Steady and unsteady flows

Steady flow is defined as that in which the various parameters at any point do not change with time. Flow in which changes with time do occur is termed unsteady or non-steady. In practice, absolutely steady flow is the exception rather than the rule, but many problems may be studied effectively by assuming that the flow is steady. A particular flow may appear steady to one observer but unsteady to another. This is because all movement is relative; any motion of one body can be described only by reference to another body, often a set of coordinate axes. For example, the movement of water past the sides of a motor boat travelling at constant velocity would (apart from small fluctuations) appear steady to an observer in the boat. Such an observer would compare the water flow with an imaginary set of reference axes fixed to the boat. To someone

on a bridge, however, the same flow would appear to change with time as

the boat passed beneath the bridge. This observer would be comparing the

flow with respect to reference axes fixed relative to the bridge. Since steady flow is usually ‹much easier to analyses than unsteady flow

reference axes are chosen, wherever possible, so that flow with respect to

them is steady. It should be remembered, however, that Newton’s Laws of Motion are valid only if any movement of the coordinate axes takes place at constant velocity in a straight .line

The great majority of flows may be analyzed assuming the fluid motion is

steady. There are, however, three cases where unsteady effects are important. In no particular order, they are as follows. First, waves formed on free surfaces display oscillatory effects, and therefore aspects

of their motion are unsteady. A second important topic is that of liquid

flows rapidly brought to rest. Such unsteady flows can generate very large pressure surges. There is a third class of unsteady flows. In this type of flow, the boundary conditions of the flow may be steady, but the flow itself is inherently unstable. The classical example of such a case involves the flow of fluid past a circular cylinder. For a certain range of Reynolds numbers, although the velocity of the flow approaching the cylinder is steady and uniform, large eddies are shed alternately and continuously from the two sides of the cylinder to form what is known as a Karman vortex street It is useful to refer to another class of flows which are described as quasi steady. This term is applied to flows when the variables are changing slowly with time. In these situations the fundamental fluid dynamics are essentially the same as for steady flow, but account has to be taken of overall changes taking place over a period of time. An example of a quasi-steady flow is the flow that results when a large tank is drained through a small outlet pipe. Over time the lowering of the head in the tank results in .a reduced flow rate from the tank

Finally, a comment about turbulent flow is relevant. It has already been shown that turbulent flows consist of irregular motions of the fluid particles, with the effect that the instantaneous velocity at a point constantly changes with time. Turbulent flows are usually considered to be steady by using time averaged values of velocity at a point. In this .way they can be regarded as steady-in-the-mean

Uniform and non-uniform

uniform if the velocity of the liquid does not change – either in magnitude or direction – from one section to another in the part of the channel under consideration. This condition is achieved only if the cross-section of the flow does not change along the length of the channel, and thus the depth of the liquid must be unchanged. Consequently, uniform flow is characterized by the liquid surface being parallel to the base of the

channel. Constancy of the velocity across any one section of the stream is

not, however, required for uniformity in the sense just defined; it is sufficient for the velocity .profile to be the same at all cross-sections

Flow in which the liquid surface is not parallel to the base of the channel

is said to be non-uniform, or, more usually, varied since the depth of the

liquid continuously varies from one section to another. The change in depth may be rapid or gradual, and so it is common to speak of rapidly varied flow and gradually varied flow. (These terms refer only to variations from section to section along the channel – not to variations with time.) Uniform flow may of course exist in one part of a channel while varied .flow exists in another part

Viscous and inviscid flows

A question worth considering is: for internal and external flows, are the

effects of viscosity equally important everywhere within the flow, or are the effects more important in some parts of the flow than in others? To answer the question we proceed along the following lines. In Section 1.6, it has been shown that the magnitude of the viscous shear stress depends on the velocity gradient at right angles to the general direction of flow. In other words, the manifestation of a fluid's viscous properties anywhere within a flow depends upon the local magnitude of transverse velocity gradients. Where transverse velocity gradients are large, the effects of viscosity have an important bearing on the characteristics of the flow. Conversely, where these velocity gradients are small, viscosity has a much smaller influence on the behaviour of the flow. In both internal and external flows, at high Reynolds numbers, the largest transverse velocity gradients occur close to a bounding surface, due to the need to satisfy the no-slip condition at the surface. Pursuing this line of argument it is evident that in some circumstances a complex flow field can be simplified by dividing the flow field into two regions. In parts of the flow close to a boundary wall, analysis of the flow region must account for the

viscous properties of the fluid. But away from the immediate influence of

the boundary wall, the characteristics of the flow might not be significantly affected by viscosity, and the flow can then be analyzed assuming the fluid is inviscid, with great advantage. The well-defined regions where viscous effects dominate in high Reynolds .number flows are known as boundary layers and these, together with other shear layers

Incompressible and compressible flows

In most cases, liquids behave as though they are incompressible, and

can be analyzed on that assumption. As we have already seen, the one

important exception to this rule is when a liquid flow is brought to rest

abruptly. For gaseous flows, the situation is rather more complicated. At low speeds, gases essentially behave as though they are incompressible. But above a Mach number of about 0.3, compressibility effects become important. At speeds approaching that of sound, new phenomena, not found under conditions of incompressible flow, occur. The major difference between compressible and incompressible flows is that in the former the fluid density varies throughout the flow, whereas in the latter it is everywhere constant. Incompressible flows can be analyzed by

invoking the laws relating to conservation of mass, conservation of energy and Newton's Laws of Motion. These fundamental laws apply equally to compressible flows which, .however, are more complex because their study also involves the laws of thermodynamics

One-, two- and three-dimensional flow

Three-dimensional flow In general, fluid flow is three-dimensional in the sense that the flow parameters– velocity, pressure and so on – vary in all three coordinate directions. Considerable simplification in analysis may often be achieved, however, by selecting the coordinate directions so that appreciable variation of the parameters occurs in only two .directions, or even in only one

Two-dimensional flow In two-dimensional flow, the flow parameters are functions of time and two rectangular space coordinates (say x and y) only. There is no variation in the z direction and therefore the same streamline pattern could at any instant be found in all planes in the fluid perpendicular to the z direction. The flow past a wing of uniform cross-section and infinite span, for instance, is the same in all planes perpendicular to its span. Water flow over a weir of uniform cross section and infinite width is likewise two-dimensional. In practice, where the width is not infinite it may be satisfactory to assume two-dimensional flow over most of the wing or weir, that is, to consider flow in a single plane; the results may then be modified by end corrections accounting for the three-dimensional flow at the ends. Axi- ymmetric flow, although not two-dimensional in the sense just defined, may be .(analyzed more simply with the use of two cylindrical coordinates (x and r

One-dimensional flow The so-called one-dimensional flow is that in which all the flow parameters may be expressed as functions of time and one space coordinate only. This single space coordinate is usually the distance measured along the centerline (not .necessarily straight) of some conduit in which the fluid is flowing

For instance, the flow in a pipe is frequently considered one-dimensional: variations of pressure, velocity and so on may occur along the length of the pipe, but any variation over the cross-section is assumed negligible. In reality flow is never truly one-dimensional because viscosity causes the velocity to decrease to zero at the boundaries. Figure 1.10 compares the hypothetical one-dimensional flow with a diagrammatic representation of flow subject to the no-slip condition in, say, a pipe or between plates. If, however, the non-uniformity of the actual flow is not too great, valuable results may often be obtained from a one-dimensional analysis. In this the average values of the parameters at any given section .(perpendicular to the flow) are assumed to apply to the entire flow at the section

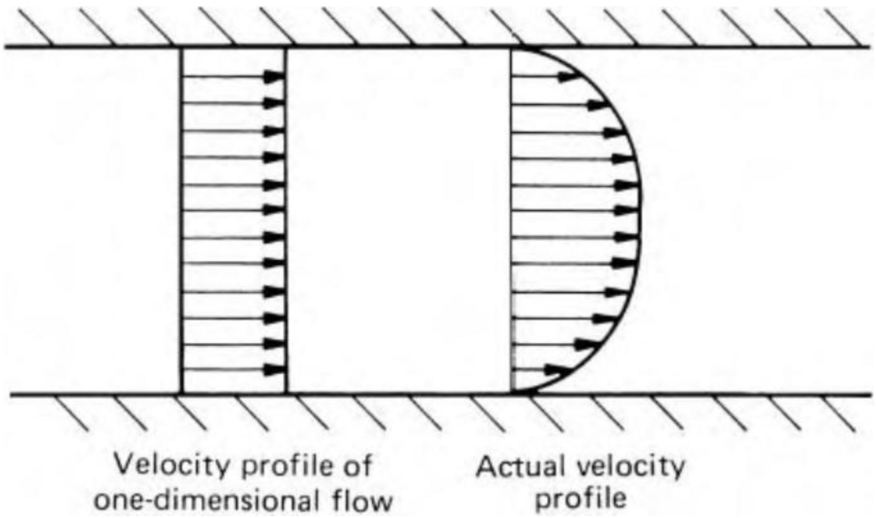

Fig. 1.10