CLASSIFICATION AND DESCRIPTION OF FLUID FLOW

It is helpful to the understanding of fluid mechanics to broadly classify certain different types of fluid flow, and here we introduce some of the terminology used.

Internal and external flows

The distinction between internal and external flows often needs to be made. When the motion of a fluid is between bounding surfaces the flow is described as internal flow. Airflow management systems are widely used to control the quality of air within buildings and vehicles; the movement of air within the ducting which forms part of such a system is an example of an internal flow. Conversely, when a body is surrounded by a fluid in motion, the flow around the immersed body is described as external flow. Examples of external flows are the flows surrounding an aircraft wing, around an entire aircraft, around a road vehicle such as a car or lorry or around a building.

Laminar and turbulent flows

From about 1840, it had been realized that the flow of a fluid could be of two different kinds. The distinction between them is most easily understood by reference to the work undertaken in the early 1880s by Osborne Reynolds (1842–1912), Professor of Engineering at Manchester University. The apparatus used by Reynolds was as shown in Fig. 1.11. A straight length of circular glass tube with a smoothly rounded, flared inlet was placed in a large glass-walled tank full of water. The other end of the tube passed through the end of the tank. Water from the tank could thus flow out along the tube at a rate controlled by a valve at the outlet end. A fine nozzle connected to a small reservoir of a liquid dye discharged a coloured filament into the inlet of the glass tube. By observing the behaviour of the stream of dye, Reynolds was able to study the way in which the water was flowing along the glass tube If the velocity of the water remained low and especially if the water in the tank had previously been allowed to settle for some time so as to eliminate all disturbances as far as possible, the filament of dye would pass down the tube without mixing with the water, and often so steadily as almost to seem stationary (Fig. 1.12a). As the valve was opened further and the velocity of the water thereby increased, this type of flow would persist until the velocity reached a value at which the stream of dye began to waver (Fig. 1.12b). Further increase in the velocity of the water made the fluctuations in the stream of dye more intense, particularly towards the outlet end of tube, until a state was reached, quite suddenly, in which the dye mixed more or less completely with the water in the tube. Thus, except for a region near

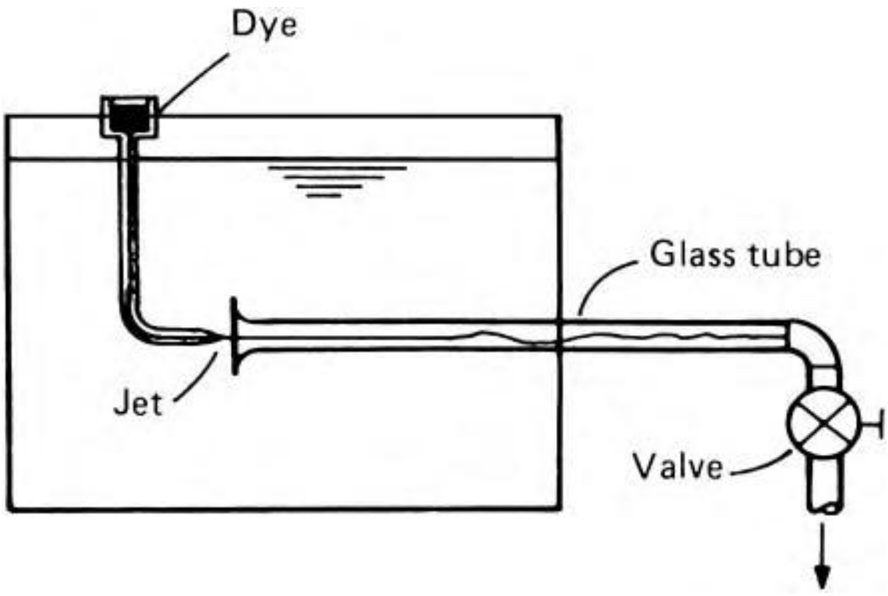


Fig. 1.11

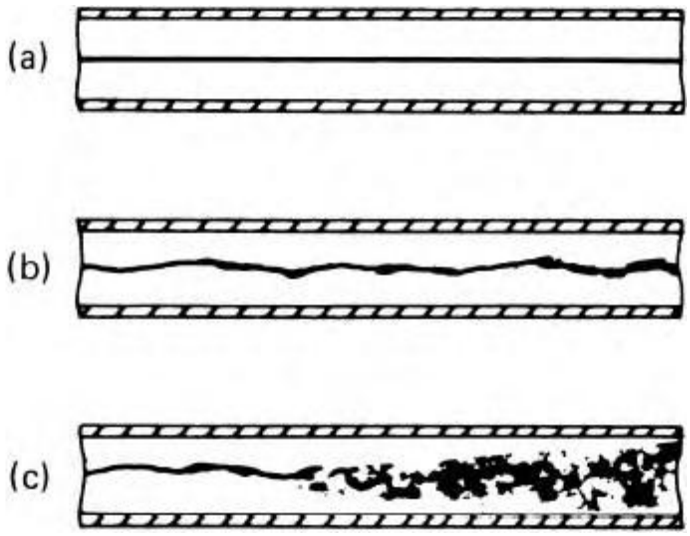


Fig. 1.12

the inlet, the water in the tube became evenly coloured by the dye. Still further increases of velocity caused no more alteration in the type of flow, but the dye mixed even more readily with the water and complete mixing was achieved nearer the inlet of the tube. The original type of flow, in which the dye remained as a distinct streak, could be restored by reducing the velocity. It is of particular interest that the disturbed flow always began far from the inlet (in Reynold's tests, usually at a length from the inlet equal to about 30 times the diameter of the tube); also that the

complete mixing occurred suddenly. Although Reynolds used water in his original tests, subsequent experiments have shown that the phenomenon is exhibited by all fluids, gases as well as liquids. Moreover, the two types of flow are to be found whatever the shape of the solid boundaries: there is no restriction to circular
tubes.

Laminar flow

In the first kind of flow, that occurring at the lower velocities, the particles of fluid are evidently moving entirely in straight lines even though the velocity with which particles move along one line is not necessarily the same as that along another line. Since the fluid may therefore be considered as moving in layers, or laminar (in this example, parallel to the axis of the glass tube), this kind of flow is now called laminar flow.

$x/D=0.07\ Re$

$f=64/Re$

Turbulent flow

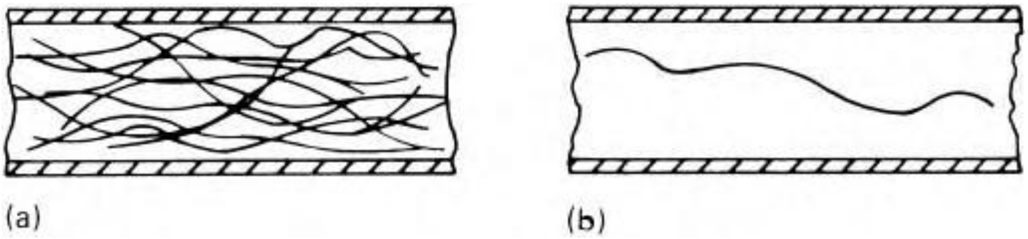
The second type of flow is known as *turbulent flow*. As indicated in Fig. 1.13a, the paths of individual particles of fluid are no longer everywhere straight but are sinuous, intertwining and crossing one another in a disorderly manner so that a thorough mixing of the fluid takes place. When turbulent flow occurs in a cylindrical tube, for example, only the *average* motion of the fluid is parallel to the axis of the tube. Turbulent flow, in short, is characterized by the fact that superimposed on the principal motion of the fluid are countless, irregular, haphazard secondary components. A single particle would thus follow an erratic path involving movements in three dimensions (Fig. 1.13b).

In engineering practice, fluid flow is nearly always turbulent. There are, however, some important instances of wholly laminar flow, for example in lubrication, and there are also many instances in which part of the flow is laminar.

, whether the flow is laminar or turbulent depends on the magnitude of the quantity $\rho\ ul/\mu$, where l and u represent a characteristic length and velocity, and ρ and μ represent the density and dynamic viscosity of the fluid. The ratio $\rho\ ul/\mu$ is a fundamental characteristic of the flow, and is now universally known as the Reynolds number, commonly denoted by the symbol *Re*. For flow in a circular pipe, in evaluating the Reynolds number, the characteristic length is conventionally taken as the pipe diameter *d* and the representative velocity is the mean velocity over the cross section (i.e. volume flow rate divided by cross-sectional area). Under normal engineering conditions, flow through pipes at a Reynolds number $\rho\, ud/\mu$ below 2000 may be regarded as laminar, and flows for *Re* > 4000 may be taken as turbulent.

$x/D=0.7\, Re^{1/4}$

Fig. 1.13



Example 1.3 Water, at 20 ◦C, flows through a pipe of diameter 4mm
at 3 m· s−1. Determine whether the flow is laminar or turbulent.

Solution

at 20 ◦C, water has a density of 103 kg ·m−3 and
a dynamic viscosity μ = 1 × 10−3 kg ·m−1 · s−1. Hence

Re = ρ ud/μ= 103 kg ·m−3 ×3 m· s−1 × 0.004 m/10−3 kg ·m−1 · s−1
= 12 000

_ The Reynolds number is well in excess of 4000, so the flow is turbulent