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GROWTH AND DECAY OF ORDERED MOTIONS IN THE TRANSITION REGION OF A TWO-DIMENSIONAL WAKE

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ABSTRACT

This is an experiment on the origin of ordered motions in turbulent flows. We generate a large-scale pattern of velocity fluctuation in a two-dimensional wake behind a strip of screen by sound from a loudspeaker. The intensity of the pattern decreases in the flow direction but remains finite at X/d more than 100. This suggests that some ordered motions in turbulent flows are born in the transition region. This indicates also that the universal fully-developed turbulent flow does not exist.

INTRODUCTION

Concerning turbulent flows there are two fundamental questions:

(1) Are ordered motions in turbulent flows generated in the transition region ?

(2) Are there any universal "fully-developed turbulent flows" which are independent of the initial conditions ?

We intend to answer these questions by an experiment on the transition process of a two-dimensional wake.

EXPERIMENTAL ARRANGEMENT

The experiment was performed in a wind-tunnel of which test section is 25 cm by 25 cm in cross section and 1 meter in length. A strip of metal screen of 0.4 cm by 25 cm was spanned normal to the uniform flow and a two-dimensional wake was formed behind the screen. Due to the flow through the screen no Kármán vortex street is formed. The wake is laminar to start with and responds nicely to the sound from outside. The wind speed is 5 m/sec and Reynolds number based on the width of screen is about 1400.

A sound with two frequencies is introduced from a loudspeaker placed outside the test section. Frequencies are chosen to be in the range of high linear growth. They are 479 Hz and 513 Hz. By the nonlinear interaction in the wake the spectral component of the frequency of the difference of two frequencies is generated. The Strouhal number for 479 Hz is 0.38 and that for 34 Hz is 0.027. Both are much different from the value 0.2 for Kármán vortex street.

WAVEFORMS OF VELOCITY FLUCTUATIONS

Wave forms of u-fluctuation at various points in the wake are shown in figure 1. The wave form of sound is shown in (a). Intensities of two sounds are almost equal and the beat of 34 Hz is observed. At X = 25 mm the wave form of velocity fluctuation is very much alike that of sound. This is because the X-station is inside the linear region.

The nonlinear interaction shows up in (c) in which 34-Hz component is clearly observed. We call the component fundamental fluctuation. At large X the wave forms become random but in (e) we can still notice the 34-Hz component. At X = 500 mm the wave form seems to be entirely random but it is not true. In the energy spectrum shown in figure 2 there is a sharp peak at 34 Hz. Harmonics are also found. It is a surprise to observe a line spectrum at such a large distance as X/d = 125. This is obviously due to the fact that the 34-Hz component is a large-scale fluctuation. The viscous decay is

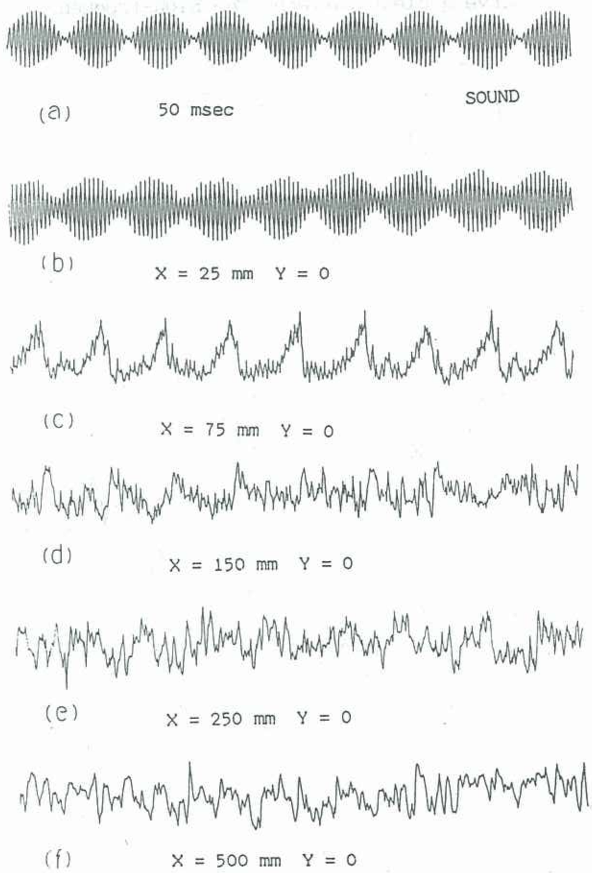

Figure 1 WAVE FORMS OF u-FLUCTUATION

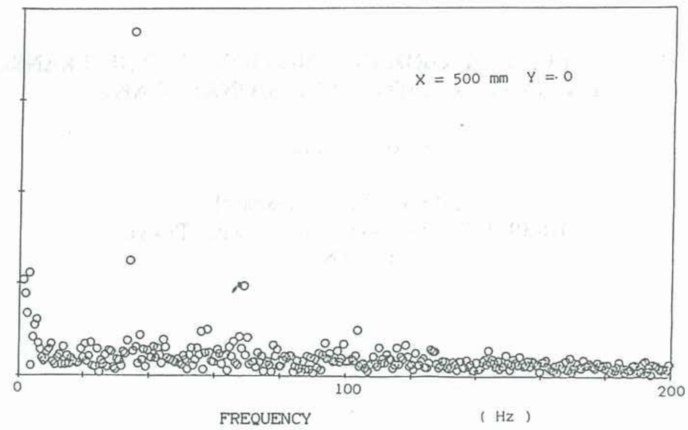

Figure 2 ENERGY SPECTRUM

small and the energy transfer to the high-frequency region is also small.

The total energy of fluctuation shows maximum at around X = 100 mm and the energy at X = 500 mm is less than one tenth of the maximum value. It is likely that the fluctuation decays out before it becomes " fully turbulent ".

PHASE-AVERAGED WAVE FORMS

Because we know the frequency of the fundamental fluctuation, we can easily take the phase average of the wave form. Figure 3 shows some examples. About 100 periods are used for the averaging and two wave lengths are shown. There is no notable change of wave form in the flow direction. Even at X = 500 mm we observe a clear pattern. The high-frequency wiggles in the wave form indicate the randomness. The root-mean-square of these wave forms can be defined "intensity of pattern". By dividing by the total RMS we have a non-dimensional intensity. This is a very important quantity when we talk about the pattern in a random field. We can extend the concept to two and three dimensions.

We use the phase averaged pattern as a test pattern and calculate the correlation with the original fluctuation by moving the test pattern along time axis. This process is usually called " wavelet analysis ". But we rather call it " pattern search ",because we are actually looking for patterns.

When the phase relation between the test pattern and the fluctuation is proper, we get a high correlation. If the phase is in inverse, we obtain negative correlation. Figure 4 shows the non-dimensionalized correlation coefficient on the time axis. We call the figure " distribution of pattern ".At small X the coefficient is large and the distribution is uniform. At large distance the coefficient becomes small and the distribution is random. We calculate the average of peak values. This is another expression of the intensity of pattern.

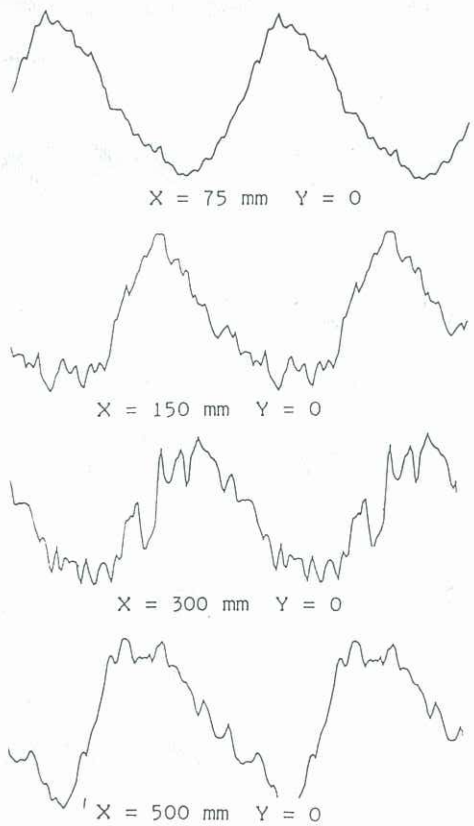

Figure 3 PHASE-AVERAGED PATTERN

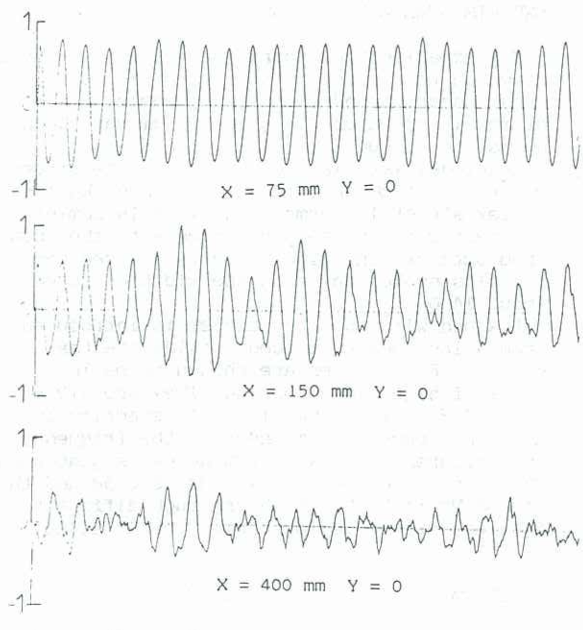

Figure 4 PATTERN DISTRIBUTION

PATTERN SPECTRUM

We divide the temporal record of velocity fluctuation by a certain time interval into many pieces and calculate the phase average. The mean-square of the averaged wave form as a function of the time interval is called " pattern spectrum ". This tells us scales of predominant pattern. For instance if the fluctuation consists of a single sinusoidal wave,the pattern spectrum is a single line at the period.

Figure 5 shows spectra at three points in the wake. The horizontal axis is the non-dimensional period. The fundamental period is taken as 100.The vertical axis is the mean-squared energy. In all figures a sharp peak appears at PERIOD = 100. Even at X = 500 mm the peak is pretty high. In other words a clear pattern is still there. A small peak is found at PERIOD = 50. This means that there is a pattern of half period. At X = 150 mm, Y = 1 mm there is another peak at 33.3 and 66.7. This means a pattern of period of one third of fundamental period. We may call these changes " pattern splitting ". This is a process how a pattern changes in X- and Y-directions.

STREAMWISE VARIATION OF PATTERN INTENSITY

Figure 6 shows the streamwise variation of pattern intensity. Both RMS and correlation coefficient are plotted against the distance from the screen. Both values are roughly equal. They increase at small X and reaches maximum at around X = 75 mm with the value of 0.8 and decrease downstream gradually. At X = 500 mm the intensity is still around 0.2. Obviously the " fully-developed " turbulent wake is not established.

CONCLUSION

We have introduced statistical quantities about patterns such as pattern intensity, pattern distribution and pattern spectrum and observed the variations of these quantities in the transition region. We are ready to answer questions posed at the beginning of this paper.

(1) There is a strong possibility of generating ordered motions in the transition region.

The initial disturbance of the present experiment is very special. In the so-called natural transition There is no such an initial disturbance. By chance at some instance the natural disturbance may generate a large-scale fluctuation whicht suvives through transition region and appears as an ordered motion in the turbulent flow.

(2) The turbulent wake can not be free from initial conditions. It is very difficult to imagine the existence of universal " fully-developed " turbulent wake.

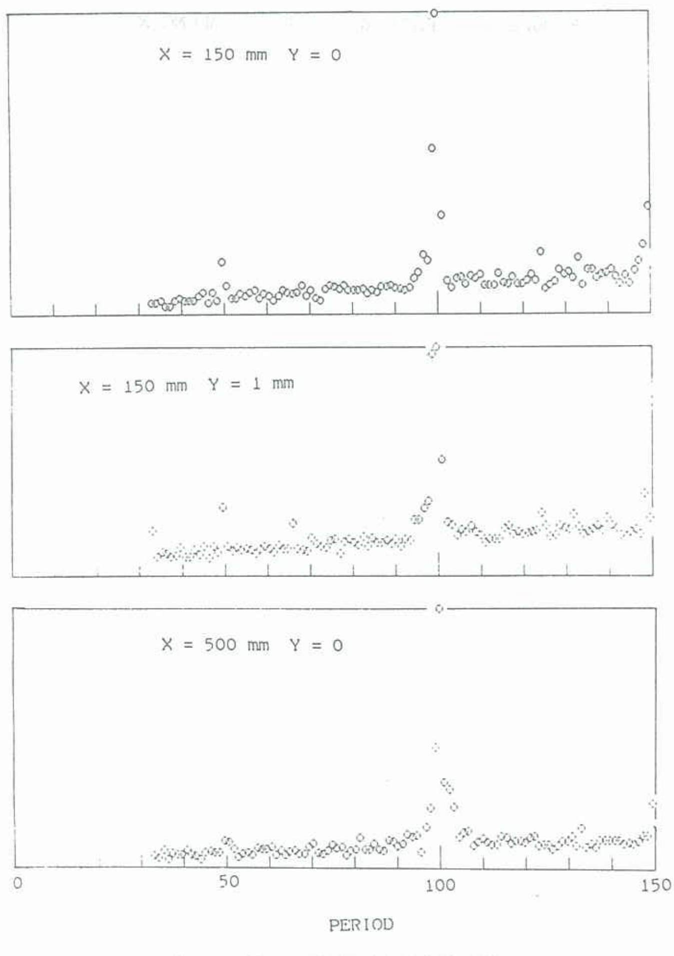

Figure 5 PATTERN SPECTRUM

This statement is convincing in the present experiment at low Reynolds number. At high Reynolds number the situation may be different. But the difference might be only quantitative. It is rather difficult to think about a critical Reynolds number at which a qualitative change takes place.

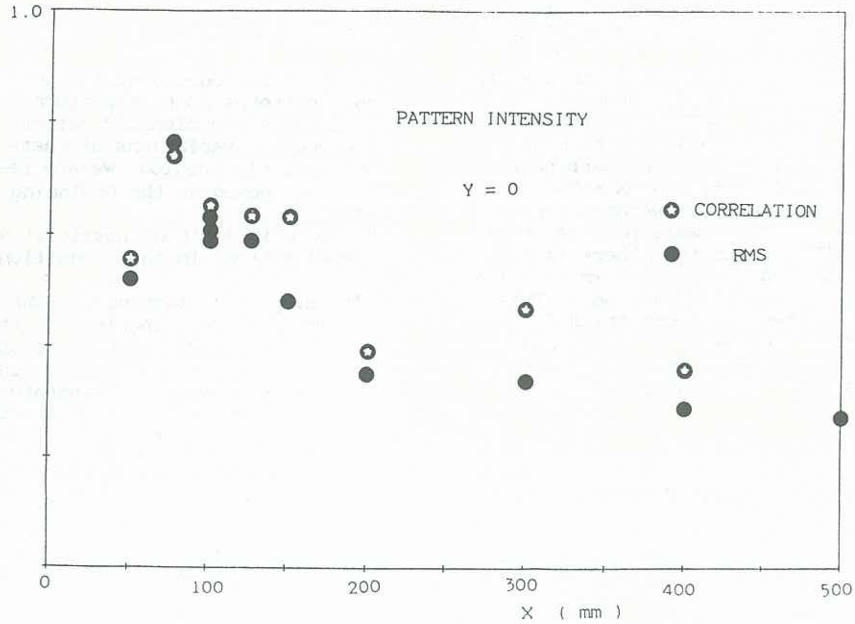

Figure 6 PATTERN INTENSITY ALONG X-AXIS