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A PAIR OF DOUBLE-ROLLER STRUCTURES IN A TURBULENT BOUNDARY LAYER

Makoto ICHIJO

Division of Mechanical Science
Hokkaido University,Sapporo, 060-0813 JAPAN

ABSTRACT

Velocities were sampled on condition that peaks of pressure fluctuation were larger than 3.5 times its root mean square, and ensemble averaged. And a pair of double-roller structures in a turbulent boundary layer was found. The downstream double-roller rotates in the same direction as legs of the hair pin do. The upstream double-roller rotates in the opposite direction. The double-roller structures are confined in a region of the wall. The conditional pattern recognition (CPR) was adopted as a technique to find detailed structures in a turbulent boundary layer. Patters the author adopted as the first patters in the CPR was conditional averaged flow patterns mentioned above. And the technique remarkably reduced jittering effects.

INTRODUCTION

Grant(1958), Payne & Lamely(1967), and Townsend(1970) showed a double-roller structures in shear layers. Townsend (1976) sketched a double-cone with wall constraint. Recently, Ferre, et al..(1990) showed a double-roller eddy by a pattern recognition technique in a plane turbulent wake. And each double-roller is counter a rotating vortex pair and it exists by itself. However Kabashi and Ichijo(1986) found a pair of double rollers in a turbulent boundary. But they measured only a 30% wall region of the boundary.

The conditional averaging techniques (for example Blackwelder and Kaplan(1976)) have been extensively used to examine coherent structures in turbulent flows. But the conditions are determined rather voluntarily and we can not avoid jittering effects in these conditional averaging. On the other hand, pattern recognitions (for example Ferre, et al.(1990)) have not jittering effects. But patterns which we use are determined also voluntarily. To avoid the jittering and the voluntaryism, the patterns which the author adopted in this work are conditional averaged velocity patterns.

EXPERIMENTS AND DATA ANALYSIS

Experiments were carried in a wind tunnel with a 50cm x 50cm test section which was 4.5m long. Turbulent structures were examined in a turbulent boundary layer developed on a smooth wall of the test section. The boundary layer was tripped when it entered the test section. A zero pressure gradient in the test section was ensured by flaring the upper side wall slightly. A wall pressure fluctuation was used as a detector to find the turbulent structures. The wall pressure fluctuation conducted to a condenser microphone connected with an amplifier through a 0.5mm diameter hole in the wall. Frequency characteristic of the pressure measurement device is 4.5KHz. Instantaneous eight streamwise velocities(u) in the spanwise(z) direction were measured by a hot-wire rake consisted of eight single I probes. The space of probes is 3mm. The rake was at the same streamwise location as the pressure hole was. The pressure and velocities were sampled at the frequency of 10kHz for 10 seconds in one measurement. The measurement was repeated three times, then 30 seconds data of pressure and velocities were stored in a computer. Velocities were conditionally sampled on condition that peaks of wall pressure fluctuation was larger than 3.5 times its root-mean-square by the computer. 400 of data before and after the peaks were conditionally sampled and ensemble averaged. Approximately 550 samples were detected in 30 seconds data.

RESULTS and CONSIDERATIONS

Characteristics of the turbulent are as follows. Mean velocity(U) is 18m/s, the boundary layer thickness defined by 99% of mean velocity(δ) is 25.4mm and Reynolds number based on momentum

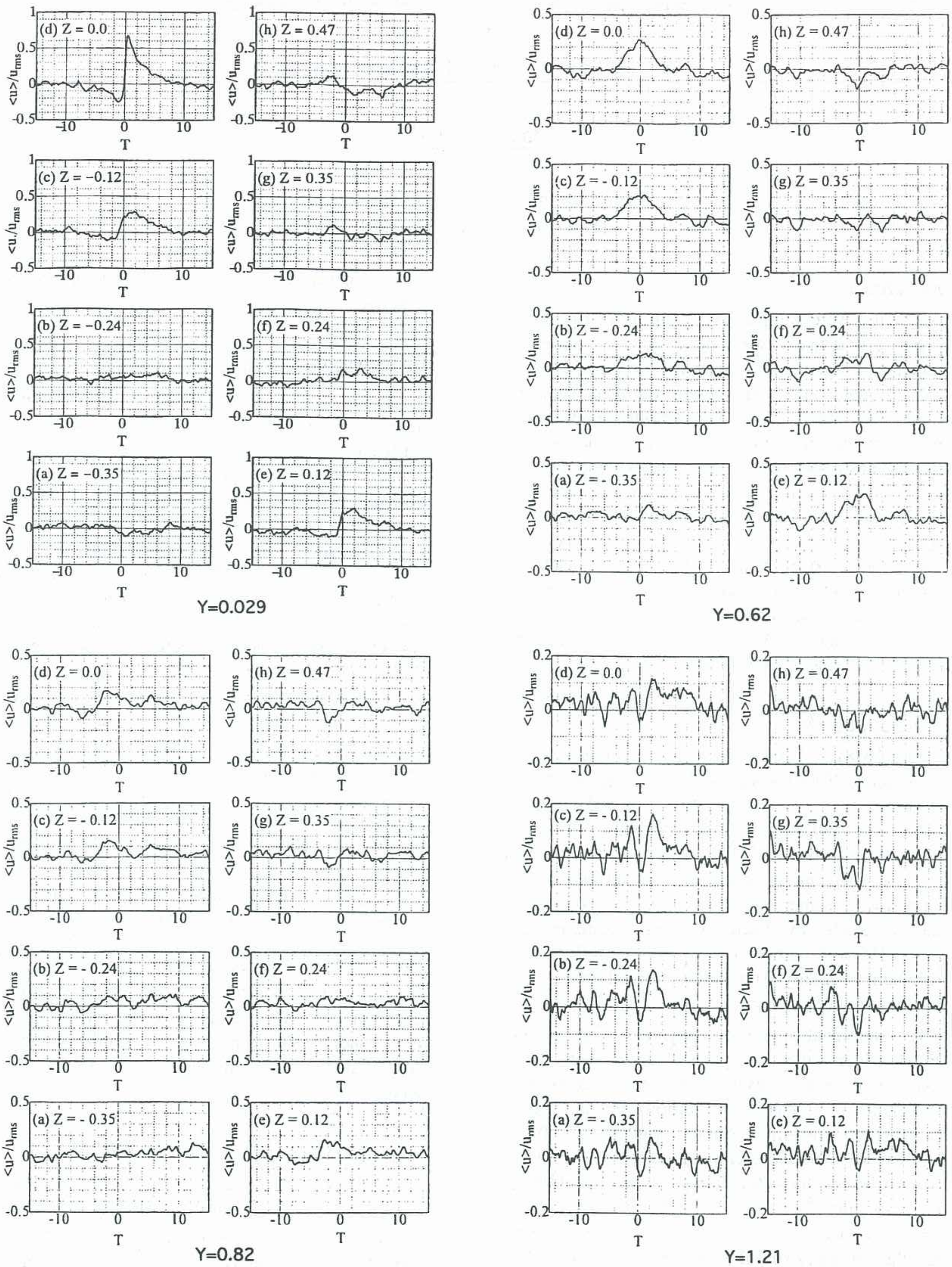

Figure 1 Ensemble averaged velocities by a condition of pressure peak

thickness(R_θ) is 3000.

Ensemble averaged stream-wise velocities at Y(y/δ)=0.029, 0.62, 0.82, and 1.21 are shown in figure 1 respectively. The ensemble averaged stream-wise velocities at Y=0.029 and z=0 shows a typical pattern of the burst, that is, ejection and sweep. In the figure as to Y=0.029, Y=0.62 and Y=0.82, turning the flow patterns at Z=-0.35 and 0.47 upside down, the upside-down patterns look like those at Z=0. So we can see a double-roller pattern which are shown in figure 2.

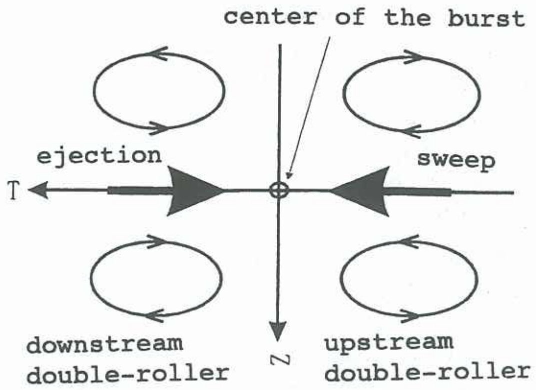

Figure 2 A model of a pair of double-rollers

And this pattern moves downstream leaving away from the wall. Therefore double-roller structures incline downstream. The downstream double-roller rotates in the same direction as legs of the hair pin do, and it causes ejection-like flow between the rollers, and the upstream double-roller rotates in the opposite direction to the downstream one, and causes sweep-like flow. The downstream double-roller is like the inclined double-roller eddy. As to the upstream double-roller, Choi(1987) also showed it associated with the near wall burst.

The flow patterns in figure Y=1.21 does not show a double-roller, differently the flow pattern shows a two dimensional structure in spite of quite a distance from the wall. And the structure is well in phase with the wall pressure peaks or the bursts. It suggests that the near wall structure is strongly related to the outer structure.

The double-roller structures do not occupy whole through the boundary layer, but exist in a part of boundary layer. The each roller of the downstream rollers may connect one another in the upside like a hairpin. But how does the upstream rollers?

The second purpose of this research is to reduce the jittering effect by means of a conditional pattern recognition technique(CPR). Suppose square waves which have the same amplitude and frequency one anther. Superimposing the arch squarer wave which is randomly phase sifted one another, the resulted wave shows smooth line in stead of sudden increase and decrease which are unique characters of a squarer wave, and an amplitude of the resulted wave decreased compared with that of the square wave. These are so called jittering effects. To avoid the effect, the author adopted the conditional pattern recognition technique.

In this research, the author used a conditional averaged velocity pattern for a first pattern recognition. Correlation between the conditional averaged velocity pattern and velocities before and after the time of pressure peak were calculated by the same way as the wavelet analysis. The times of a maximum correlation were detected. And the velocities before and after the times were detected

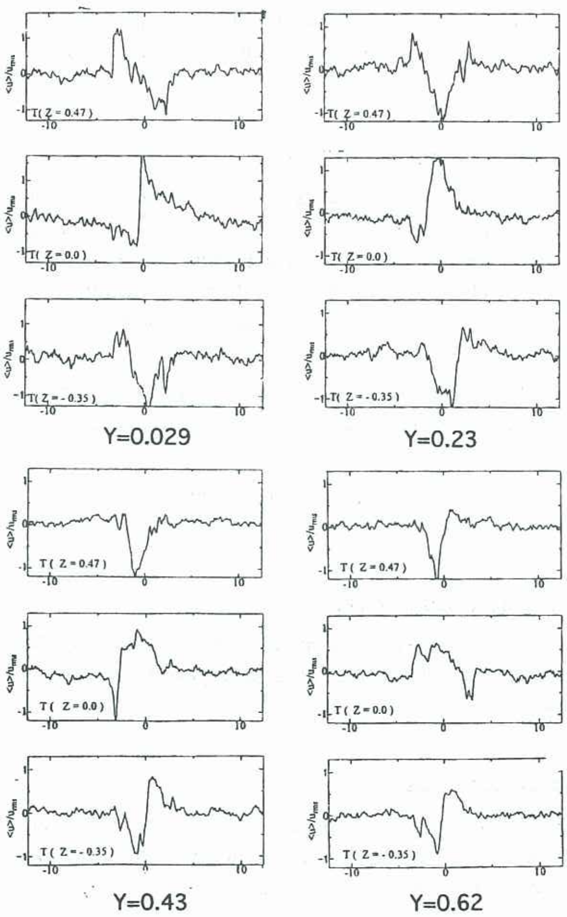

Figure 3 Ensemble averaged velocities by a conditional pattern recognition

and were ensemble averaged. The resulted pattern by the first conditional pattern recognition is used for a next pattern recognition. This procedure were repeated four times. But resulted patterns by the second pattern recognition was enough to obtain reasonable structures. Resulted patterns at Y=0.029, 0.23, 0.43, 0.62 are shown in figure 3. The patters show that the jittering effects are remarkably reduced. That is, sharp acceleration and sharp deceleration are appeared, and the amplitudes are increased with respect to the original ones.

Now there is steep deceleration and steep acceleration or a deep and narrow negative valley in the averaged velocity in the figure Y=0.43 and Y=0.62 of Z=0. The valley occur downstream at Y=0.43, however the valley occur upstream at Y=0.62 . The deep valley may be caused by lifting up of a low speed fluid lump near the wall same as the ejection. And this lifting-up is stronger upstream than downstream. There are two kinds of lift-up flow. The phenomenon may be related to the two kinds of bulge suggested by Falco(1977).

CONCLUSION

(1) There is a pair of double-roller structures in a turbulent boundary layer. The double-roller in the downstream rotates like a hair pin leg and produce ejection like flow. On the other hand, the double-roller in the upstream rotates otherwise and produces sweep like flow.

(2) The pair of double-roller structures is not exit whole through the boundary but in a distance of the wall.

(3) A conditional pattern recognition technique reduces the jittering effect.

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