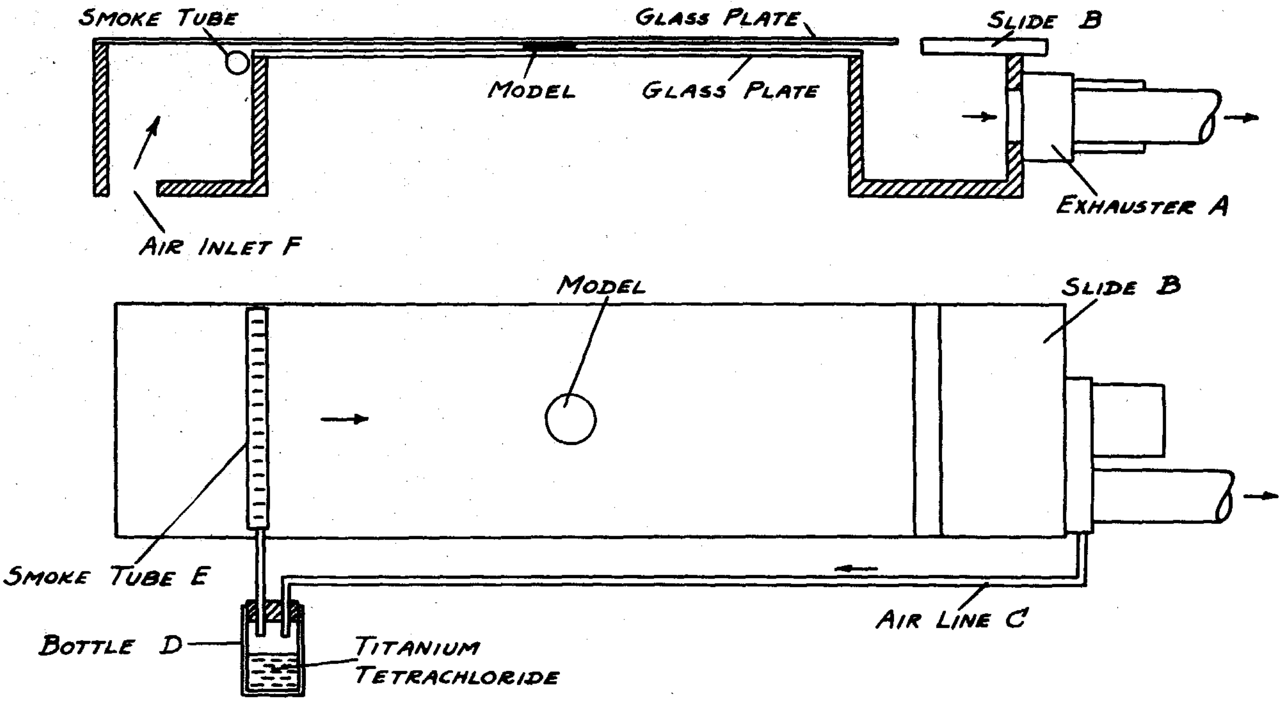


FIG. 1—Main features of simple smoke tunnel.

SMOKE FLOW PATTERNS

By R. C. BINDER

NUMEROUS problems in development, design, and research involve the flow of some fluid through a channel or around a body. For some problems it is essential to build rather elaborate apparatus, instruments, and laboratories. For other problems it is very helpful, and sometimes necessary and sufficient, to obtain qualitative flow patterns quickly by means of apparatus which is simple to construct and relatively easy to operate.

One simple method of obtaining flow patterns is to introduce smoke into an air stream flowing in a channel formed by two glass walls a short distance apart. Various models can be held between the glass plates, and the pattern viewed directly or photographed. Although this method has some limitations, apparatus employing this method can be useful for a wide variety of applications.

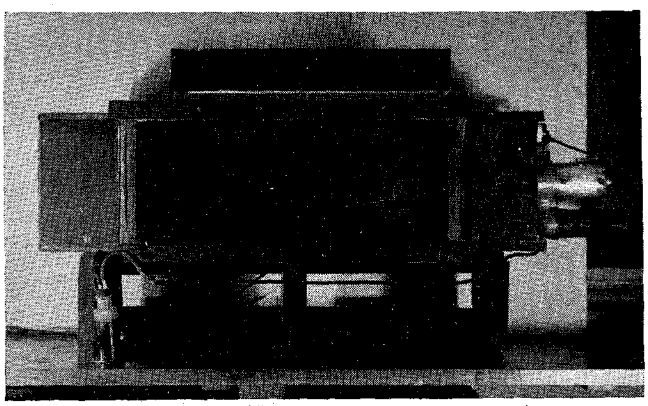


FIG. 2—Smoke tunnel as constructed from available materials.

APPARATUS

Fig. No. 1 illustrates diagrammatically one simple design of apparatus. Air is drawn between the two parallel glass plates by means of the exhauster *A*. The model which is held between the glass plates is the same thickness as the gasket material between the plates along the edges. Slide *B* can be used to vary the rate of flow between the plates.

Air line *C* connected to the discharge side of the exhauster is led to the bottle *D* which contains titanium tetrachloride, a convenient material for making filaments of air visible. As the humid air comes in contact with the titanium tetrachloride a dense white smoke is formed. Titanium tetrachloride ($TiCl_4$) is a light-yellow liquid; when it is exposed to humid air, titanium dioxide (TiO_2) is formed. Titanium-dioxide particles are very small and follow the flow of air in which they are formed.

The generated smoke is forced into the smoke tube *E*. The smoke tube can be a simple cylindrical tube with small holes or slots cut at equal intervals along the smoke tube axis. A valve in air line *C* can be employed to control the amount of smoke generated. As air coming from the inlet *F* flows over the smoke tube, smoke is picked up and streamlines in the channel between the glass plates are made visible.

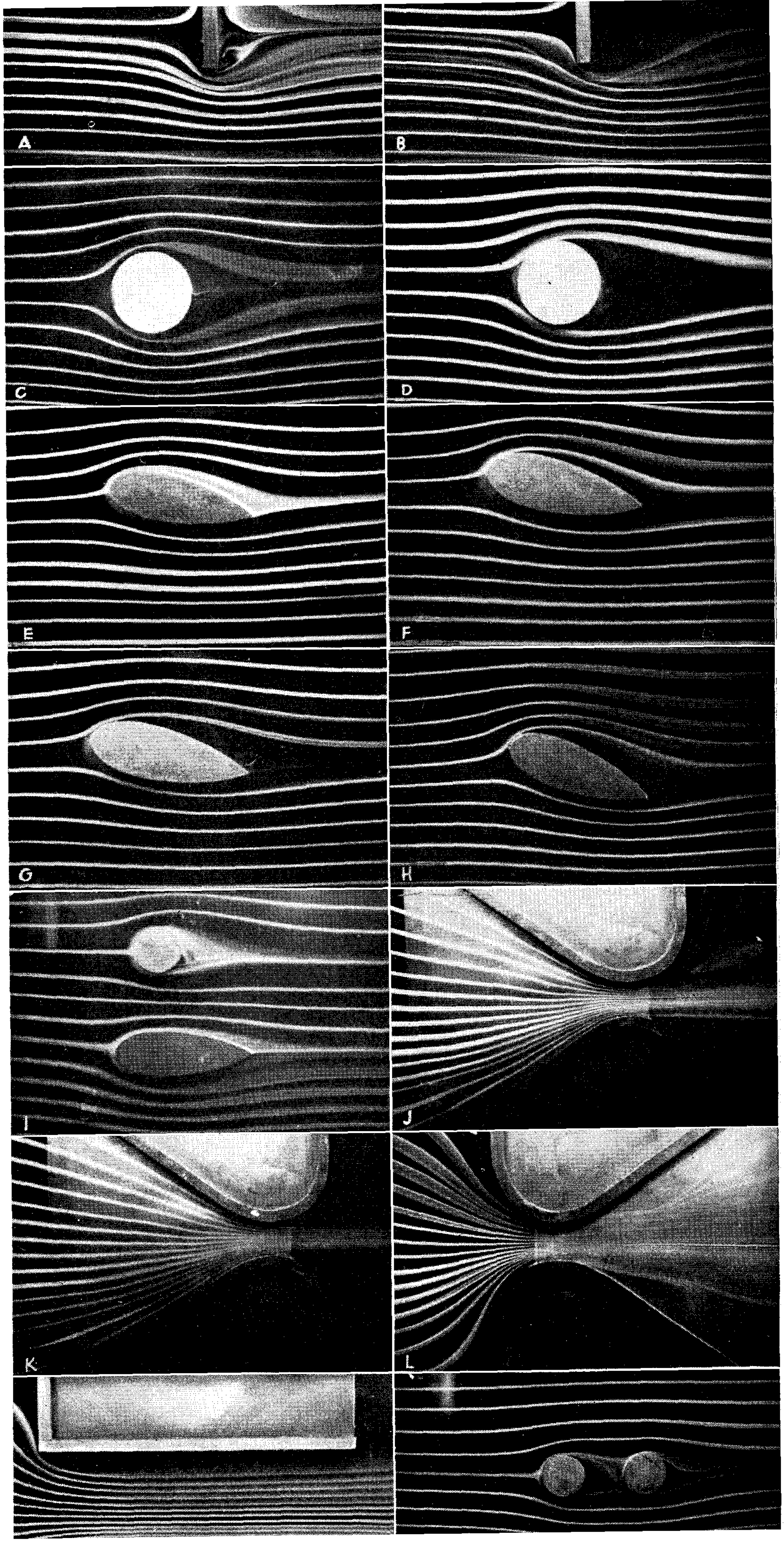
Many variations are possible in the actual construction of apparatus. Fig. No. 2 shows an improvised arrangement. An ordinary vacuum cleaner unit was used for the exhauster. The glass plates were placed one-fourth-inch apart. The flow channel width is about 12½ inches, and the length about 32 inches. Holes in the smoke tube were placed three-fourths-inch apart. Models can be cut without difficulty from one-fourth-inch thick sponge rubber or wood. Such apparatus need not be expensive, nor require much space in a laboratory, shop, or drawing room.

ILLUSTRATIONS OF FLOW PATTERNS

Fig. No. 3, A to T, gives some illustrations of flow patterns taken with the apparatus shown in Fig. No. 2. In each picture the flow is from left to right. For the same model, pictures in a series are in the order of increasing velocity. In each pattern the relative spacing between streamlines gives some indication of the relative velocity. The streamlines upstream from the model are equally spaced. For an incompressible fluid, a converging of the streamlines is associated with an increase in velocity of the fluid between the streamlines. There is a crowding of the streamlines above the tapered or strut section (Fig. No. 3-H) and in the throat of the nozzle (Fig. No. 3-J). At the nozzle throat, particularly, the velocity is considerably higher than that some distance upstream.

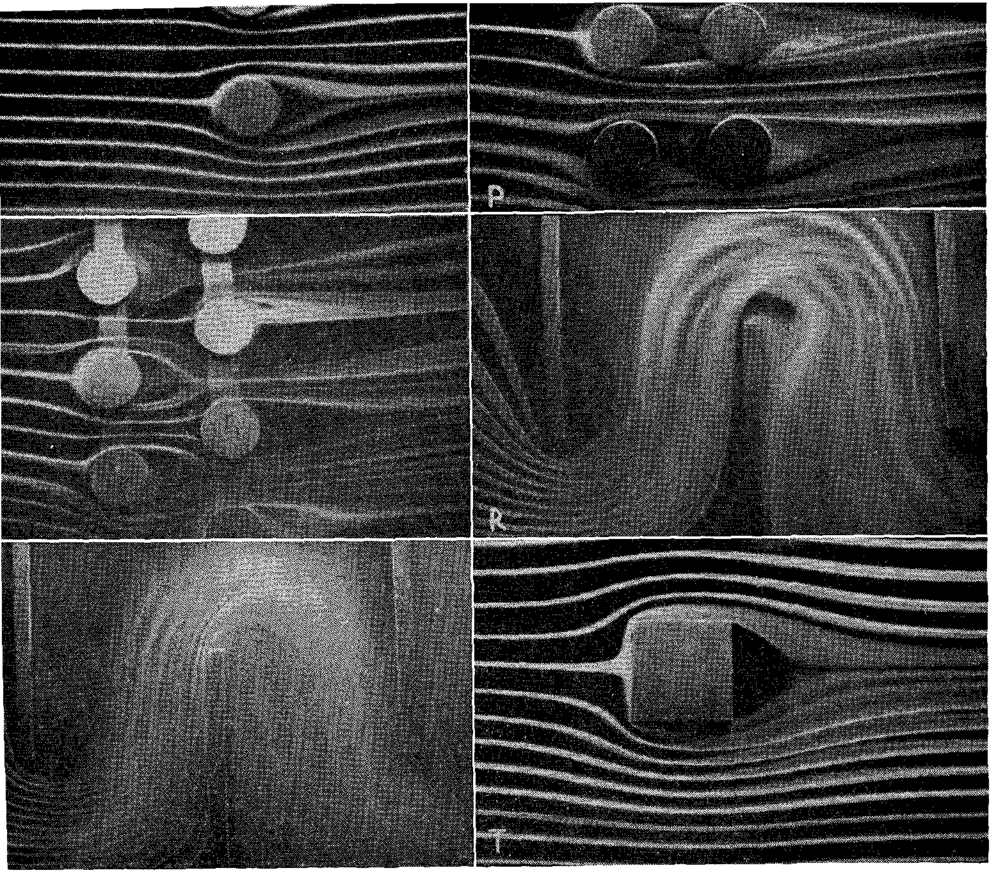
As fluid approaches an orifice or short tube, the streamlines converge; the streamlines continue to converge beyond the orifice. At a certain distance from the plane of the orifice the jet has a minimum area where all the streamlines are parallel. This minimum section of the jet is commonly called the *vena contracta.* This effect is shown in Fig. No. 3-M.

The flat plate and cylinder models (Figs. No. 3-B and 3-D) show a marked eddying wake behind each body at high velocities. This eddying wake, of course, contributes to the resistance. Fig. No. 3-I show a cylinder and a strut in the same stream. The tapered strut at low angle of attack shows no appreciable wake. Fig. No. 3-R, for flow in a baffle



AT RIGHT:

FIG. 3—Illustrations of smoke flow patterns for various models. In each illustration the flow is from left to right.



AT LEFT:

Fig. 3. (Continued)

arrangement, shows a marked separation of the fluid and a considerable disturbance of the flow.

In some pieces of equipment it may be highly desirable to induce eddying flow. Figs. No. 3-P and 3-Q show two different types of cylinder arrangements; each might represent a bank of boiler tubes. The flow in Fig. No. 3-Q is probably more desirable as far as heat transfer is concerned.

USE OF APPARATUS

For low velocities the streamlines approximate the two-dimensional flow of a frictionless incompressible fluid. In some problems studies of this type of flow are important, whereas in other problems it is necessary to investigate three-dimensional flow.

The apparatus cannot be operated continuously for a long time because of the clogging of small passages and the depositing of white particles on the glass plates. Thus frequent cleaning is necessary for continued operation. It is necessary to make suitable arrangements for exhausting the mixture of air and smoke so that it cannot irritate the human body or corrode steel surfaces. Piping the exhaust outside to the open atmosphere is usually a satisfactory arrangement.

Placing an open dish of ammonium hydroxide upstream from the smoke tube makes the smoke more dense. Tin tetrachloride can be used instead of titanium tetrachloride. Dry ice might be used for generating smoke, but it offers some disadvantages as far as continuous handling and control are concerned. Kerosene vapor forms a good dense smoke, but it is difficult to control and generate without igniting.

Baffles and screens can be arranged at different places in the air stream to control the flow and make it uniform. For test purposes the glass plates can be arranged in a horizontal plane with the top plate simply resting on the model and the gaskets along the edges. Models can be changed easily with this arrangement. For instructional purposes the glass plates can be clamped together along the edges and mounted in a vertical plane. A series of lights and a reflector along the top edge of the apparatus can be provided for showing the flow patterns to large groups.

Marine Power Plants

(*Continued from Page 7*)

engine delivers the brake power, *bhp*, which is equal to the indicated power minus the mechanical losses in the engine. From this mechanical efficiency $= \frac{bhp}{ihp}$.

From the coupling to the stern tube bearing, power is lost in bearing friction, and, if a transmission is present, in friction in the transmission. The ratio of power actually delivered to the propeller, divided by the brake power delivered by the engine, is called transmission efficiency.

The power required to overcome the resistance of the ship at a given speed is called the effective power, *ehp*, and is equal to the product of speed and resistance. The ratio of effective power over propeller power, *ehp/php*, is called propulsive efficiency. Propulsive efficiency can be subdivided into propeller efficiency, hull efficiency and relative rotative efficiency, which represents the effect of the wake on the propeller. It is seen that all sources of loss between the combustion chamber of the engine and the power represented by the motion of the ship are accounted for. The product of the above terms is called propulsive coefficient and can be written:

$$\text{Propulsive coefficient} = \left(\frac{ehp}{php}\right)\left(\frac{php}{bhp}\right)\left(\frac{bhp}{ihp}\right) = \frac{ehp}{ihp}.$$

In connection with Diesel drives, propulsive coefficient is often used to denote the ratio $\frac{ehp}{bhp}$.

We then have the relation

$$\frac{ehp}{ihp} = \left(\frac{ehp}{bhp}\right)\left(\frac{bhp}{ihp}\right) = \left(\frac{ehp}{bhp}\right) \text{mechanical efficiency.}$$

For electric drive the above equations remain unaltered. Only the transmission efficiency is modified to account for the losses in electrical transmission.

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