EXPERIMENTAL STUDIES OF THE LIFT ON TWO EQUAL CIRCULAR CYLINDERS PLACED SIDE BY SIDE IN A UNIFORM STREAM AT LOW REYNOLDS NUMBERS

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EXPERIMENTAL STUDIES OF THE LIFT ON TWO EQUAL CIRCULAR CYLINDERS PLACED SIDE BY SIDE IN A UNIFORM STREAM AT LOW REYNOLDS NUMBERS

By Sadatoshi TANEDA

Summary :—Lifts acting on two equal circular cylinders placed side by side in a uniform stream were measured by means of lamp scale and mirror method at Reynolds numbers from 0.01 to 1.6. The results obtained are as follows:

1. Each cylinder experiences a repulsive force.
2. The value of lift coefficient decreases monotonously as the Reynolds number is increased.
3. When the Reynolds number is sufficiently small, the value of lift coefficient increases first and then decreases as the ratio of the distance between two cylinders to the diameter of the cylinder increases.

These results are in good agreement with the theoretical conclusions which are led from the Oseen's linearized equations of motion.

The photographs of the actual flow pattern were also taken.

1. Introduction In a recent paper,[1] the forces acting on two parallel circular cylinders of equal diameter with their axes in one plane perpendicular to a uniform flow have been discussed by Fujikawa on the basis of Oseen's linearized equations of motion, and several interesting results were obtained. The present author was interested especially in the conclusions that when two equal cylinders are placed side by side they repulse each other, and that when Reynolds number is small, the lift increases first and then decreases with the increase of the distance between the two cylinders. However, so far as is known to the author, there has been no experimental verification up to the present.

In the present experiments, the lifts acting on two equal circular cylinders placed side by side were measured for several cases when the ratio of the distance between the axes of the two cylinders to the diameter of the cylinder is equal to 4.6, 10, 18 and 50, the Reynolds number of the flow varying from 0.01 to 1.6. To obtain the flow with such a low Reynolds number, the glicerine-water solutions were used as the viscous fluid. And the lift, which was extremely small (order of 10^{-1} dyne), was sensibly detected by means of lamp scale and mirror method. The results were in good agreement with the theoretical ones based on the Oseen's equations.

2. Apparatus The experiments were carried out with the moving metal vessel of 200 mm in length, 100 mm in width and 80 mm in depth. The general arrangement of the apparatus is shown in Fig. 1. The vessel is filled with the glicerine-water solution, and is set on the small carriage which is advanced uniformly along the straight rails by means of lead screw. The value of Reynolds number can be varied by changing the density of the glicerine-water solution.

The two cylinders are hung as the pendulums on a horizontal bracket by means of needle edges so as to be free to swing only across the stream (see Fig. 2). When the vessel is at rest, the following adjustments have to be made:

1. The plane containing two cylinders has to be made perpendicular to the direction in which the vessel is moved.
2. The two cylinders have to be inclined slightly each other so as to be exactly parallel when the vessel is in motion.

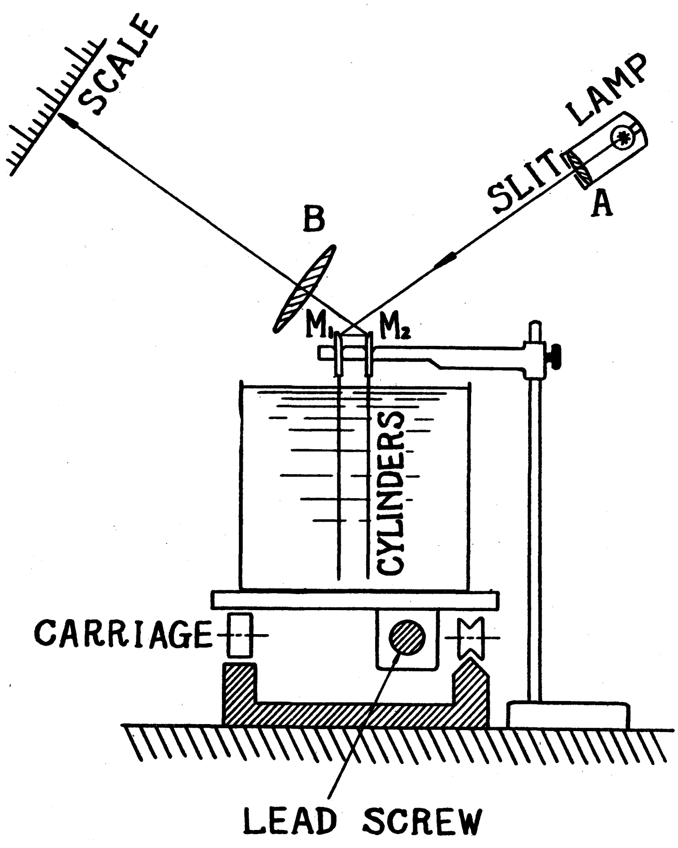


Fig. 1. Schematic diagram of the apparatus.

A, B: Convex lenses, M_1, M_2: Plane mirrors.

3. The ray of light from the lamp has to be thrown on a scale after reflections in the mirrors M_1 and M_2 which are attached to the pendulums facing each other.
4. The image of the light source has to be formed on the mirror M_1 by means of lens A.
5. The image of the slit has to be formed on the scale by means of lens B.

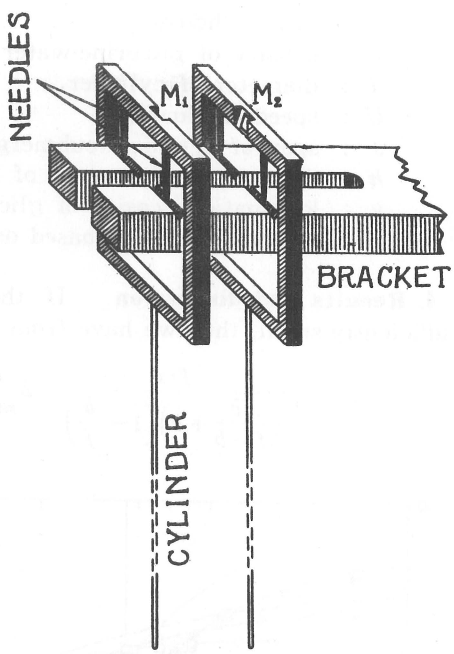


Fig. 2. Sketch of the pendulums.

Then the vessel is set in motion, and the small inclinations of the pendulums which are caused by the lift are measured by reading the movement of a spot of light on the scale.

The fine brass wires of four different sizes were used as the models, their diameters being 0.30 mm, 0.40 mm, 0.60 mm and 0.77 mm respectively. It must be noted that steel wire cannot be used as the model because it is strongly affected by the weak magnetism existing in the apparatus. The distance between two cylinders was varied from 1 mm to 15 mm at the interval of 1 mm.

On the other hand, the actual flow pattern around the two circular cylinders was photographed by means of aluminium dust method with the glass water tank of 100 cm in length, 20 cm in width and 30 cm in depth. A general description of the apparatus and an account of the photographic technique were given in the previous paper,[2] and so need not be repeated here.

3. Notations

- m : mass of pendulum
- l : distance between needle edge and center of gravity of the pendulum
- l^* : distance between needle edge and center of lift
- g : acceleration of gravity
- x : displacement of spot of light on the scale
- a : distance between two mirrors M_1 and M_2
- b : distance from middlepoint of M_1 and M_2 to lens. B
- c : distance between lens B and scale
- f : focal length of lens B
- D : distance from middle point of M_1 and M_2 to scale
- L : lift

C_L : lift coefficient
ρ : density of glicerine-water solution
d : diameter of cylinder
U : speed of carriage
s : span of cylinder (submerged portion of cylinder)
h : distance between axes of two cylinders
ν : kinematic viscosity of glicerine-water solution
R : Reynolds number based on diameter of the cylinder (Ud/ν)

4. Results and discussion If the inclinations of the pendulums are sufficiently small, then we have from the condition for balance of the forces

$$\frac{Dx}{\left(\frac{fb}{f-b}+c\right)\left(1-\frac{b}{f}\right)}=2\frac{Ll_1^*}{m_1gl_1}(a+D)+2\frac{Ll_2^*}{m_2gl_2}D$$

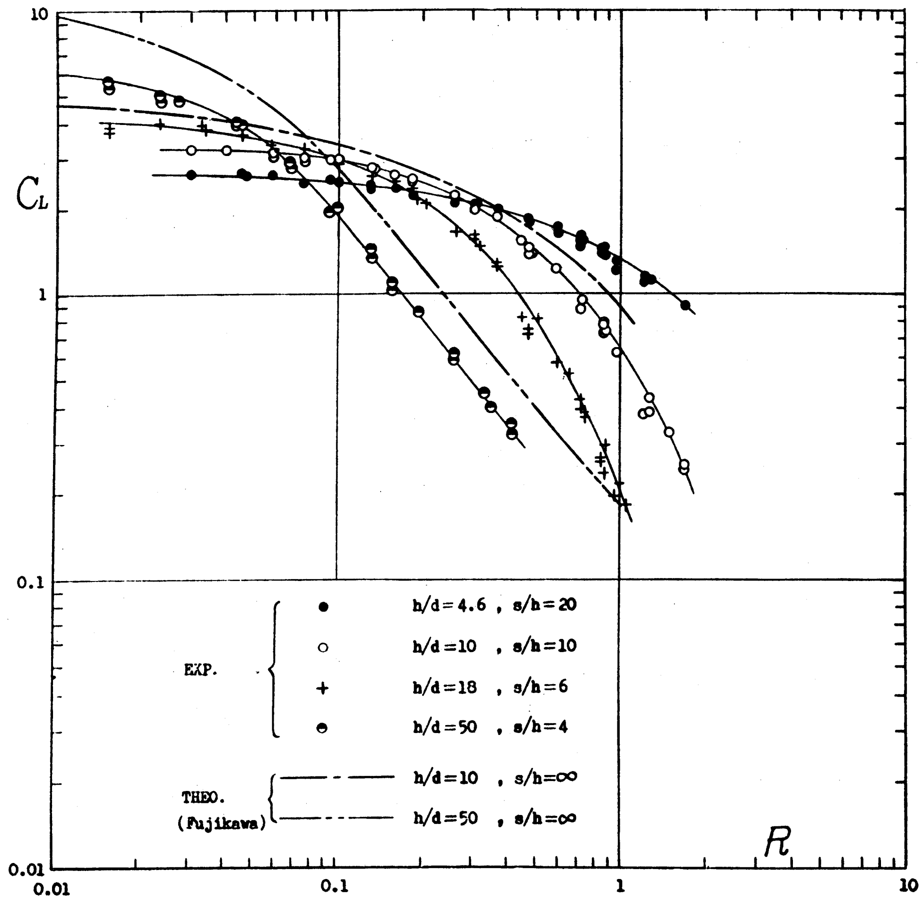


Fig. 3. Lift coefficient.

Hence
$$L=\frac{Dgx}{2\left(\frac{fb}{f-b}+c\right)\left(1-\frac{b}{f}\right)\left\{\frac{l_1^*(a+D)}{m_1 l_1}+\frac{l_2^* D}{m_2 l_2}\right\}},$$

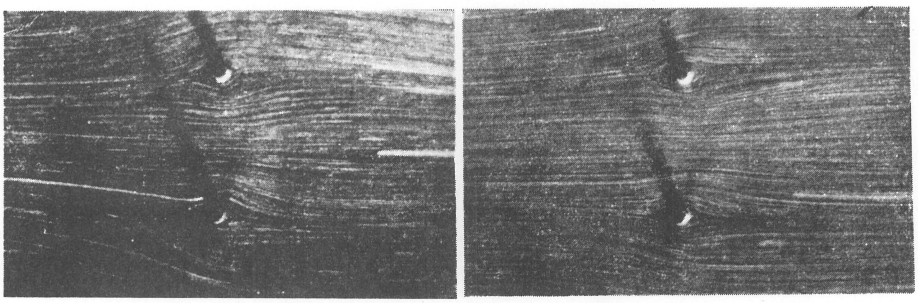
and therefore
$$C_L=\frac{L}{\rho d U^2 s}$$
$$=\frac{Dgx}{2\rho d U^2 s\left(\frac{fb}{f-b}+c\right)\left(1-\frac{b}{f}\right)\left\{\frac{l_1^*(a+D)}{m_1 l_1}+\frac{l_2^* D}{m_2 l_2}\right\}}$$

Thus by measuring the value x, the lift coefficient C_L can be calculated. In the present experiments, the inclination of the pendulum which was caused by the lift was less than 1/200. When the Reynolds number R is higher than about 1.5, the lift is too small to be accurately measured by means of this method. On the other hand, when R is lower than about 0.02, the influence of the vessel wall is not so small as can be neglected. Therefore the measurements were made only at Reynolds numbers form 0.01 to 1.6.

Fig. 3 shows the experimental results, together with the theoretical values for the two cases $h/d=10$ and 50. The general conclusions drawn from the experiments are summarized as follows:

1. Two cylinders repulse each other.
2. Lift coefficient decreases monotonously as the Reynolds number is increased.
3. When Reynolds number is small, the value of lift coefficient increases first and then decreases as the ratio of the distance between the axes of the two cylinders to the diameter of the cylinder is increased.

These conclusions are in complete agrrement with the theoretical. However, the observed, lift coefficient is slightly lower than the theoretically calculated, the discrepancy being probably due to the end effect and the wall effect. The theoretical calculations apply to an unlimited field of fluid around the two cylinders of infinite length, while the experiments were made in a tank of finite size using the cylinders of finite length.



(a) $R=0.486$, $s/h=12$. (b) $R=1.460$, $s/h=12$.

Fig. 4. Photographs showing flow pattern around the two equal parallel circular cylinders placed side by side in a uniform stream.

Photographs of the actual velocity field around the two equal parallel circular cylinders are shown in Fig. 4. It will be noticed that the wakes produced by two cylinders repulse each other.

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