paper*, 84-2298.

Chatlynne, E., Rumingny, N., Amitay, M., Glezer, A., 2001, "Virtual aero-shaping of a Clark-Y airfoil using synthetic jet actuators", *AIAA paper*, 2001-0732.

Gad-el-Hak, M., 2000, *Flow control*, Cambridge Univ. Press.

Glezer, A., 1999, invited lecture, "Shear flow control using fluidic actuator technology", invited lecture in the *1st Symposium on Smart Control of Turbulence*, Dec.2-3, 1999, Tokyo, pp.39-45.

Hsia, F-B., Liu, C-F., Shyu, J-Y., 1990, "Control of wall-separated flow by internal acoustic exciteation", *AIAA J*. 28(8), pp.1440-1446.

McCormick, D.C., Lozyniak, S.A., MacMartin, D.G., Lorber, P.F., 2001, "Compact, high-power boundary layer separation control actuation development", *ASME paper* FEDSM2001-18279.

Neuburger, D., Wygnanski, I., 1988, "The use of a vibrating ribbon to delay separation on two dimensional airfoils: Some preliminary observations", in Proc. Workshop II on Unsteady Separated Flow, ed. J.M. Walker, Frank J. Seiler Research Laboratory Report No.TR-88-0004.

Ozaki, Y., Ohyama, T. Yasuda, T. and Shimoyama, I., 2000, "An air flow sensor modeled on wind receptor hairs of insects", in *Proc. MEMS 2000*, Miyazaki, Japan, Jan. 23-27, pp.531-536.

Takagi,S., Tokugawa,N., Yoshida,H., Abe,H., Atobe,T., Yamamoto,K., 2001, "Observation and control of separation from bluff bodies", *Proc. 2nd Symp. Smart Control of Turbulence*, Univ. Tokyo, March 4-6, pp.121-126.

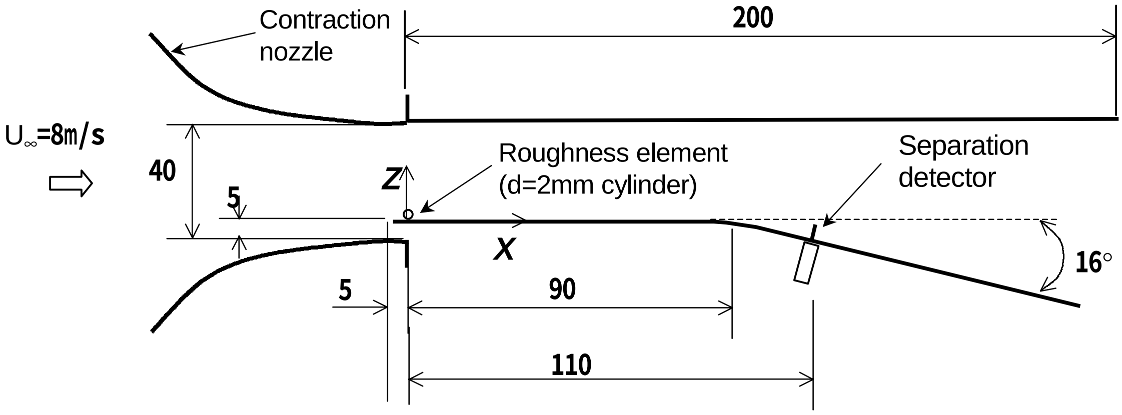


Fig.1 Schematic of wind tunnel and test section with a separation detector and roughness element installed on the test plate.

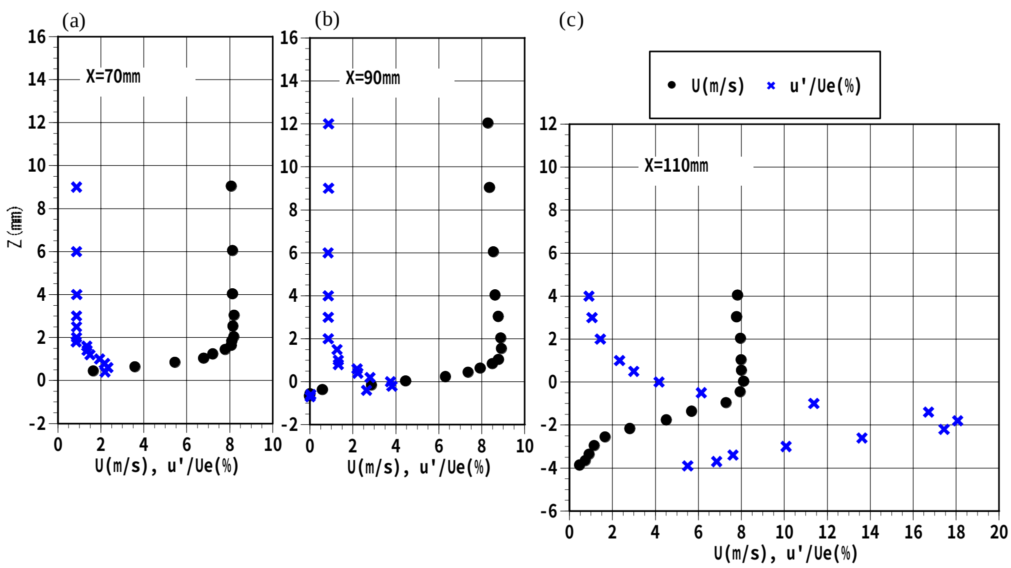


Fig.2 Profiles of mean and fluctuating velocities at three locations for a case of laminar boundary layer at the leading edge.

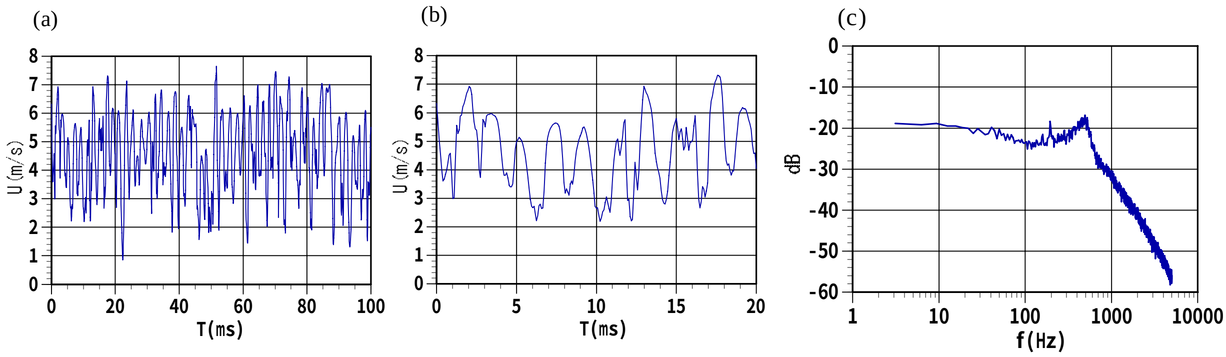


Fig.3 Hot-wire signal captured at the peak of velocity fluctuation at *X*=110mm.

(a) Hot-wire signal, (b) Hot-wire signal enlarged in time, (c) Power spectrum.

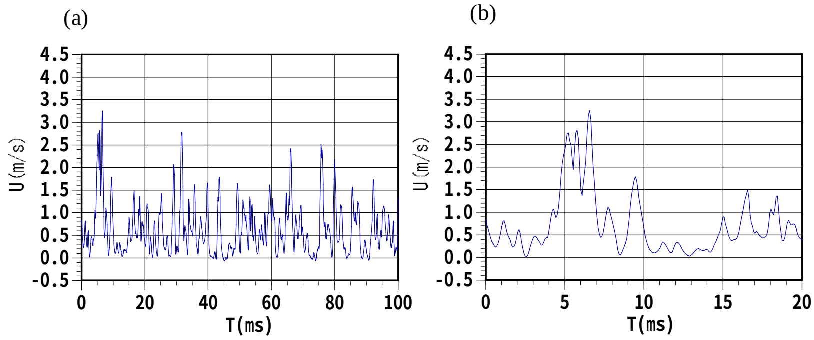


Fig.4 Hot-wire signal at a height of –3.9mm in Figure 2(c).

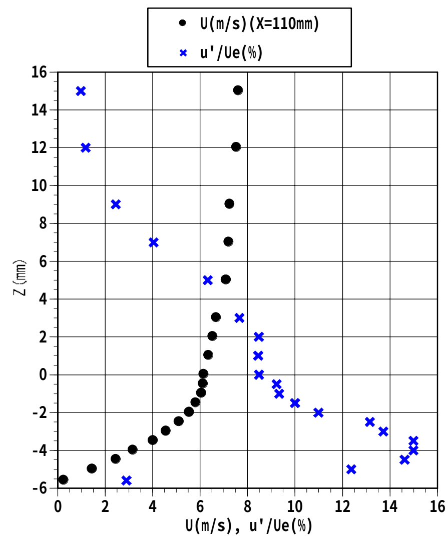
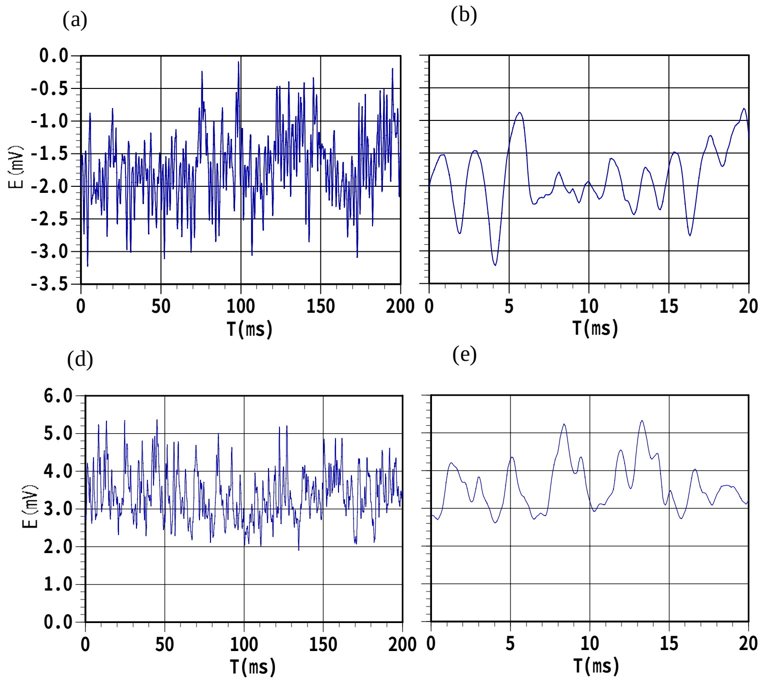


Fig.5 Profiles of mean and fluctuating velocities at *X*=110mm for a case of turbulent boundary layer.



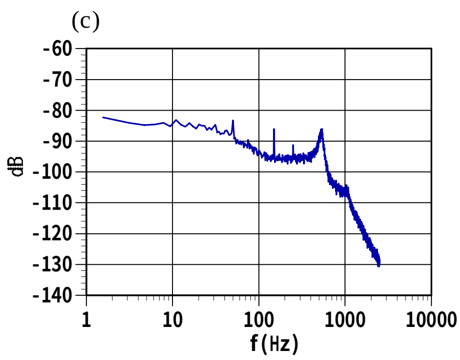


Fig.6 Separation detector signal and power spectrum at *X*=110mm.

(a)-(c) a case of laminar boundary layer, (d),(e) a case of turbulent boundary layer.