Another confusing word about vortex is the 'induced velocity'. In some paper the author, after establishing the existence of a vortex, states some flow is induced by the vortex. The question is : Is the induced flow field a part of vortex or passively induced by the vortex which is a different source of energy? I think we should avoid the use of induced velocity in describing experimental results.

At present it seems to be impossible to find completely objective and unambiguous expression for patterns in the turbulent flow.

VI CONCLUDING REMARKS

In order to promote the investigations on patterns in the turbulent flow I should like to make following suggestions:

1 To increase the number of point-measuring probes —— such as hot wires and laser Dopplers —— and try to acquire field informations.

2 To improve techniques of visualization of flow field and obtain quantitative and objective informations.

3 To understand that we can obtain any kind of pattern from random field.

4 To develop ways of expressing complicated patterns and establish the scale of values on various patterns.

LAMINAR-TURBULENT TRANSITION: THE INTERMITTENCY REVISITED

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The flow during transition from the laminar to a turbulent state in a boundary layer is best described through the distribution of the intermittency γ. In constant pressure, two-dimensional flow turbulent spots appear to propagate linearly; the hypothesis of concentrated breakdown, together with Emmon's theory, leads to an adequate model for the intermittency distribution, over flow regimes ranging all the way from low speeds to hypersonic. However, when the pressure gradient is not zero, or when the flow is not two-dimensional, spot propagation characteristics are more complicated. Experimental results in such situations, and possible models, will be reviewed and discussed.

sedimentation, and colloidal dispersions generally, this is a stimulating period. Research on colloidal dispersions is not a part of main-stream fluid mechanics, but specialists in fluid mechanics are now providing their own distinctive insights and expertise and are developing their own approach to the subject.

An indication of the contents and scope of the lecture is given by the following headings:

1. The distinction between local influences (from neighbouring particles) and global influences (from distant parts of the flow field) on the mean velocity of a particle.

2. The mean velocity of a particle in a statistically homogeneous dispersion in a container. Calculation of the mean velocity for a dilute monodisperse system; what determines the pair-distribution function in the case of larger particles for which Brownian diffusion is weak? Polydisperse systems. Relevance of these calculations for the Brownian diffusivity of particles.

3. The formation of streaming columns in a bidisperse system.

4. Dispersions with vertical variations of particle concentration. Concentration waves. Shock transitions in batch settling. The notion of particle stress. The contribution to particle diffusion due to fluctuations in the configuration of neighbouring particles. Growth of the small amplitude of a concentration wave due to particle inertia, and formation of 'bubbles' in fluidized beds.

5. Steady states with both sedimentation and bulk motion of the mixture. Examples: (a) a spherical cloud of particles falling through clear fluid (or a spherical region of clear fluid rising through the mixture); (b) settling beneath an inclined wall of a container and the Boycott effect.

COGNITION AND DESCRIPTION OF PATTERNS IN TURBULENT FLOWS

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I INTRODUCTION

In the past decade extensive experimental investigations have been made on ordered motions or patterns of fluctuation in turbulent flows. There are many interesting findings on the patterns but none of them are conclusive and convincing. There are several reasons for that. First of all most of the reported results are inclined to be subjective. For instance an author claims that he found eddies in a flow. In his picture circular streaks are seen but it is not clear if they are really eddies in a strict sense. It is extremely difficult to conclude the existence of an eddy in random fluctuations. Another difficulty lies in the quantitative description. Usually patterns are so vague that they can not be described with enough accuracy. Therefore, very often the discussions diverge and every experimenter keeps his own 'pet'.

In the present paper I discuss about the process of cognition of ordered motions and also about the method of describing them for communicating to public. In order to avoid the confusion I restrict my discussion only on patterns in the 'fully-developed' turbulent flow. In other words, I do not discuss patterns in the process of laminar-turbulent transition. Obviously, they are formed by the linear or nonlinear growth of periodic fluctuations before the turbulent flow is established. On the contrary, patterns in the fully developed turbulent flow are burried in random fluctuations and have no definite 'roots'.

II ACQUISITION OF DATA

The methods for acquiring informations out of a turbulent flow are classified in various ways:

1 Point Data and Field Data

More than 90 % of quantitative informations are acquired by hot-wire anemometers and laser-Doppler velocity meters. They provide accurate velocity data but only at one point in the flow. On the other hand, one-shot flow pictures give infinite amount of information about the whole flow field but they are hardly quantitative.

2 Eulerean Information and Lagrangean Information

What we acquire by hot wire or laser are Eulerean informations, namely, they illustrate the temporal change of velocity at a fixed point in the flow. These informations are not sufficient for constructing three-dimensional patterns which move around in the flow. The acquisition of Lagrangean informations is seriously wanted.

It is very difficult to find a pattern burried in random fluctuations by one-point data. If the flow field is periodic, we can repeat the measurement at each phase and construct a whole picture. But fully-developed turbulent flows have no periodicity. What we should do for acquiring more informations is to increase the number of hot wires and laser beams. If we can manage 20 hot wires in a flow without mutual interactions, we can obtain enough spatial resolution about ordered motions.

It has been pointed out that the pictures of flow fields are sometimes misleading. The reason is that the displacement of the tracer in the flow

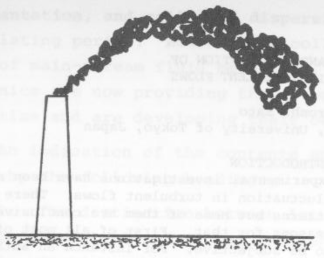

Figure 1

is the integrated effect between the time of release of tracer and the instant of observation. We can imagine many different processes from one picture. Figure 1 is an example. It shows smoke from a stack. If one takes a look at the figure, he might imagine a steady flow as shown by smoke. Of course, it is possible but an entirely different flow field shown in figure 2 also results in the same pattern of smoke. The flow field in figure 2 is uniform and unsteady: In one minute to down-right, in one minute to right and in the last one minute up-right. Generally speaking 'old smokes' which have traveled long distance in the flow mislead us. Therefore, the recommendation here is to use only 'young smoke'. Figure 3 is an example of picture of young smokes released from many smoke wires in the boundary layer. Smokes indicate instantaneous direction of flow. By processing this picture we can obtain quantitative informations.

The acquisition of Lagrangean information has been tried. One method is to follow the motion of a small lump of air which is marked by smoke or heat. Results by this technique are a little ambiguous, because the smoke pattern does not necessarily reflect the real motion of fluid.

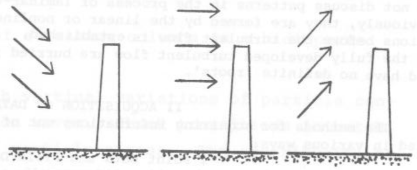

Figure 2

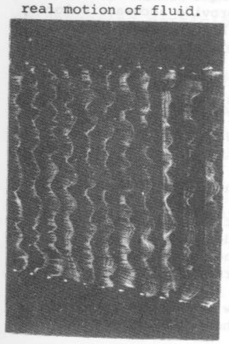

Figure 3

Another method is the optical tracking of a small non-buoyant solid particle in the flow of water. Although the experimental technique is complicated, we expect to obtain high-quality Lagrangean informations by this mehod.

III FILTERING OF DATA

After acquiring high-quality data of enough qunatity we start the selection, namely, we keep high-value data and discard low-value data. This is entirely different from statistical processing in which all data are used without discrimination. The selection is, of course, based on the usefulness for the construction of patterns. This

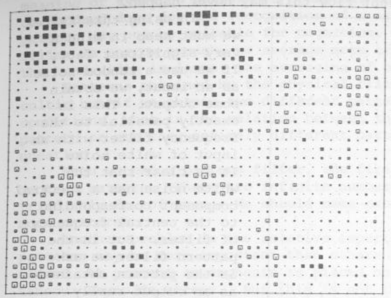

Figure 4

process has been called conditional sampling but because we treat also picture informations, the word, 'filtering' seems to be more appropriate.

Two kinds of filtering is possible. One is the physical filtering. Here we consider some physical phenomenon as a manifestation of a pattern. One example is the Reynolds stress near the wall and another is the large-scale motion of a lump of fluid. We expect that these physical properties reflect the action of ordered motions. If there are no actions, there is no need for seeking ordered motions. This process is passive and no a priori assumption of pattern is necessary. The choice of physical property is arbitrary and different choice many result in different patterns.

The other device of filtering is the pattern filter. Here we set a pattern by ourselves, compare the input with it and obtain the output. This process is very much alike to the use of a band-pass filter for determining the energy spectrum of velocity fluctuations. The preset pattern corresponds to the central frequency of the band-pass filter. By changing preset pattern we know which pattern is abundant. In this method we do not care about the physical process.

The pattern filter is actually operated as follows;

We select a central pattern, P_0 which can be a definite wave form of velocity fluctuation or visualized vortex. The input is compared with this preset pattern and the deviation, δe is calculated. If the total squared at deviation,

$$\int_p (\delta e)^2 d\sigma$$ is smaller than the band width Δp, we count this one hit. If the preset pattern is simple and the band width is large, we have many hits. The output is expressed by hits/s or hits/cm^3. These are temporal or spatial densities of a certain pattern. Patterns with high density may be called strong patterns and those with low density, weak. By changing the central pattern, P_0 we can obtain the spectrum in the pattern space. If there are peaks in the spectrum, we can be sure that they are

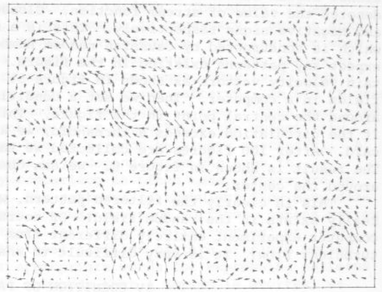

Figure 5

strong patterns. But in the turbulent flow this may never happen.

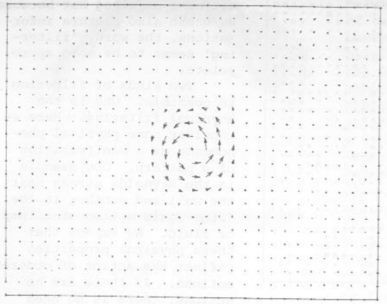

Figure 6

In using this filter we must keep in mind a very significant fact. If we use a random noise as an input, we obtain some output. This is exactly parallel to the frequency filter with an input of white noise. It is clear that the white noise has a spectral component corresponding to the central frequency of filter. But in the pattern filter we ask: is the pattern obtained as an output really included in the orginal ranodm noise? This question leads us to 'theorem of hidden pictures' , which reads:

More patterns are hidden in more random field.

In the limit we can find any pattern in a perfectly random field. An example of this theorem is the constellation. The random positioning of a large number of stars in the sky enabled ancient people to find many patterns, such as bears, ox or even unseen gods.

We have made a simple computer experiment concerning the theorem. Results are shown in figures 4, 5 and 6. We first make up random field of two-dimensional stream-function as shown in figure 4. The size of square in the figure denotes the value of stream function. Closed and open squares denote positive and negative signs respectively. This is a mathematical random flow field which is constructed by Gaussian random numbers. Therefore, we should not expect any patterns existing in the figure. From the stream function we obtain velocity vectors as shown in figure 5. We can generate many similar flow fields in a computer. Then we set a condition on the value of circulation around the central point in the figure. This is an example of preset pattern. If the circulation exceeds a threshold, we keep the figure. If not, we discard. After 100 figures are collected we take the average of stream functions. The result is shown in figure 6. We can observe a distinct vortical motion around the center.

This is clearly the filtered pattern. We ask ourselves if this motion really exists in the random field? Of course, the answer is no! But is this computer experiment entirely different from what we are doing in the real turbulent flow? It is very difficult to answer.

IV COGNITION OF PATTERNS

Now we are at the heart of our discussion: How to cognize ordered motions. Cognition is defined as 'the process of knowing'. When we find an old friend among crowd, we say we recognize him. This is because we have known him before. On the contrary, nobody has ever known patterns in the turbulent flow. In such a case the knowing is called cognition. When we try to cognize patterns, there are several problems.

The construction of a pattern out of filter output is made by the averaging of many individual patterns. The averaging process is quite clear for numbers but the averaging of patterns is a questionable procedure. Not only there is no established method for pattern averaging but also the

meaning of averaged pattern is doubtful. We do not use the averaged pattern of hundred dogs for the recognition of a new dog. Therefore, the averaged pattern may not be suitable for cognition. When the band width of the pattern filter is narrow enough, we average more or less similar patterns. But if the band width is large, the averaging of output is meaningless.

Patterns obtained by the physical filter are cognized without difficultis but if we obtain two different patterns by two different physical conditions, what is the relation between the two? Are they parts of one pattern or are they entirely different patterns. This is another difficult question.

When we use a pattern filter, the first problem is how to choose the central pattern. There are infinite number of choices and so far we have tried only few of them. We should make extensive experiment and try to find more patterns.

Another problem is the relative importance of various patterns. Some patterns may be more important than others but where is the scale for importance? At present an emphasis is placed on the contribution to the instantaneous Reynolds stress. But this is not the only scale of importance. There may be another scale. The capability of transportation is an example.

Some of these problems are quite formidable. In the course of cognition we may have to deal with some concepts we have never met. But we should not be afraid of extending our discussion sometimes beyond the border of coventional physical science.

V DESCRIPTION OF PATTERNS

Now I discuss the way of describing three-dimensional, unstationary patterns. In a conventional sense the good 'scientific' expression is objective and unambiguous. For instance, experimental results are usually described by graphs and tables of data which include no possibility of distortion in the communication from the writer to readers. Therefore, if we describe patterns with these ways, no discussion is necessary. But an abstract description of pattern is not necessarily adequate. For instance when we try to explain an elephant to a person who has never seen it, tables of data of elephant are no use. There are two better ways. One is to draw a picture and the other is to compare with other known patterns. An old Chinese saying 'One looking is better than hundred hearings' is true. Then what kind of picture should we draw? One problem about pictures is the objectivity. We try to avoid subjective pictures but it may not be always successful. A picture can be interpreted in various ways depending on who sees it.

The expression of patterns by comparison is often made. There are so many description 'it is like ...'. For patterns in turbulent flow many description have been made: horse-shoe vortex, mushroom vortices, banana vortex etc. The most frequently used pattern for comparison is 'vortex' or 'eddy'. Undoubtedly the vortex is one of the most familiar pattern of fluid motion for us. Actually we have no other appropriate words for expressing patterns of the flow of fluid. When we tell somebody that a motion is avortex, we expect a full understanding. But this is very dangerous, because the image of vortex is not the same for all of us. Although the vorticity is a well-defined physical quantity, the definition of vortex or eddy is not established. This is especially true when we talk about vortex burried in the turbulent flow. In a random flow field such as figure 5 we can find many patterns which look like vortices. If we define 'vortex' by a circulating flow around a point, any flow includes many vortices. In a two-dimensional flow field vortical motions are found around extrema of stream function. Then the flow and the vortex are almost a synonym and there is no use of vortex for describing specific patterns.