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HONJI, Hiroyuki
Research Institute for Applied Mechanics, Kyushu University : Lecrurer

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AVERAGE FLOWFIELDS AROUND A GROUP OF CIRCULAR CYLINDERS

By Hiroyuki HONJI*

A visualization study was made on time-mean flows around finite rows of multiple circular cylinders placed with their common axes normal to the uniform stream at Reynolds numbers below 700. The hydrogen bubble technique and electrolysis method were used for flow visualization. Appearance of an equilibrium region of reversed flow was observed clearly in the time-mean wake of the cylinder row.

Nomenclature

U	: Uniform flow speed	ν	: Kinematic viscosity
d_0	: Cylinder diameter	t_e	: Exposure time
d	: Row breadth	t	: Time elapsed since starting
l	: Spacing between neighboring cylinders	R_s	: $= Ud_0/\nu$
		R_g	: $= Ud/\nu$

1. Introduction

In a preceding paper, the present author[1] investigated the laminar wake of a finite row of equal parallel circular cylinders arranged, with equal spacing, perpendicularly to the undisturbed stream at low Reynolds numbers. It was observed that an isolated vortex pair is formed downstream of the cylinder row at appropriate values of l/d_0, R_s, and R_g. For cylinder rows of $l/d_0 \lesssim 2$, the laminar wake begins to collapse when R_g exceeds about 40. At $R_g \gtrsim 40$ the periodic vortex street is formed behind the cylinder row. It is known that if time-mean is taken the unsteady periodic flow has some definite equilibrium flow pattern related with the region of mean reversed flow.

This work is concerned with a visualization study of the time-mean flow around cylinder rows at low Reynolds numbers. Although the essential result of this work was already reported in another paper of the present author[2], some aspects of the flow are discussed in more detail, and a number of photographs omitted there owing to limited space are given at the end of the paper.

* Lecturer, Research Institute for Applied Mechanics, Kyushu University.

2. Experimental Method

The experiment was carried out using a 30 cm × 30 cm × 200 cm water tank. A bird's-eye view of the apparatus is shown in Photo 1. The tank was equipped with a towing carriage to which test bodies were attached vertically. The carriage speed could be varied from 1.5 up to 7.0 cm/s continuously.

The hydrogen bubble and partly electrolysis methods were used for flow visualization: Refs. 1 and 3 should be referred for these techniques. Long-time-exposure photographs were taken in order to visualize the time-mean flowfield.

The value of t_e ranged from 20 to 70 seconds, which covered many periods of the wake oscillation. Test bodies were made of five to fifteen cylindrical rods, which were placed with equal spacing perpendicularly to the oncoming stream. The cylinder diameters were 0.0810 or 0.200 cm, and the length was 18 cm. The breadth of rows ranged from 0.5 to 1.5 cm. The range of R_g examined was between 140 and 700. Owing to some rate of rise of hydrogen bubbles in water the experiment was not made at the lower range of R_g.

3. Experimental Results

Typical laminar wakes are shown in Photo 2. These flow patterns are visualized with the electrolysis method, but streamlines of aluminum dusts suspended in water are superposed. As will be seen from Photo 2 (a), streaks of dye flow downstream being pushed aside by a symmetrical vortex pair formed at a distance downstream of the cylinder row. In this case, filaments of dye were educed electrochemically from the surface of the test cylinders after the steady state of flow was reached. When the dye was introduced from the beginning of motion, it came into the region of a closed vortex pair and was trapped there as will be seen in Photo 2(b). The dye was, however, diffused slowly and the tails of dye was observed far downstream of the cylinder row.

In the flow past a cylinder row started from rest impulsively with a constant speed, a vortex pair of the same type is also formed in the wake as shown in Photo 3. This type of vortex wake develops downstream with time, and is ultimanely turned into a vortex street if R_g is not small. It should be noted that the unsteady vortex pair has more symmetrical form in the flow direction than the steady one.

Formation of the isolated vortex pair was observed for cylinder rows of $l/d_0 \lesssim 2$ only when $R_g \lesssim 40$. When $R_g \gtrsim 40$, the alternate shedding of vortices was always observed for these rows of cylinders. An example of the vortex street formed behind a cylinder row is shown in Photo 4, being taken with a camera placed at rest with respect to the undisturbed fluid.

Time-averaged oscillating wakes behind obstacles have, in general, a quasi-steady flow pattern having good spatial reproducibility. This equilibrium flowfield is thought to be closely correlated with the region of reversed flow behind the obstacle. In Photo 5, three patterns of the same flow are shown, which were photographed for the different times of exposure. In this flow the period of wake oscillation would be about 3 seconds. Photo 5 (a) and (b) show the unsteady oscillating flow pattern, and Photo 5 (c) shows the quasi-steady one, all of which were taken with a camera placed at rest with respect to the test cylinder row. From Photo 5 (c), it will be seen that a closed dark region is formed at some distance downstream from the cylinder row. This region which seems to correspond in qualitative character to the isolated region of a vortex pair in the case of the laminar wake will be identified later with the region of mean reversed flow.

Some other examples of the similar flow pattern are presented in Photos 6 and 7. A flow pattern at a relatively large value of R_g is shown in Photo 7 (b), in which the dark region like an arrowhead appears in the wake. For comparison the mean flow pattern for a cylinder row having $l/d_0=0$ is shown in Photo 8, in which a dark bubble is not isolated, but attached to the rear of the cylinder row directly.

Flow reversion in the isolated flow bubble is shown in Photo 9. A tracer generating wire is located in the bubble. From the photographs it can be seen that the tracers move upstream on the average, and the forms of the reversed-flow region are different with R_g. The head of the region is sharpend when R_g exceeds about 300 for this cylinder row having $R_g/R_s=14.4$. This means that at high values of R_g the wake almost split into two streams behind the cylinder row owing to the existing intense reversed flow. There seems to be a close relationship between the two flow patterns presented in Photos 7 (b) and 9 (c).

The electrolysis method of flow visualization was used only partly in the present experiment. The region of reversed flow is clearly shown in Photo 10. As in the case of flow pattern visualized by means of hydrogen bubbles, the reversed flow does not reach the cylinders. The dye was introduced just upstream of the cylinder row, and the observation of flow pattern was also made using the same test body. The reversed-flow region visualized with this method is shown in Photo 11, in which a nearly symmetrical closed region is observed in the wake. This closed region seems to well correspond to the region of a vertex pair in the laminar wake of the cylinder row.

When R_g/R_s is relatively small for a cylinder row ($R_g/R_s=7.0$), localized vortices are formed immediately behind the outermost cylinders at $R_s \sim 65$ as shown in Photo 12(a). In this case, no isolated region of reversed flow is formed clearly. When R_s is larger than this critical value and R_g is large, the wake splits into two parts immediately behind the cylinder row. Such a wake is shown in Photo 12 (b).

4. Conclusions

The equilibrium flow patterns around rows of circular cylinders were investigated using the hydrogen bubble and electrolysis techniques of flow visualization. It was observed that even the periodic wake of a cylinder row has a definite equilibrum region of reversed flow in it if time-mean is taken. The reversed flow bubble is always isolated in the wake when $l/d_0 \neq 0$, but it is attached directly to the cylinder row when $l/d_0=0$.

For a cylinder row of $l/d_0=0.494$ and $R_g/R_s=14.4$, two types are observed of the form of the reversed flow region: the critical value of R_g for transition from one type to another is about 300. For another cylinder row of $l/d_0=0.500$ and $R_g/R_s=7.0$, localized secondary vortices are formed behind the outermost cylinders at $R_s \sim 65$. These vortices seem to be formed when R_s is relatively large.

Acknowledgments

The author wishes to thank Professor S. Taneda and Professor R. Sawada for useful comments and discussions.

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References

1) Honji, H., Viscous Flows past a Group of Circular Cylinders, J. Phys. Soc. Japan, Vol. 34, No. 3, 1973, pp. 821-828.
2) Honji, H., Formation of a Reversed Flow Bubble in the Time-Mean Wake of a Row of Circular Cylinders, J. Phys. Soc. Japan, Vol. 35, No. 5, 1973.
3) Taneda, S. and Honji, H., Vortex Wakes of Oscillating Circular Cylinders, Bull. Res. Inst. Appl. Mech., No. 29, 1968, pp. 17-39 (in Japanese).

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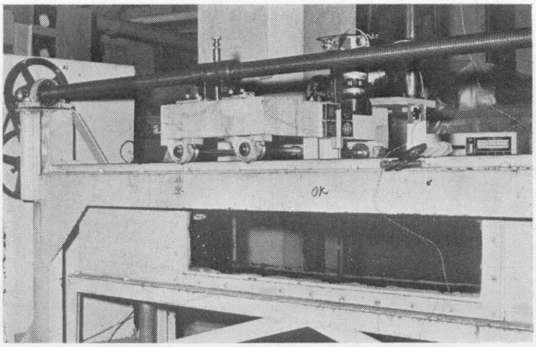
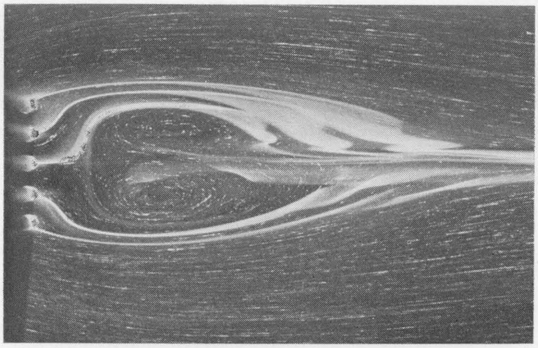


Photo 1 Experimental apparatus.



(a) Flow pattern when dye is introduced after establishment of the steady state.

(b) Flow pattern when dye is introduced from the beginning of motion.

Photo 2 Laminar wakes of a cylinder row: $U=0.153$ cm/s, $d=1.80$ cm, $d_0=0.200$ cm, $l/d_0=1.00$, $R_s=3.43$, $R_g=30.8$.

(*Facing p.* 20)

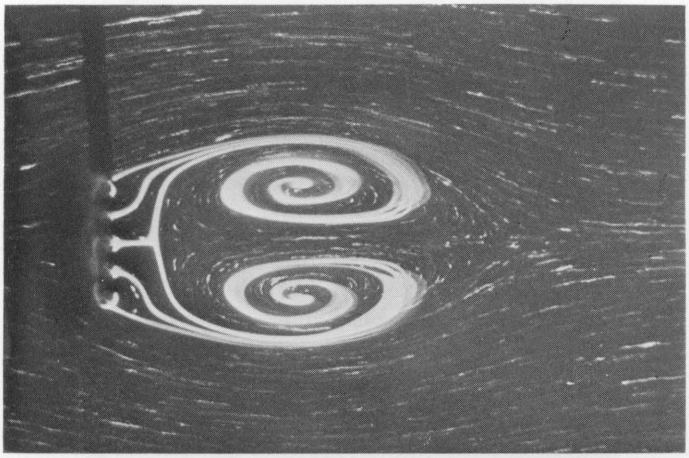


Photo 3 An initial stage of starting-flow development: $U=1.00$ cm/s, $d=1.40$cm, $d_0=0.200$ cm, $t=9.10$ s, $Ut/d=6.50$, $l/d_0=0.500$, $R_s=21.4$, $R_g=150$.

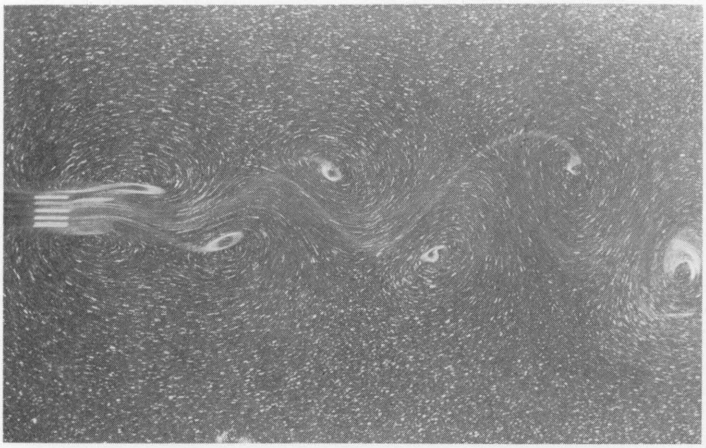
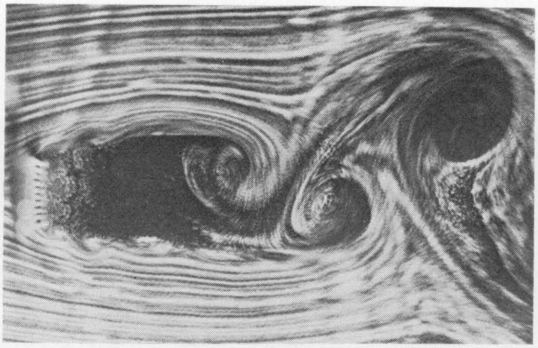
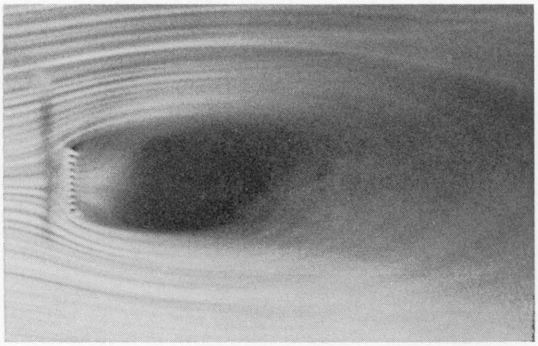


Photo 4 Formation of a periodic wake: $U=0.285$ cm/s, $d=1.40$ cm, $d_0=0.200$ cm, $l/d_0=0.500$, $R_s=6.21$, $R_g=43.4$.



(a) $t_e = 0.067$ second.

(b) $t_e = 1.0$ second.



(c) $t_e = 30$ seconds.

Photo 5 Flow patterns for different t_e: $U = 2.44$ cm/s, $d = 1.17$ cm, $d_0 = 0.0810$ cm, $l/d_0 = 0.494$, $R_s = 20.0$, $R_g = 288$.

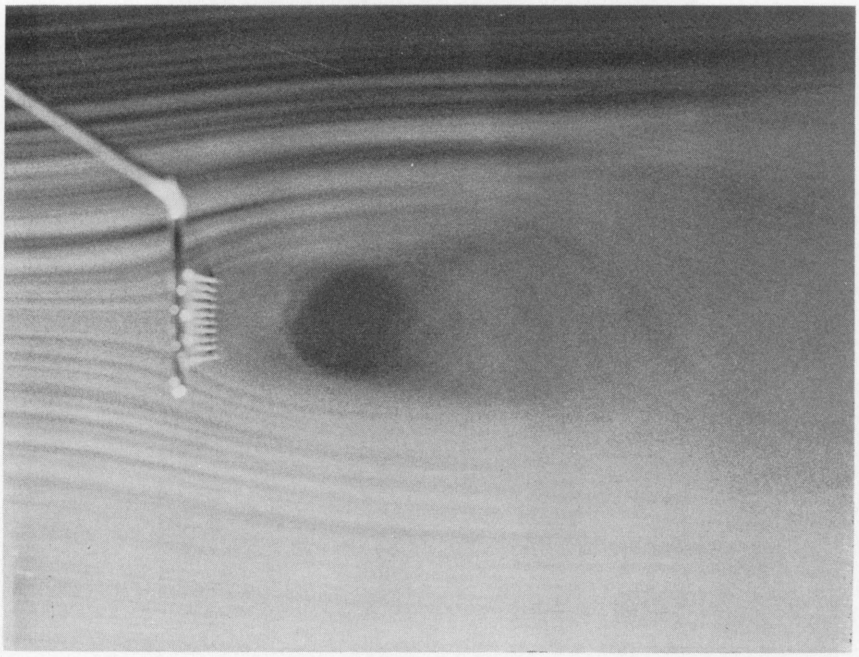
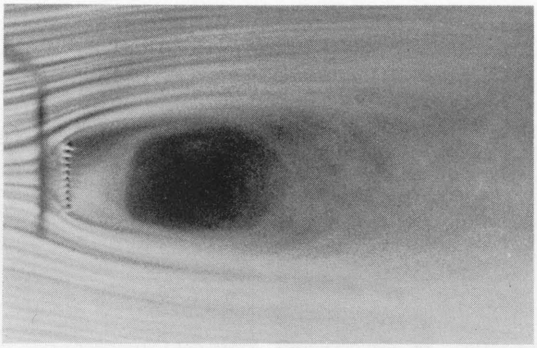
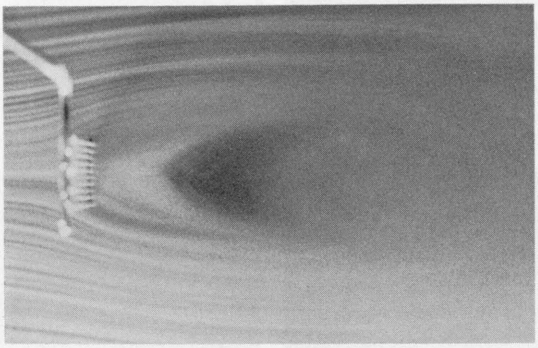


Photo 6 An isolated reversed-flow bubble visualized by means of hydrogen bubbles in the time-mean wake of a cylinder row : U=2. 40 cm/s, d = 1. 17 cm, d_0 = 0. 0810 cm, t_e = 40 seconds, l/d_0 = 0. 494, R_s=19. 1, R_g = 275.



(a) $U = 2.35$ cm/s, $R_s = 18.5$, $R_g = 267$.



(b) $U = 3.33$ cm/s, $R_s = 26.5$, $R_g = 382$.

Photo 7 Reversed flow bubbles at different Reynolds numbers: $d = 1.17$ cm, $d_0 = 0.0810$ cm, $l/d_0 = 0.494$, $t_e = 30$–44 seconds.

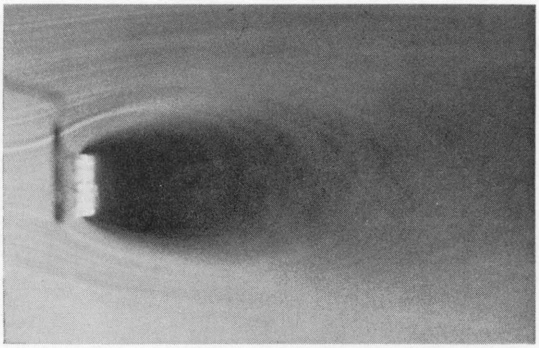
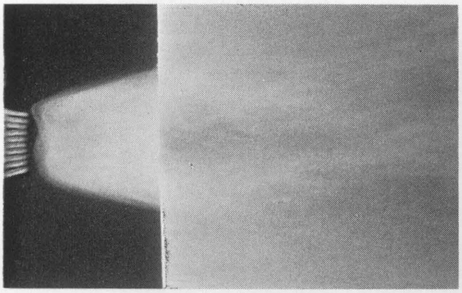
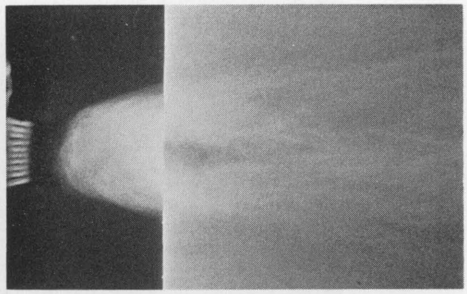


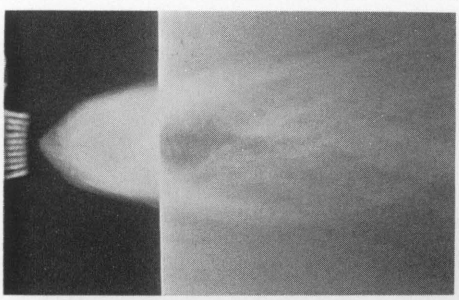
Photo 8 Reversed flow bubble behind a cylinder row of $l/d_0=0$: $U=2.91$ cm/s, $d=1.10$ cm, $d_0=0.0810$ cm, $t_e=30$ seconds, $R_g=326$.



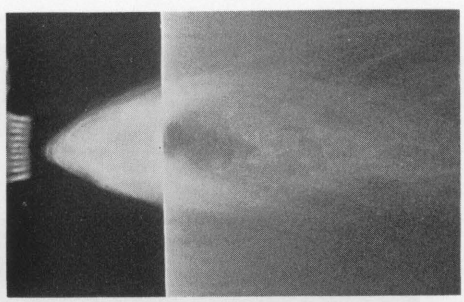
(a) U=2. 03 cm/s, R_s=14. 2, R_g=204.



(b) U=2. 75 cm/s, R_s=18. 8, R_g=271.



(c) U=3. 26 cm/s, R_s=22. 3, R_g=321.



(d) U=4. 23 cm/s, R_s=28. 8, R_g=416.

Photo 9 Variation of reversed-flow pattern when a tracer generating wire is located downstream of the cylinder row : $d = 1.17$ cm, $d_0 = 0.0810$ cm, $t_e = 25$–57 seconds, $l/d_0 = 0.494$.

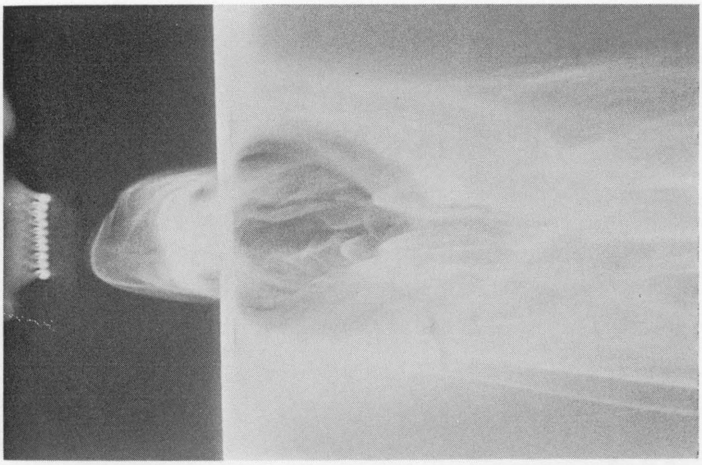


Photo 10 Reversed-flow pattern visualized by the use of the electrolysis method, in which a tracer generating wire is located in the wake: $U=2.40$ cm/s, $d=1.17$ cm, $d_0=0.0810$ cm, $l/d_0=0.494$, $R_s=19.1$, $R_g=275$.

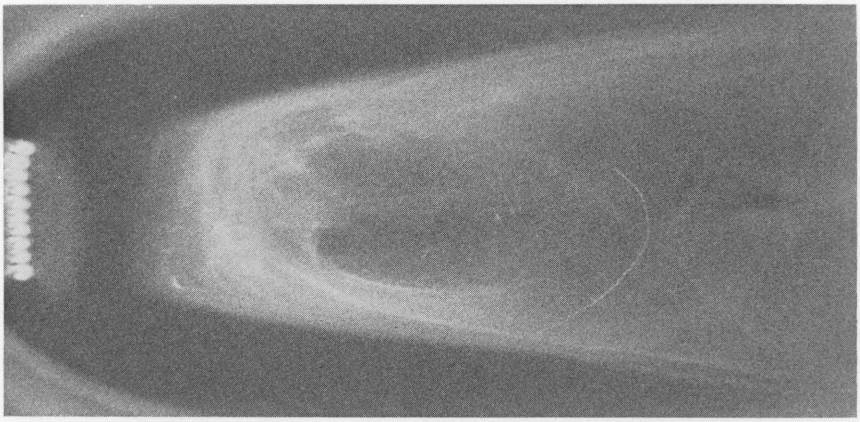
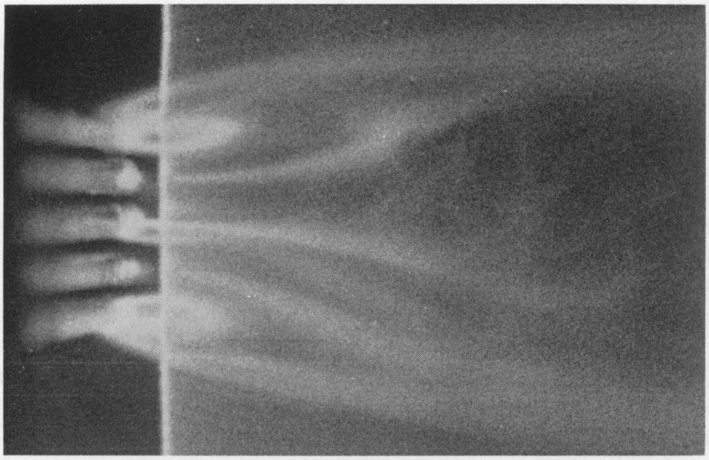
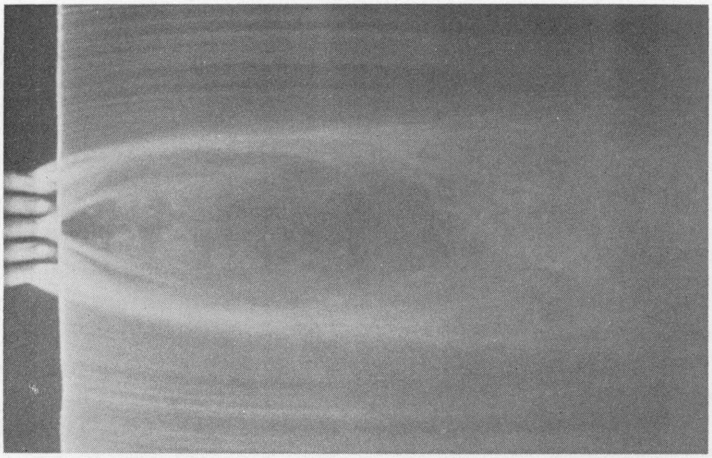


Photo 11 Same as Photo 10, but a tracer generating wire is located just upstream of the same test body: $U=2.36$ cm/s, $R_s=18.3$, $R_g=264$.



(a) Localized vortices behind the outermost cylinders: $U = 4.17$ cm/s, $R_s = 70.2$, $R_g = 491$.



(b) Bifurcation of the wake: $U = 5.29$ cm/s, $R_s = 89.2$, $R_g = 624$.

Photo 12 Flow patterns at relatively large Reynolds numbers: $d = 1.40$ cm, $d_0 = 0.200$ cm, $l/d_0 = 0.500$.