Chapter 9
External Flows

Abstract

This chapter on external flows is divided into three parts. The first is the development of the idea of a boundary layer, a momentum penetration depth where fluid velocity changes from zero at a surface to the freestream velocity a small distance away. On a horizontal flat plate with no pressure gradient, scaling analysis shows a boundary layer thickness proportional to the square root of the distance along the plate from the leading edge. The fluid slows when it enters the boundary layer due to viscous drag between the fluid and the plate, and the local shear stress exerted on the plate is infinite at the plate leading edge and decreases as the inverse of the square root of distance downstream. These results are confirmed by integral and similarity solutions of boundary layer flow. The idea of a boundary layer is used to define the entry length of a conduit, before a flow is fully developed. The second part is a discussion of the characterization of turbulent flow structure and how it develops from laminar flow. Turbulence is vigorous, disordered, and has a high Reynolds number; it has a wide frequency spectrum of velocity fluctuations, related to vortex size distribution from the size of the flow down to small eddies with no internal velocity gradients. This behavior advects momentum through the layer more effectively than pure diffusion in laminar flow. The initiation and growth of disturbances during transition to turbulent flow is described. Finally, flow over bluff bodies is examined, with a definition of a drag coefficient and flow separation, with tabulated experimental values over a range or Reynold number. Behavior of gas bubbles and liquid droplets are also discussed.