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

ON THE STRUCTURE OF THE CYLINDER WAKE

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ABSTRACT

The wake of a single and short aspect ratio cylinder placed in a uniform flow is experimentally investigated. Using an ultrasound anemometry technique, the critical behavior of the spatial shape of the transversal velocity of the Bénard-Von Kàrmàn streets is studied. It is shown that the envelop of the velocity fluctuations which is called the global mode of the wake, follows universal scaling laws given by the theory of phase transitions. In a second set of experiments, the behavior of the longitudinal velocity fluctuations is also investigated. The presence several diameter behind the cylinder of a special point playing the role of a wave maker, is discovered.

1. Experimental arrangement

Our experimental facility consists of a water loop and is fully described in [1]. A single cylinder having a diameter d equal to 4 mm, is positionned on one of the horizontal walls of the channel. Its length being 20 mm, it is in close contact with the other horizontal wall. The shape of the Bénard-Von Kàrmàn wake of this confined flow is studied by ultrasound anemometry whose operation principle is also presented in [1].

We proceeded to two sets of experiments. In the first, the ultrasound probe is placed in a groove machined in the middle plane of the side-wall of the channel. The complete transversal velocity profile can be measured along lines crossing the main flow in the y direction. The transversal velocity profiles are recorded every 69.8 ms, in 128 space positions separated by 0.74 mm. 1024 instantanneous profiles are then digitized and recorded for several Reynolds numbers R. In the second set of experiments, the ultrasound probe is positionned inside the water flow, 10 cm downstream of the cylinder and 2 mm on its side (y/d= 0.5). In this manner, longitudinal velocity profiles are obtained with the same configuration of the acquisition channel.

2. Results and discussion

Modelling the Bénard-Von Kàrmàn instability in terms of global modes, needs to represent the velocity wake fluctuations by the product of two independent functions linked to the temporal and spatial evolutions of the velocity field. It has then been proved that the temporal behavior of the vortex shedding can be modelled by a Landau equation [2] which represents the growth and the non linear saturation of a periodic disturbance which has the same frequency every where in space. On the contrary, the spatial behavior of this periodic disturbance is much more difficult to study because traditionnal anemometry techniques (hot wire or laser anemometry) need heavy mappings of the flow. The ultrasound profile monitor presents in this context a new and interesting alternative.

2.1 Transversal velocity profiles

The first experimental studies of the envelop of the fluctuations in a wake [3] have shown that these fluctuations possess a maximum whose position is clearly defined and varies with the Reynolds number. More recently, experimental [4] and numerical [5] studies have shown that the wakes of triangular bodies present a critical behavior at small Reynolds numbers. In particular, it is shown that the amplitude and the position of the maxima of the transversal velocity oscillations obey power laws of the Reynolds number.

As explained in the introduction, we measure the complete profiles of the transversal velocity in 8 different positions downstream the cylinder and for several Reynolds numbers. Figure 1 presents such a space time diagram, where we recognize the periodic oscillation of the transversal velocity due to the vortex shedding.

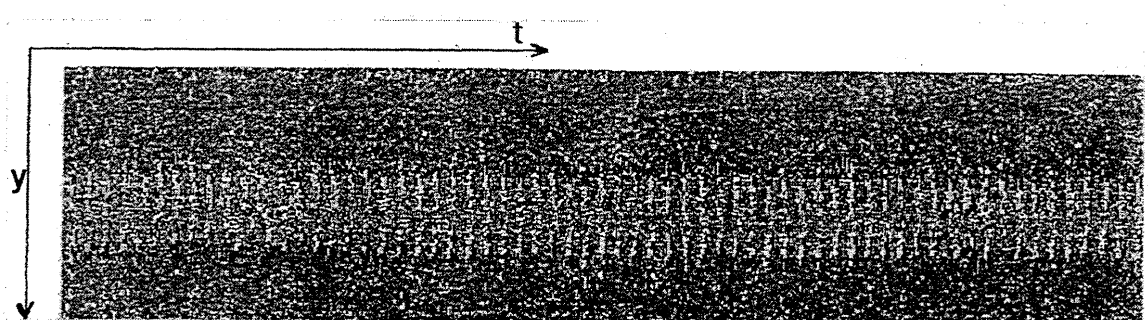

Figure 1: Space time diagram of the transversal velocity fluctuations (x/d= 7, R=142)

Then, taking the temporal Fast Fourier Transform in each of the 128 space points, it is possible to compute the profiles of the squared amplitude of the fundamental mode. These profiles are then gathered on the same diagram and give a three-dimensionnal view of the global mode of the circular cylinder wake.

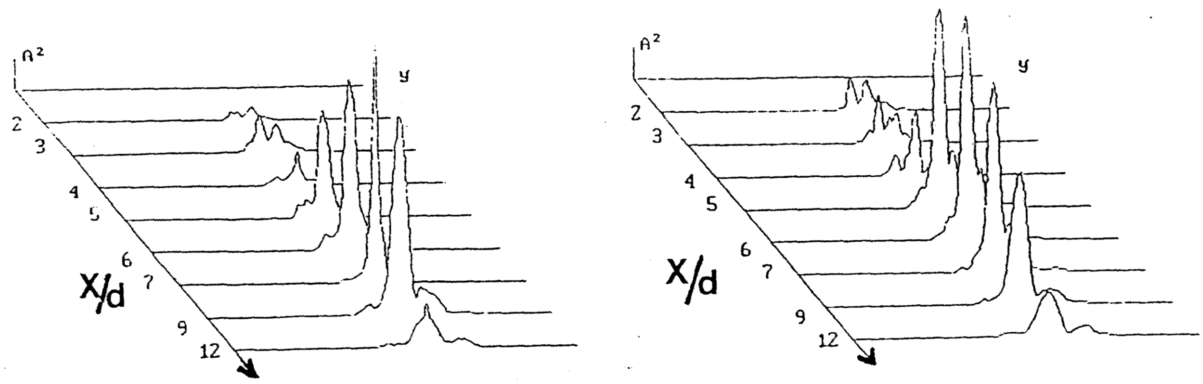

Figure 2: Three-dimensionnal representation of the energy of the transversal velocity oscillations (R=170 and R=185).

Plotting the amplitudes taken by these profiles along the x axis, in the direction of the fluid flow, we can observe the deformation of the global mode with the Reynolds number. On Figure 3, we observe a rapid increase of the amplitude of oscillation up to a maximum whose position varies between 5 and 9, when decreasing the Reynolds number. Then, the decrease of these envelops far away from the cylinder can be interpreted as a viscous relaxation of the far wake.

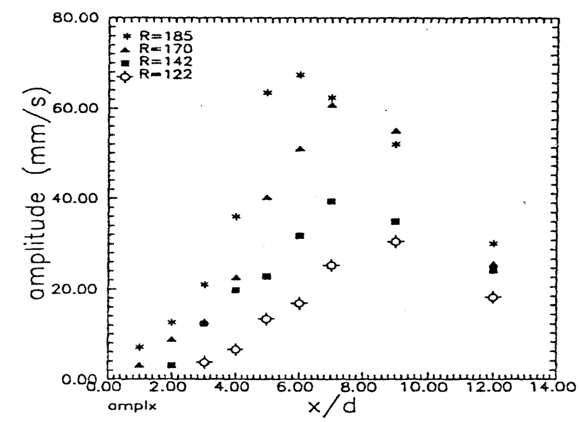

Figure 3: Amplitude of the transversal velocity oscillations downward the cylinder (y/d=0).

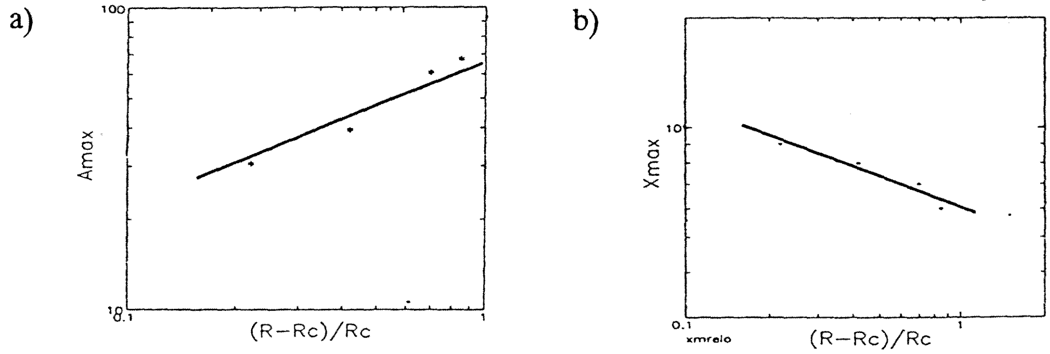

Figure 4: Amplitude (a) and position (b) of the maximum of the transversal velocity oscillations as a function of the Reynolds number.

It is then easy to compute the evolution of the position and level of the maximum of the mode as a function of the Reynolds number. The logarithmic representations of figure 4 show the critical behavior of the envelops as already observed in [4] and [5]. Moreover, we confirm the exponent of the power laws (1/2 and -1/2) observed in [5] contrary to what was measured in [4].

2.2 Longitudinal velocity profiles

In the second set of experiments, the probe is placed inside the water channel, aligned with the x axis in order to measure the longitudinal velocity fluctuations. Because this mode is odd, its amplitude is null along the x axis, and we placed the probe at the transversal position y = 0.5d. Figure 5 gives a space time diagram obtained by the ultrasound monitor. As it can be observed, waves representing the alternate vortex shedding are generated from a point positionned at x/d=6 downstream of the cylinder. Thus some waves propagate in the downstream direction, but also others in the upstream direction. This experimental observation confirms the existence in the cylinder wake of a region of the flow where the instability is of "absolute type"[6].

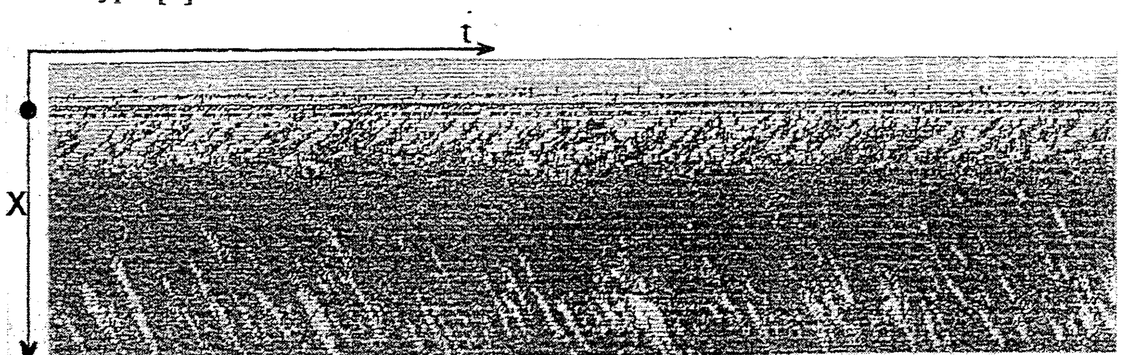

Figure 5: Space time diagram of the longitudinal velocity component (R=142, y/d=0.5)

3. References

[1] I. Peschard, J.F. Ravoux ,P. Le Gal, Y. Takeda and M.P. Chauve, Collective behavior of wakes shed by a row of cylinders, 1st International Symposium on Ultrasonic Doppler Methods, these proceedings, (1996).

[2] M. Provansal, C. Mathis and L. Boyer, Bénard-Von Kàrmàn instability: transient and forced regimes, J. Fluid Mech. **182**, 1 (1987).

J. Dusek, P. Le Gal and Ph. Fraunié, A numerical and theoretical study of the first Hopf bifurcation in a cylinder wake, J. Fluid Mech. **264**, 59 (1994).

[3] C. Mathis, Propriétés des composantes transverses dans l'écoulement de Bénard-Von Kàrmàn aux faibles nombres de Reynolds, Thèse, Univ. de Provence, France (1983).

[4] S. Goujon-Durand, J.E. Wesfreid and P. Jenffer, Downstream evolution of the Bénard-Von Kàrmàn instability, Phys. Rev. E **50**,308 (1994).

[5] B.J.A. Zielinska and J.E. Wesfreid, On the spatial structure of global modes in wake flow, Phys. Fluids **7**, 6 (1995).

[6] P. Huerre and P. Monkewitz, Local and global instabilities in spatially developing flows, Annu. Rev. Fluid Mech. **22**, 473 (1990).