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KINETOGRAPHIC FLOW PICTURES

By L. Prandtl and O. Tietjens

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KINETOGRAPHIC FLOW PICTURES.*

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According to a method worked out by Professor F. Ahlborn in Hamburg, the flow of water can be photographed by strewing on its surface fine particles (such as lycopodium spores, grass seed, or powdered aluminum) and making short time-exposures. Each particle travels a certain distance during the exposure and is photographed as a short straight line. The total of all these short lines accordingly produces a picture which shows the direction of flow at every point and also its velocity (by the length of the line). With the right amount of powder and a suitable length of exposure, the latter run together so as to indicate the streamlines directly.

If it is desired to make such pictures with a kinetograph, in order to determine the temporal succession of the flow phenomena, the difficulty may easily arise that the marks will be too short on the individual negatives, due to the shortness of exposure, so that the streamlines will not be recognizable. We therefore changed the driving mechanism of a kinetograph, so that the illumination lasted only 7/8 of the time allotted for each exposure, 1/8 being allowed for the shifting of the film

* "Kinematographische Stromungsbilder," reprinted from "Die Naturwissenschaften," Vol. 13, pp. 1050-1053.

in preparation for the next exposure. In order not to overtax the mechanism, the velocity of the shifting film must not be greater than in ordinary operation, in which about 0.4 of the time can be allowed for the actual exposure and 0.6 for the shifting of the film (at least in our camera, which is an old type made by Liesegang in Düsseldorf). On the basis of 16 exposures per second in ordinary operation, we thus obtained 3 exposures per second, which were sufficient for our purpose.

The "film time-pictures" thus obtained are poorly adapted for kinetoscopic reproduction, since they give a very unnatural effect, even when correspondingly retarded by copying each individual picture several times in succession on the positive film, as is done in trick pictures. The object of such pictures is not the same as in motion pictures, but only to enable the separate observation of each successive picture. Obviously the successive pictures show the path of each particle practically without interruption, since only 1/8 of the distance is lost for each exposure. Hence the accelerations can be determined, from which conclusions can be drawn regarding the field of force underlying the motion.

Since the device we employed might be applicable to other kinds of motion analysis, we will add a few words concerning it. In addition to the normal 8-picture crank, there is also an axle for 4 pictures per revolution. We mounted a Maltese cross on the latter axle, as is customary in kinetoscopes.

In Fig. 1, a is the axle of the Maltese drive, which is itself driven in turn by an electric motor, by means of a cord, and is provided with a flywheel. The 4-picture axle b carries the Maltese cross and a cogwheel, which engages with another cogwheel on the axle c (diagrammatically represented, since the cogwheel on the 8-picture axle really intervenes). In short, the action of the mechanism is such that (with a uniform rotational speed of the axle a) the Maltese cross rests during 3/4 of a rotation of the axle a, but then, during the remaining 1/4 rotation of the axle a, is itself carried through a quarter revolution by means of the pin s, which at first imparts to it a gradually accelerated motion and then, at the end, a correspondingly retarded motion. The axle c thereby makes a full revolution, only the middle portion of which is utilized for advancing the film, so that for exposing and advancing the film, about 7/8 and 1/8 respectively, of a revolution of the axle a is utilized.

The pictures we have thus far taken concern the phenomena of flow past rotating and non-rotating cylinders, in which, after our experiments on the Magnus effect, we felt an especial interest. (Cf. "Naturwissenschaften" 1925, p. 93 ff.) For these pictures we had a water tank 35 cm wide, 30 cm deep and 3 m long (about 1.15 × 0.98 × 9.84 ft.). The obstacle used was a vertical cylinder, 4.5 cm (1.77 in.) in diameter and 25 cm (9.84 in.) long, which was rotatable on ball bearings and had on its lower end, near the bottom of the tank, a disk 9 cm (3.54 in.) in diameter. The top end was just even with the surface of the water, as shown in Fig. 2. The cylinder was mounted on a car, which ran on rails and was set in motion by falling weights. Since the streamlines of the relative motion of the liquid with reference to the cylinder axis were to be photographed, the camera and motor both had to be mounted on the car. The cylinder was rotated by means of a cord, one end of which was wound around a spool at the top of the cylinder, its other end being either fastened to the edge of the tank or passed around a pulley and returned to the car, thereby doubling the rotational speed of the cylinder. Other rotational speeds may be obtained by using spools of different diameters.

Both the film strips (Figs. 3-4) plainly show the difference between the customary film picture (Fig. 3) and the film time-pictures obtained with the modified camera (Fig. 4). Both sets of pictures were made of the flow phenomenon, namely, the formation of a pair of eddies behind the rotating cylinder. It is obvious that Fig. 3 shows nothing regarding the motion of the liquid, but only the momentary state of the powdered surface, while Fig. 4 is a set of streamline pictures which give a good idea of the nature of the flow.

Figs. 5-12 are enlargements of the film time pictures, Figs. 5-8 showing the flow about the non-rotating cylinder, while Figs. 9-12 are the corresponding pictures for the rotating cylinder. In the time-film, the individual pictures do not follow immediately after one another, but are so selected (with the omission of some of the pictures), as to show especially characteristic flow phenomena. The direction of flow is from left to right in all the pictures.

Fig. 5 shows how, at the beginning, (in the condition of acceleration), there is an almost pure potential flow, while Fig. 6 shows how two eddies begin to form from the boundary-layer material collecting at two points on the rear wall of the cylinder. Fig. 7 shows this pair of eddies in considerably augmented state, just before the instant when they dissolve (since this condition is unstable) and give place to an irregularly agitated dead-water region. Fig. 8 shows the permanent condition.

Figs. 9-12 show the corresponding phenomena for the rotating cylinder, and indeed for the case when the ratio of the peripheral velocity of the cylinder (u) to the velocity of the undisturbed flow (v) is 4, ($\frac{u}{v} = 4$), the direction of flow being from left to right and the rotation of the cylinder being in the clockwise direction. Fig. 9 differs but little from Fig. 5, the flow being likewise potential in the first stage of the motion. Figs. 10-12 show the constantly increasing effect of the rotation. Instead of the pair of eddies, there is now only <u>one</u> eddy and this is on the side of the cylinder where the water and the cylinder surface are moving in opposite directions. After this so-called "starting-eddy" has advanced to a certain stage (dependent on the rotation speed of the cylinder) and has left the cylinder, we have a flow picture in which the front and the rear damming point almost coincide and in which the original direction of flow has undergone a considerable deflection.

Fig. 12 shows how the streamlines are crowded closer together on the upper side of the cylinder, corresponding to a greater velocity and a reduced pressure (negative pressure), and how, on the other side, the streamlines spread farther apart, corresponding to a smaller velocity and a consequent greater pressure (positive pressure). These pressure differences produce the cross-current force which is known as the "Magnus effect" and which, in this case, is directed from below upward.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

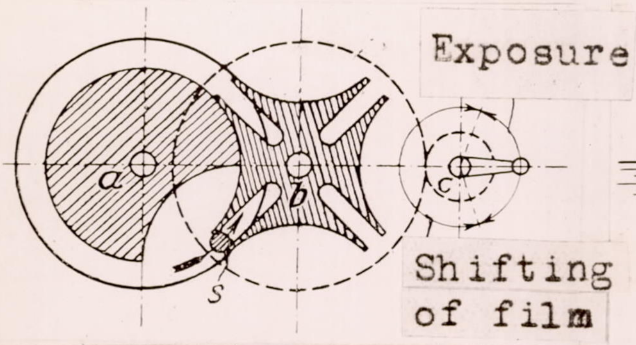

Fig.1 Change in the drive of the kinetograph by the introduction of a Maltese cross.

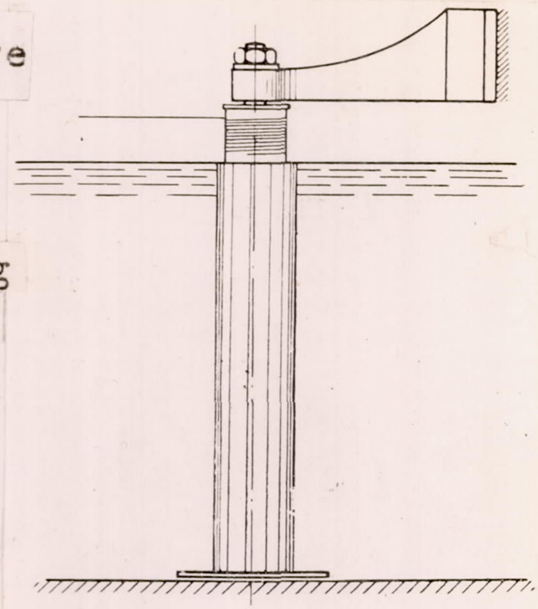

Fig.2 Cylinder with driving cord and supporting arm.

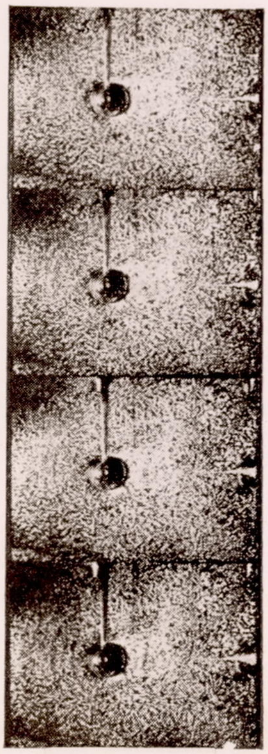

Fig.3

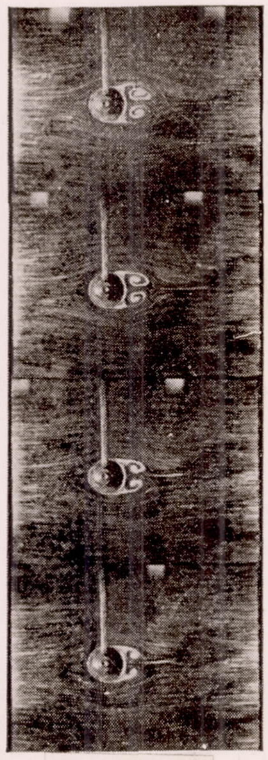

Fig.4

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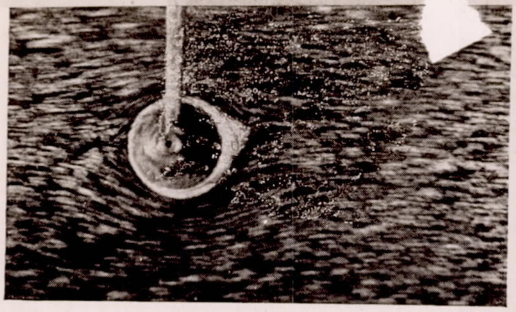


Fig. 5.

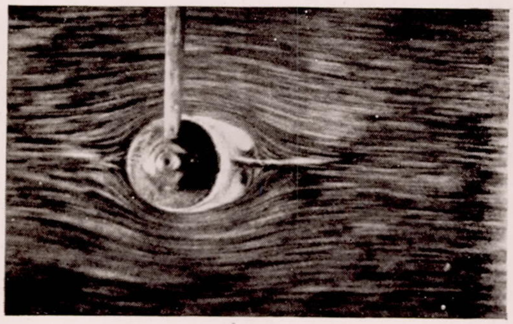


Fig. 6.

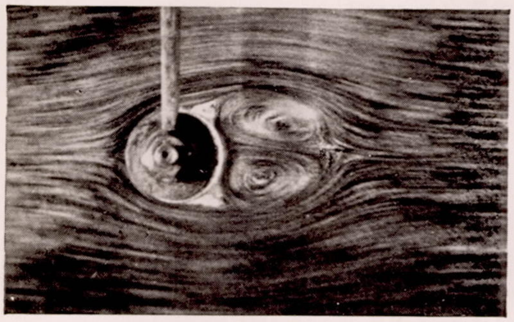
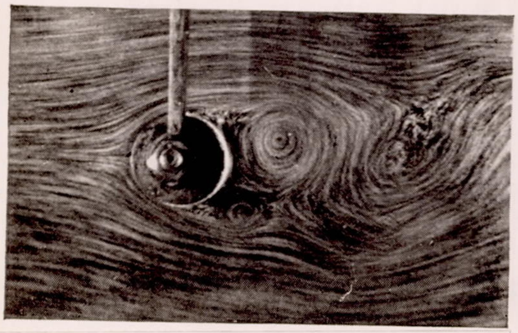


Fig. 7.



Figs.5-8 Non-rotating Cyl.

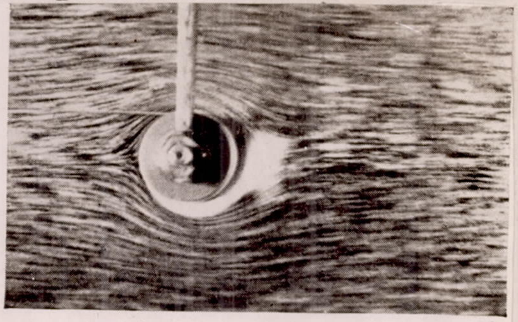


Fig. 9.

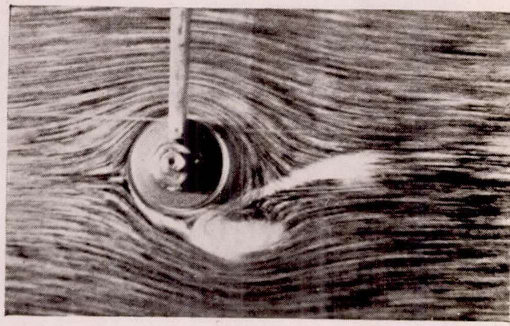


Fig. 10.

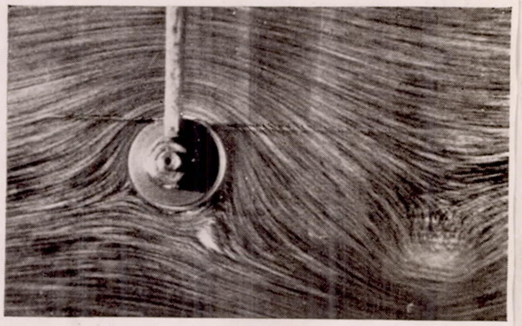
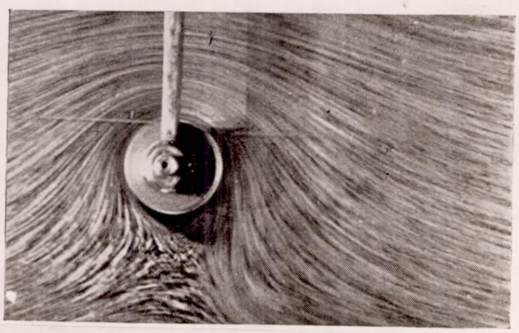


Fig. 11.



Figs.9-12 Rotating cyl.u/v=4

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