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

AN EXPERIMENTAL STUDY ON A WAKE OF A TORUS USING UVP MONITOR

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ABSTRACT

Measurements by using the ultrasonic velocity profile monitor (UVP) are presented for the spatiotemporal flow structure behind a torus. The flow around the torus has a complicated three-dimensional structure, and it is very difficult in this flow to measure the multi-components of velocities by means of other usual methods. In this study the instantaneous velocities along the measuring line are successively measured, and the spatial distribution of power-spectra and two-point correlation are analyzed in case that the torus is set at zero incidence.

1. Introduction

The flow around a torus body is a basic flow applicable to many problems including bio-fluid mechanics for DNA polymer, flows with micelles, those around helical heating tubes, and so on. This flow has a three-dimensional complicated structure, and so far little studies have been made but for analytical one for low Reynolds numbers (Johnson & Wu [1] and Goren & O'Neill [2]) and flow visualization experiments focused on vortex arrangement or its stability in the wake behind the torus (Amarakoon et al. [3], Monson [4] and Leweke & Provansal [5]). The details of the three-dimensional spatial structure on this flow is remained to be clarified.

The objective of this study is to make clear the flow structure around the torus. The present authors have so far made some experiments in which, for the torus set aslant with the mean flow direction, the flow around the torus is visualized, and the drag and lift of the torus are measured. In this experiment, the instantaneous velocity distribution behind the torus set at zero incidence against the main flow is measured by using a ultrasonic velocity profile monitor explained in detail in reference [6], and then the spatiotemporal flow structure is examined.

2. Experimental apparatus and procedure

Flow field and coordinate system are shown in Fig. 1. The cross-sectional diameter and center-line diameter of a torus are defined as d and D, respectively. A ratio D/d is a geometrical parameter of the torus, and in this study the case of $D/d = 3$ and 5 with $d = 30$ mm are investigated. The torus is set at zero incidence against the main flow, so that its axis of symmetry is coincided with the x-axis, i.e., the main flow direction. The origin of coordinate system is at the center of the symmetrical plane of torus, and the y-axis is normal to the x-axis, that is, parallel to

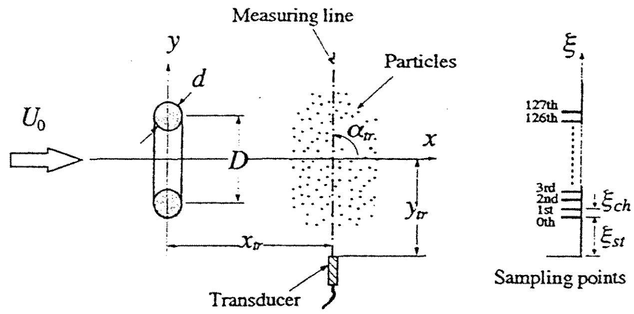

Fig. 1 Flow field and coordinate system.

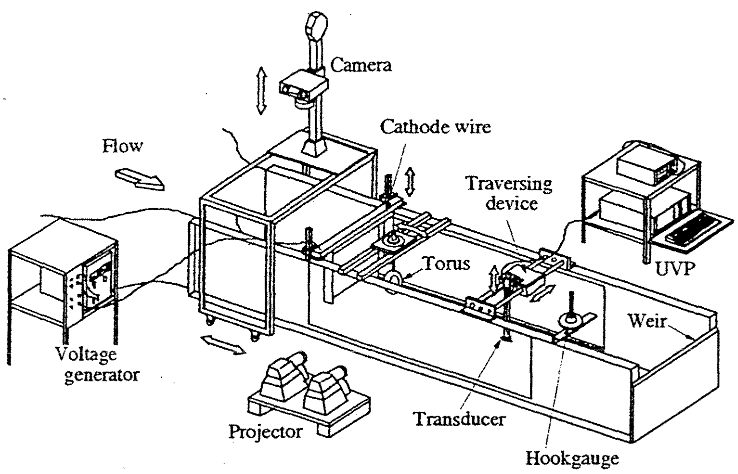

Fig. 2 Sketch of the test section.

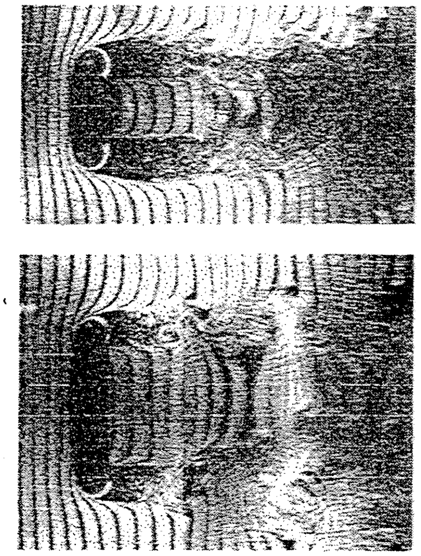

Fig. 3 Flow visualization.
(a) $D/d = 3$, (b) $D/d = 5$.

the horizontal plane in a test section.

The experiment has been made using a water channel with a test section of 3 m length, 0.7 m width and about 0.6 m depth, as shown in Fig. 2. The torus is supported at the 1 m downstream position from the entry by an 8 mm diameter brass-rod, and can be rotated normal to a uniform flow. An ultrasonic transducer is inserted parallel to the x-y plane at the positions shown in Table 1 using a traversing device. The uniform flow velocity U_0 is kept constant 50 mm/s and then the Reynolds number based on the cross-sectional diameter is about 1500.

The UVP monitor used in this study is a model X3-PS (Met-Flow). A basic frequency of the ultrasonic transducer is 4 MHz and the other measuring parameters are shown in Table 1. Hydrogen bubbles electrolytically generated from a 30 μm diameter Pt-wire are utilized for the ultrasonic reflection and also for the flow visualization. The UVP data are processed on the personal computer PC-9801BA3 (NEC).

3. Results and discussion

3.1 Spatiotemporal velocity field

For the sake of taking the general view of the flow field around the torus, the flow visualized by means of a hydrogen-bubble method is shown in Fig. 3. Mean flow fields for $D/d =$ 3 and 5 are axi-symmetric, but the vortical structures for these flows are different from each other. For $D/d = 5$, in the near wake region, say within 1 D downstream of the torus, the separated shear layers from the inner and outer surface of the torus roll up alternately, and vortex rings are shed in the downstream, whereas in case of $D/d = 3$ any vortex ring is

Table 1 Specifications of measurement

	x – direction	y – direction
ξ_{st} (mm)	15.29	5.00
ξ_{ch} (mm)	4.41	3.68
f_{prf} (Hz)	978	1050
x_{tr} (mm)	600	– 200, – 190, ····, 200
y_{tr} (mm)	100, 150, ····, 700	– 254
α_{tr} (°)	180	90

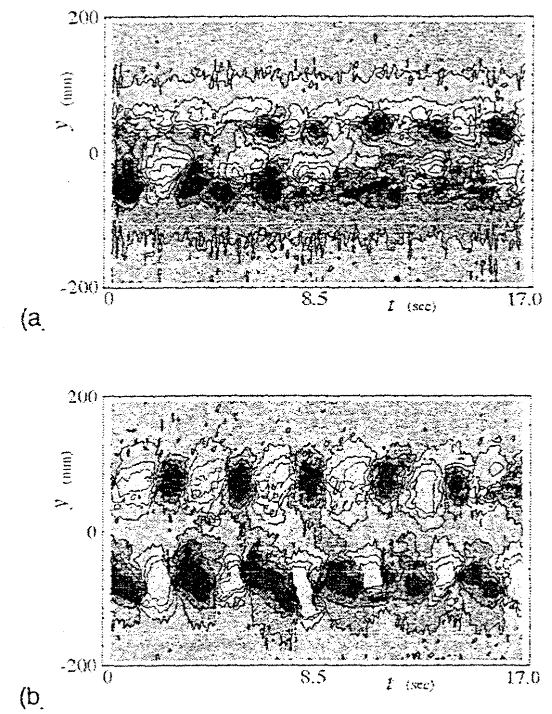

Fig. 4 Contours of velocity component in the y-direction at $x = 150$ mm. (a) $D/d = 3$, (b) $D/d = 5$.

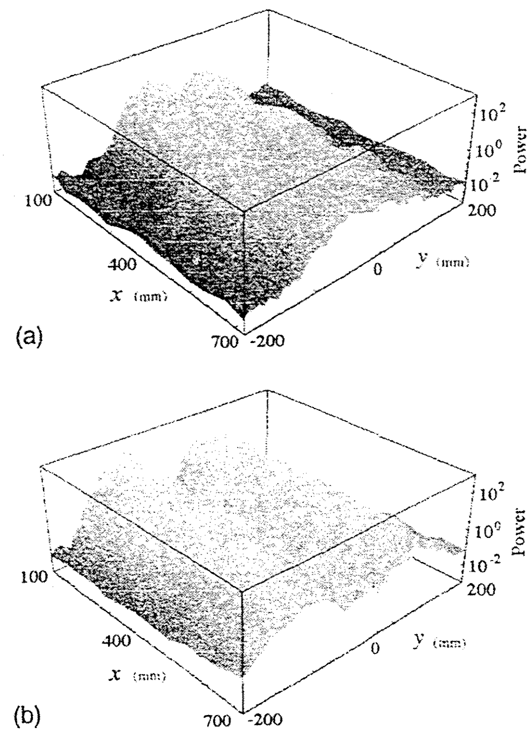

Fig. 5 Power of fluctuating velocity in the x-y plane. (a) $D/d = 3$, $f = 0.31$ Hz, (b) $D/d = 5$, $f = 0.34$ Hz.

not discernible in this visualization picture.

Figure 4 shows the contours of the instantaneous velocity component in the y-direction $\tilde{v}$ measured by UVP along the line parallel to y-axis at $x = 150$ mm. The abscissa is time, but the figure shows nearly the flow pattern in space in which the flow direction is right to left. Although the flows for $D/d = 3$ and 5 are both periodic, the latter is more regular and the periodical structure of this flow is also axi-symmetric.

3.2 Power spectra of fluctuating velocity

As mentioned in the preceding section, the vortices are shed in the wake of the torus. In case of $D/d = 5$, in particular, the regular street of vortex ring is formed. The regularity of the periodic motion will appear in power spectral distribution of fluctuating velocities. In this study, 512 points time-series data are Fourier transformed, although one data set of velocity profile consists of the data of 128 points in space and 1024 points in time domain. Then the two power spectra obtained from one data set are averaged.

Figure 5 shows the power spectral density of v-fluctuating velocity with dominant frequency of vortex shedding f_s. Two mountain ranges of this power spectral density are clearly discernible in case of $D/d = 5$ compared with $D/d = 3$, showing the regularity of the former flow is higher.

3.3 Flow structure

The space correlation of fluctuating velocities at two point separated in the main flow direction is difficult to measure by the method of hot-wire, because the upstream probe disturbs the flow seriously. The UVP can measure such quantities without error due to the probe-induced disturbance, and the two-point correlation coefficients of u-component R_{11} so measured is presented at the reference position $x = 150$ mm in Fig. 6, where r_x denotes the streamwise spacing. The correlation shows the periodical structure of this flow.

Figure 7 shows the conditionally averaged profiles of the velocity component in the y-direction for $D/d = 5$ at $x = 150$ mm. The reference signal is a signal at $y = 60$ mm of the same data set, and each of maxima of the reference signal is used as a trigger. The upper figure is the condi-

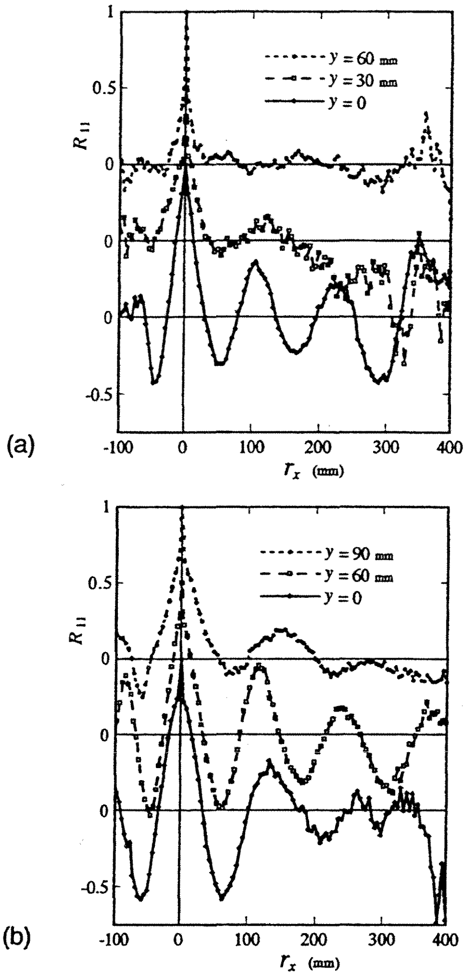

Fig. 6 Two-point correlation in the x-direction (reference position; $x = 150$ mm). (a) $D/d = 3$, (b) $D/d = 5$.

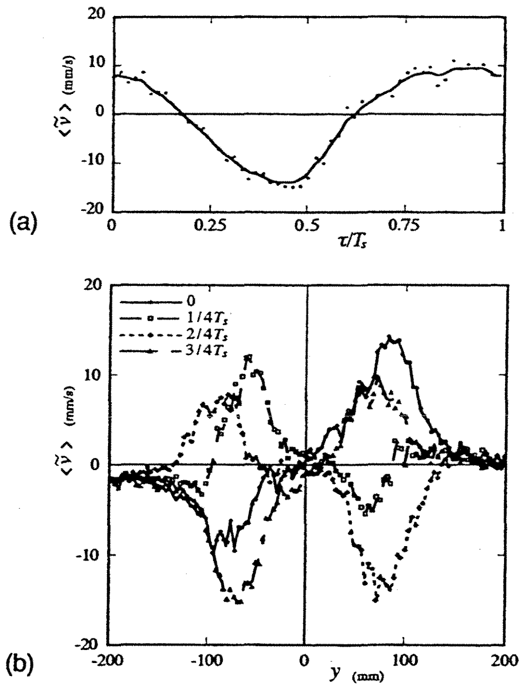

Fig. 7 Conditionally averaged profile of the v-component. (a) Reference signal, (b) averaged profiles corresponding to each phase.

tionally averaged reference signal. The number of averaging times is 18 and the mean periodic time T_s is 2.96 sec. This kind of conditional average elucidates the flow structure quantitatively, and these profiles clearly show that, although the flow is unsteady, it has an axi-symmetrical nature.

4. Concluding remarks

The spatiotemporal flow structure behind a torus was investigated by using the UVP monitor. Instantaneous flow pattern and various statistical quantities including the streamwise two-point correlation, power spectral density of fluctuating velocity and conditionally averaged velocity profiles were analyzed. These quantities made clear the structural properties of the wake of the torus. Experiments and their analysis utilizing the UVP system are relatively speedy and easy in comparison with the traditional measuring system such as hot-wire anemometer, and it is expected that the flow structure around a torus set at attack angle will be clarified with the UVP system.

Acknowledgement

The authors wish to express their appreciation to Dr. Ing. Yasushi Takeda of Paul Scherrer Institut for his advice on UVP system.

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