WAKES OF A CIRCULAR CYLINDER IN STRATIFIED FLUIDS

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NOTE

WAKES OF A CIRCULAR CYLINDER IN STRATIFIED FLUIDS

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The results are reported of a preliminary flow-visualization experiment on the characteristics of two-dimensional wakes of a circular cylinder moving in stratified fluids in the horizontal direction. To summarize the results:

1) The development of vortex wakes behind a circular cylinder is suppressed by the stable stratification of ambient fluids.
2) The vortex streets developed initially evolve into a pair of standing vortices as the cylinder moves at critical values of a stratification parameter k for vortex shedding.
3) The formation of internal lee waves dominates the cylinder wakes at low Reynolds numbers.

Key words : Wakes, Stratified fluids, Flow visualization.

1. Introduction

Stratified flows past a circular cylinder seem to have not been investigated extensively. Recently, however, the flows attract growing attention to their interactions with large-scale engineering structures.

The purpose of this note is to report some results of a preliminary experiment on the characteristics of wakes behind a circular cylinder moved with its horizontal axis normal to the direction of motion in density stratified fluids.

2. Experimental methods

The experiment was carried out using a tow tank 3 m long, 25 cm wide, and 30 cm deep. The experimental set-up is illustrated in Fig. 1. The side walls of the tank were made of transparent plexiglas plates. The tank was equipped with two reservoir tanks for water stratification and a motor-driven carriage.

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Two circular cylinders of 23 cm in length were used as the test bodies; the diameter (D) of one brass cylinder was 1.00 cm and D of the other plexiglas cylinder 2.50 cm. A circular cylinder supported with its axis in the horizonal direction was moved by the carriage to the direction normal to the axis through a stratified water.

Salt was used for setting up a stratified water in the tow tank, and salt concentrations were measured with a refractometer. The density distributions in water were approximately linear before the cylinder was moved.

The electrolytic precipitation method[1] was used for flow visualization. For the 2.50 cm diameter cylinder, a solder rake was employed to produce thin lines of dye at regular height intervals of 2 cm. Flow patterns around a circular cylinder were illuminated through a slit with a 1 kW slide projector placed outside of one end wall, and photographed by a 35 mm camera placed outside of one side wall of the tow tank.

3. Results and discussion

Flow patterns visualized with the dye and viewed from the side of the tank are presented in Figs. 2–6, in which the direction of cylinder motion is from left to right in Figs. 2 and 3, and from right to left in Figs. 4, 5, and 6.

The wakes of a circular cylinder in stratified fluids are governed by the Reynolds number R ($= UD/\nu$), H/D, and a stratification parameter k ($= ND/U$), where U is the speed of the cylinder, ν the kinematic viscosity of salt water, H the water depth, and $N^2 = -(g/\rho)\ (d\rho/dz)$ with g, ρ, and z being the acceleration due to gravity, the density of salt water, and z the vertical coordinate, respectively. No dependence of ν on salt concentration will be considered.

The dependence of cylinder wakes on k is shown in Fig. 2. Figure 2(a) shows a double row of vortices behind a circular cylinder moving in a homogeneous water. As will be seen from the figure, the vertical distance between the upper and lower vortex streets increases downstream. Figure 2(b) shows a double row of vortices in a water with a small density gradient. The vortices are shed periodically similarly as in the case of a homogeneous water, but the vertical distance between the two vortex streets does not increase downstream. With the increase of k, two vortex streets are merged into a single straight wake downstream as shown in Fig. 2(c). In this case, the vortex shedding frequency was 0.2 Hz, which gives the Strouhal number of 0.16. This is nearly equal to that for a homogeneous flow at the same Reynolds number. When k is increased further, no vortices are shed and, as shown in Fig. 2(d), a pair of standing vortices form immediately behind the cylinder. The flow pattern variation shown in Fig. 2 indicates that the shedding of vortices from a circular cylinder is suppressed by the stable stratification of ambient fluids.

Another feature of variation of a cylinder wake is shown in Fig. 3, where t

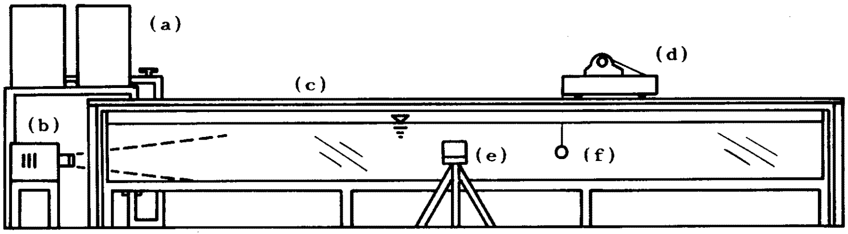

Fig. 1. Experimental set-up
(a) Reservoirs, (b) slide projector, (c) tow tank,
(d) carriage, (e) camera, (f) circular cylinder

is the time passed after the start of the cylinder motion. This figure shows that a spatially periodic wake in (a) evolves into a standing vortex wake in (b) as the cylinder moves to right. When R and H/D are fixed, this transfiguration occurs only for a critical value of k at which the wake changes its form from a standing-vortex type to a periodic-vortex type. The effect of H/D may not be conspicuous for the $D = 1$ cm cylinder. It should be also noted that when $k = 0$ the periodic vortex shedding occurs at $R \lesssim 40$. No mechanism for this type of transfiguration is known at the present, but the formation of a well-mixed stable region of fluids behind a cylinder during its motion seems responsible for it.

The value of R for Fig. 3(a) is nearly equal to that for Fig. 2, and so Fig. 3(a) may be put between Figs. 2(c) and (d) for comparison's sake. Based on this, the critical value of k at which a standing- to periodic-wake occurs at about $R = 115$ is estimated roughly as 0.7.

Figures 4, 5, and 6 show flows around the 2.5 cm diameter cylinder. When R is low and k is large, internal lee waves form behind a circular cylinder and dominate the wake of the cylinder. Figure 4 shows a typical flow pattern at a relatively small value of R; the direction of cylinder motion is from right to left. As will be seen in the figure, a region of upstream wake forms on the upstream side of the cylinder. The form of the downstream wake is completely dominated by the lee waves.

Figure 5 shows a close-up view of flow at a larger value of R. A rotor vortex is seen in the lower lee wave behind the cylinder. A pair of counter-rotating vortices are also seen in the wake. Note that this vortex pair is detached from the rear of the cylinder.

Two flow patterns at larger values of R, but at smaller values of k, are shown in Fig. 6; (a) shows the flow at $R = 275$, and (b) at 572. In Fig. 6(a), the internal waves are still clearly seen and also a pair of standing vortices on the rear of the cylinder. When R is increased further, the vortices begin to be shed periodically from the cylinder as shown in Fig. 6(b). No internal waves form in this case.

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Reference

1) Honji, H., Taneda, S. and Tatsuno, M., Rep. Res. Inst. Appl. Mech., Kyushu Univ. **28**, 89 (1980) 83.

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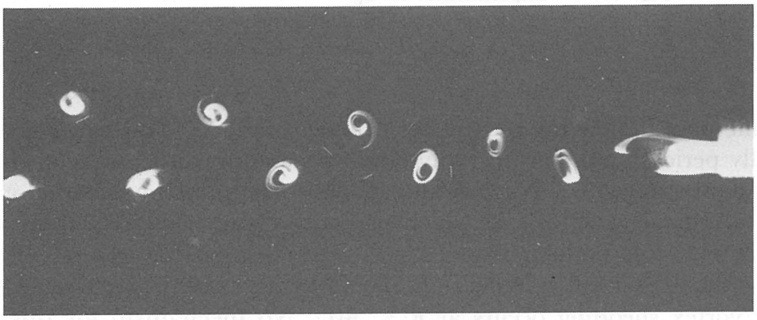
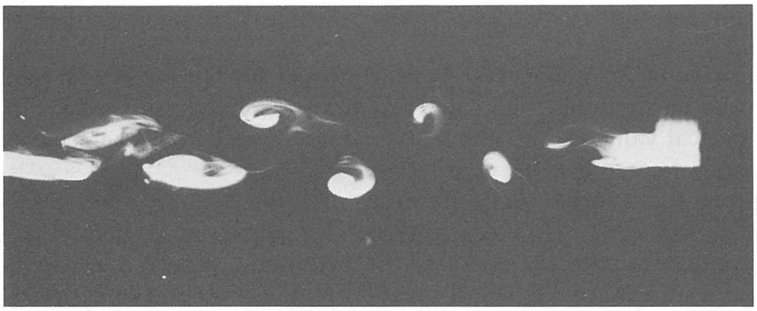
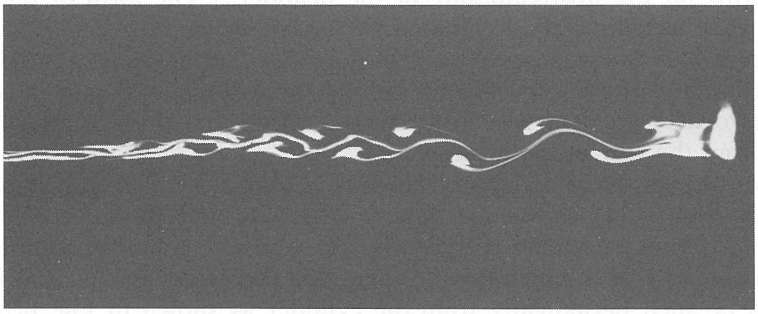


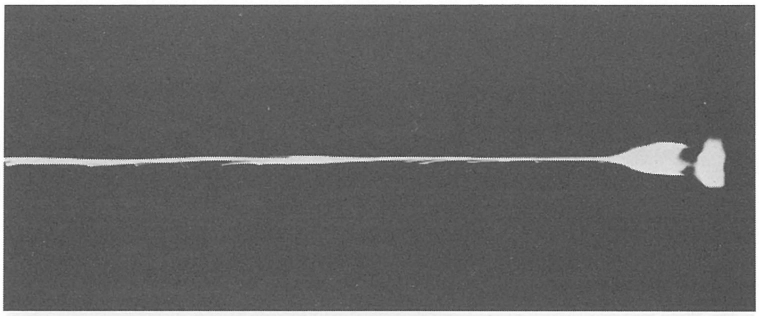
(a) $k=0$, $U=1.26$ cm/s



(b) $k=0.25$

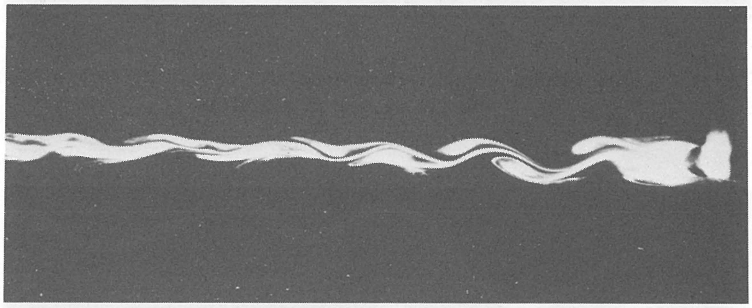


(c) $k=0.49$

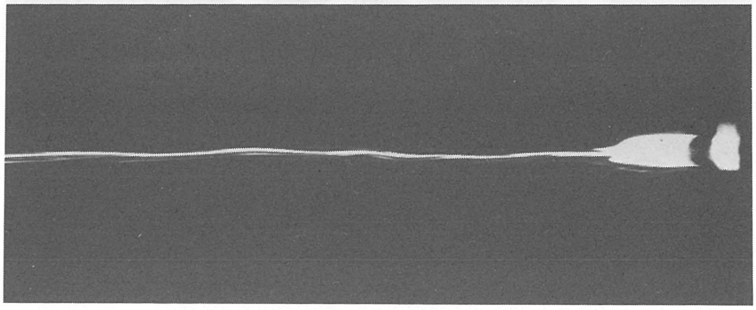


(d) $k = 0.87$

Fig. 2. Wakes of a circular cylinder of $D = 1.00$ cm at $R = 113$ and $H/D = 18$.



(a) $t = 46$ s



(b) $t = 137$ s

Fig. 3. Transfiguration of a cylinder wake with time at $R = 117$, $H/D = 18$, $k = 0.62$, $U = 1.31$ cm/s, and $D = 1.00$ cm.

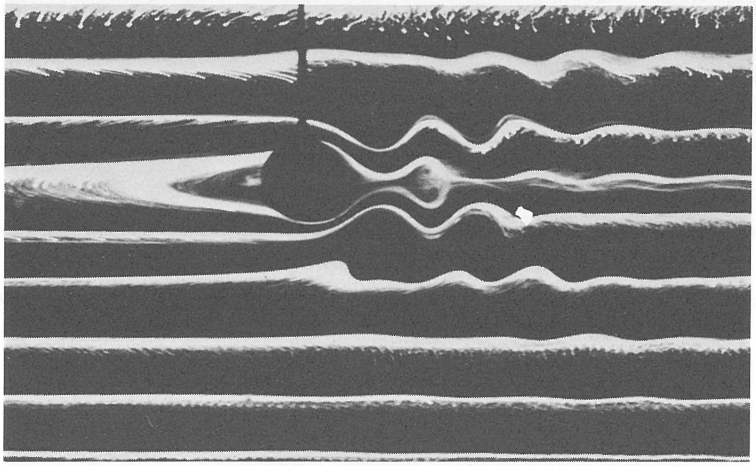


Fig. 4. Flow pattern around a circular cylinder at $R = 56$, $H/D = 8.7$, $k = 5.3$, $U = 0.256$ cm, and $D = 2.50$ cm.

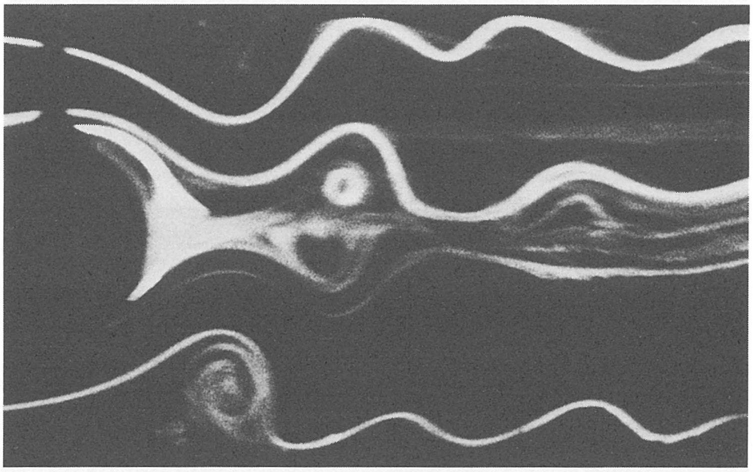
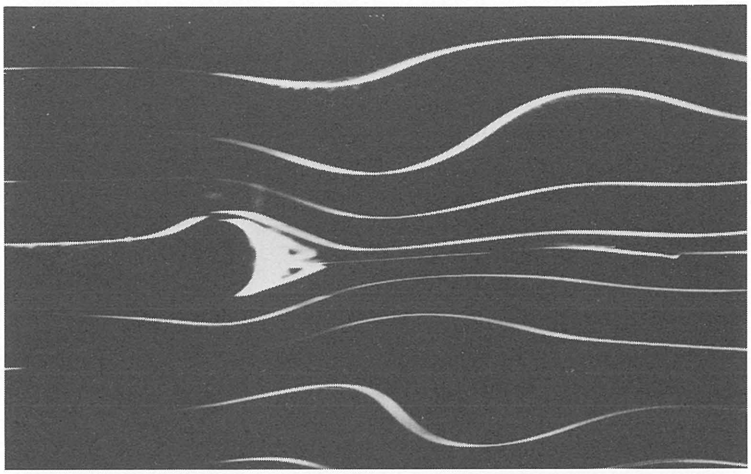
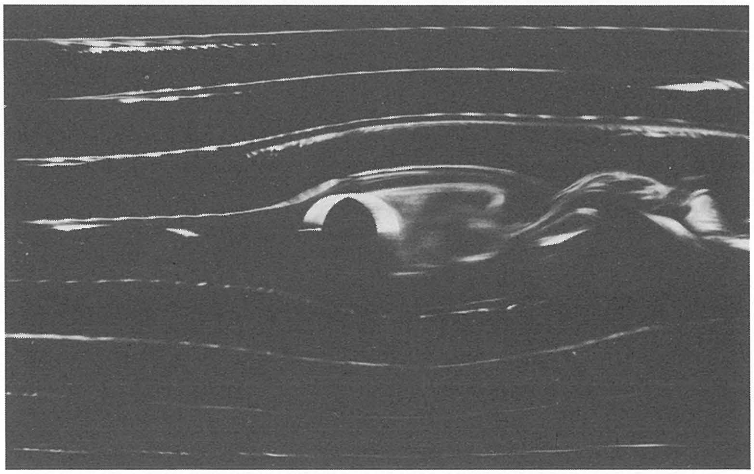


Fig. 5. Close-up flow pattern around a circular cylinder at $R = 95$, $H/D = 6.8$, $k = 4.5$, $U = 0.450$ cm/s, and $D = 2.50$ cm.



(a) $R = 275$, $k = 0.70$, $U = 1.30$ cm/s



(b) $R = 572$, $k = 1.5$, $U = 2.70$ cm/s

Fig. 6. Flow patterns around a circular cylinder at $H/D = 7.0$, and $D = 2.50$ cm.