1. ISUD
1st International Symposium on Ultrasonic Doppler Methods
for Fluid Mechanics and Fluid Engineering
September 9-11, 1996
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

COLLECTIVE BEHAVIOR OF WAKES SHED BY A ROW OF CYLINDERS

I. Peschard[1], J.F. Ravoux [1], P. Le Gal[1], Y.Takeda[2] and M.P. Chauve[1]

[1]Institut de Recherche sur les Phénomènes Hors Equilibre
UM 138, CNRS - Universités d'Aix-Marseille I & II
12, Avenue Général Leclerc,13003 Marseille, France
[2]Laboratory for Spallation Neutron Source
Paul Scherrer Institut
CH-5232 Villigen PSI, Switzerland

ABSTRACT

This experimental study is devoted to visualization and ultrasonic velocity measurement of the wakes formed behind a row of parallel cylinders placed side by side, perpendicular to an incoming flow at low Reynolds numbers. When the distance separating the cylinders is small compared to their diameter, two instability mechanisms, associated with different patterns and dynamics compete. A first spatial symmetry breaking appears when the stationary wakes behind each cylinder are deviated towards one side or the other and form large clusters containing from 2 to sometimes more than 10 wakes. These clusters are separated by intense recirculating zones. When the Reynolds number is increased, the wakes belonging to the widest clusters experience a secondary temporal oscillatory bifurcation. Classical Bénard-Von Kàrmàn vortex streets are thus shed in phase by these cylinders (acoustic mode), by contrast with the wakes outside these cells which stay stationary. Finally, the flow around far appart cylinders is also investigated. The primary instability does not occur in this case and a perfect optical mode of vortex shedding, with neighbours in phase opposition, takes place in the flow.

1. Experimental arrangement

Our experimental facility consists of a water loop with two reservoirs: the first one is set at 3 meters from the floor in order to generate the hydrostatic pressure that creates the flow which is stabilized by a classical 1 meter long settling chamber. Then, a home-made convergent creates a uniform velocity profile at the entry of a horizontal rectangular test channel 20 mm high and 128 mm wide. The length of this channel is 700 mm and a 50 mm diameter circular pipe leads to the second reservoir which lies on the floor. A water pump equiped with a by-pass, permits to adjust the flux of water through the loop. 21 cylinders having a 4mm diameter, are glued on one of the horizontal walls of the channel. Their length being 20 mm, they are in close contact with the other horizontal wall. The rather small aspect ratio of these cylinders was chosen to freeze the three-dimensional phase dynamics of the cylinder wakes. The row of the 21 cylinders is set 15 cm downstream the convergent and fill entirely the channel, from one side to the other, with only half a pitch between the end cylinders and the sidewalls of the channel.

The electro-chemical technique used to visualize the flow is based on the oxydation of a tin wire which is stretched across the experimental channel at mid-height and upstream of the cylinders row. When a 0.1 Ampere electric current flows between this 0.5 mm diameter wire and a carbon electrode, a white smoke of tin hydroxyde is emitted by the wire. When enlighted from the side, this smoke allows a perfect visualization of the entire flow. The video images are recorded by a frame grabber driven by a micro-computer. The Reynolds number of the flow is calculated on the diameter of each cylinder and on the flux of water passing through the row of cylinders. The ultrasonic transducer is set in a groove, machined in the mid-plane of the vertical wall of the channel. The diameter of the beam is 5 mm and the probe is positionned perpendicular to the channel at a distance of 20 mm from the cylinders axes. The operation principle is echography. An ultrasonic burst signal is emitted through the excitation of a piezoelectric transducer. The beam propagates through the fluid seeded with 100 micron size bubbles. These hydrogen bubbles are generated upstream by a platinum wire inducing an electrolysis of water and we have checked that their small size allows them to behave as a passive scalar. The sound waves reflect on these bubbles moving with the flow and are received by the same piezoelectric transducer. Thus the position of the reflecting bubble can be calculated from the time delay between the burst emission and the reception of the echoe. We can also obtain the velocity of the bubble by an analysis of the Doppler shift of the sound frequency. Therefore, the complete transversal velocity profile can be measured along the line crossing the flow. The velocity profiles are recorded every 135 ms, in 128 space positions separated by 1.48 mm. The width of the test channel being 128 mm, only the 85 first data points are used to cover the entire flow width. 1024 instantanneous profiles are then digitized and recorded.

2. Results and discussion

Each wake is coupled to its neighbours and as expected, global behavior of the one dimensionnal array of oscillators are observed. Different dynamical regimes are obtained when controlling the Reynolds number of the flow and the distance separating the cylinders. Two typical situations have been extensively studied: a strong and a weak coupling situation.

In the first one, the distance separating two successive cylinder axes is 1.5 times the cylinder diameter. At a Reynolds number equal to about 100, a first spatial symetry breaking arises. Due to the Coanda effect, each wake can be deviated towards one side or the other [1]. Thus several groups of merged wakes (or jets) are created. These regions are separated by recirculation zones. An analogy with magnetic domains separated by Bloch walls can be made. When increasing the Reynolds number to a value close to 110, some of the wakes exhibit an oscillatory instability. The oscillating wakes are confined in some regions of the flow and are locked in phase. This mode of vortex shedding is analog to the acoustic mode of phonons propagation. We present in figure 1 such flow patterns with one or two cells of oscillating wakes. Note that these different flows are obtained just by changing the initial conditions.

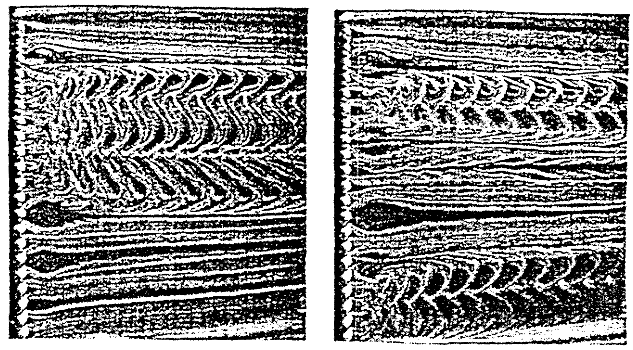

Figure 1: Two visualizations obtained at a Reynolds number of 115.

Figure 2 shows an example of space-time diagrams acquired by the ultra-sound anemometer for R=140. The color coding used on the picture allows the observation of two oscillating zones separated by a strong recirculation. Inside each zone we observe in phase oscillations made visible by the succession of black and white strips: all the wakes inside these groups are thus entirely correlated in a collective oscillation. Moreover, we notice also that the global oscillation of the wakes in one of these regions is in phase opposition with the global oscillation of the wakes in the other region. So, the recirculating zone between the two oscillating clusters is pulsating in a kind of varicose mode.

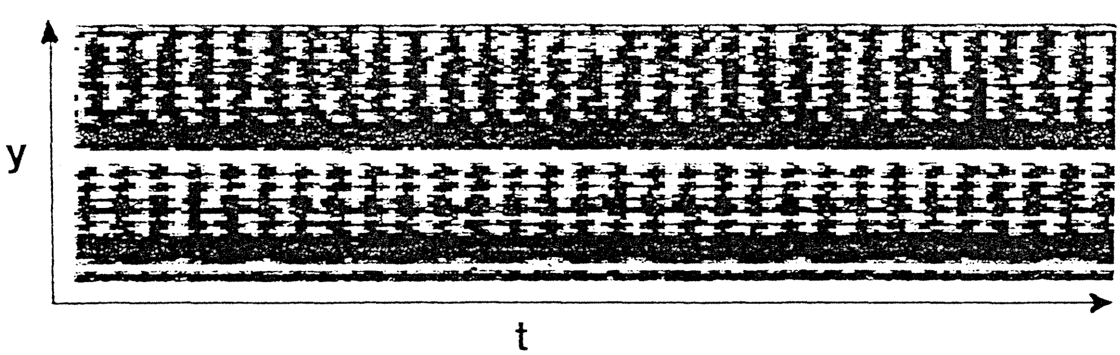

Figure 2: Two cells of in phase vortex shedding (acoustic mode) at strong coupling.

In the second set of experiment, the distance separating two successive cylinder axes is 3 times their diameter. In this case, no stationnary spatial bifurcation occurs and at a Reynolds number about 110, Bénard-Von Karman streets are shed with first neighbours in phase opposition. Figure 3 presents a space time diagram of this mode which is called the optical mode of phonons propagation.

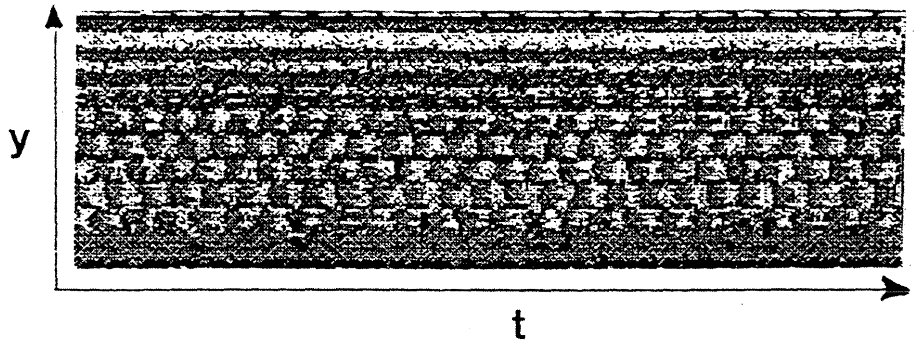

Figure 3: The optical mode of vortex shedding at small coupling.

The space-time diagrams are then analysed using the Bi-Orthogonal Decomposition which permits to separate the different components of the dynamics. We present in figure 4 the two first modes which represent respectively the main spatial and temporal structures of the flow.

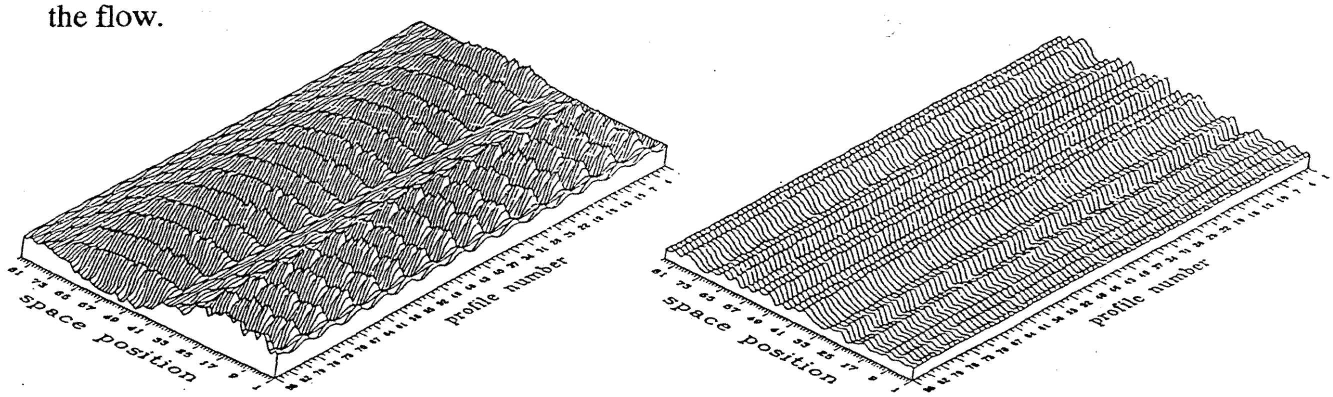

Figure 4: The two first modes of the BOD analysis of the flow.

3. Conclusion

Besides these experimental investigations, analytical and numerical studies of a coupled oscillators model have been realized. The model which is based on the diffusive coupling of Hopf bifurcations leads to a dicrete form of the Ginzburg-Landau equation [2]. Stable states and transition to chaos in this model present strong similarity with the experimental observations.

4. References

[1]- Ishigai S. and Nishikawa E., Experimental study of structure of gas flow in tube banks with tube axes normal to flow, Bulletin of the JSME., 18, 528, (1975).

- Auger J.L. et Coutanceau J., Ecoulement transversal de l'air à travers une grille de tubes, Entropie, 86,13, Edt Bartheye, (1979).

[2] - Chauve M.P. and Le Gal P., Complex bi-orthogonal decomposition of a chain of coupled wakes, Physica D, 58, 407 (1992).