Other Secondary Flows

Most pumps operate at high Reynolds numbers, and, in this regime of flow, most of the hydraulic losses occur as a result of secondary flows and turbulent mixing. While a detailed analysis of secondary flows is beyond the scope of this monograph (the reader is referred to Horlock and Lakshminarayana (1973) for a review of the fundamentals), it is important to outline some of the more common secondary flows that occur in pumps. To do so, we choose to describe the secondary flows associated with three typical pump components, the unshrouded axial flow impeller or inducer, the shrouded centrifugal impeller, and the vaneless volute of a centrifugal pump.

Secondary flows in unshrouded axial flow inducers have been studied in detail by Lakshminarayana (1972, 1981), and figure 1, which was adapted from those publications, provides a summary of the kinds of secondary flows that occur within the blade passage of such an impeller. Dividing the cross-section into a core region, boundary layer regions on the pressure and suction surfaces of the blades, and an interference region next to the static casing, Lakshminarayana identifies the following departures from a simple flow following the blades. First, and perhaps most important, there will be a strong leakage flow (called the tip leakage or tip clearance flow) around the blade tips driven by the pressure difference between the pressure surface and the suction surface. Clearly this flow will become even more pronounced at flow rates below design when the blades are more heavily loaded. This leakage flow will entrain secondary flow on both surfaces of the blades, as shown by the dashed arrows in figure 1. Second, the flow in the boundary layers will tend to generate an outward radial component on both the suction and pressure surfaces, though the former may be stronger because of enhancement by the leakage flow. The photographs of figure 2, which are taken from Bhattacharyya *et al.* (1993), show a strong outward radial component of the flow on the blade surface of an inducer. This is particularly pronounced near the leading edge (left-hand photograph). Incidentally, Bhattacharyya *et al.* not only observed the backflow associated with the tip clearance flow, but also a "backflow" at the hub in which flow reenters the blade passage from downstream of the inducer. Evidence for this secondary flow can be seen on the hub surface in the right-hand photograph of figure 2. Finally, we should mention that Lakshminarayana also observed secondary vortices at both the hub and the casing as sketched in figure 1. The vortex near the hub was larger and more coherent, while a confused

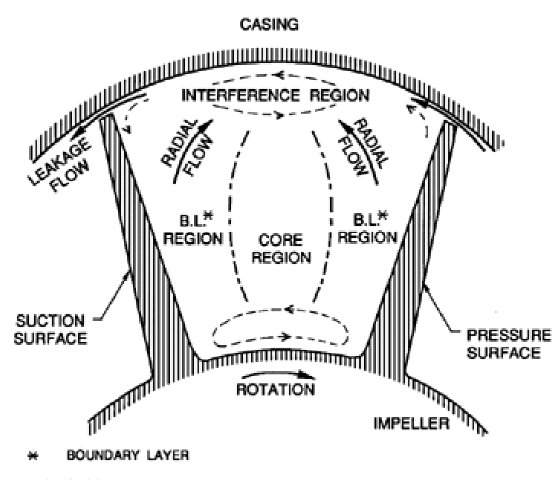

Figure 1: Cross-section of a blade passage in an axial flow impeller showing the tip leakage flow, boundary layer radial flow, and other secondary flows (adapted from Lakshminarayana 1981).

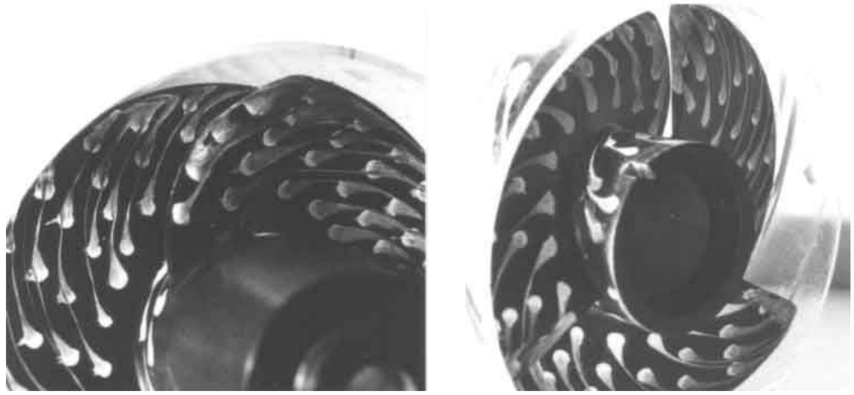

Figure 2: Photographs of a 10.2 cm, 12° helical inducer with a lucite shroud showing the blade surface flow revealed by the running paint dot technique. On the left the suction surfaces viewed from the direction of the inlet. On the right the view of the pressure surfaces and the hub from the discharge. The flow is for 2000 rpm and $\phi_1 = 0.041$. From Bhattacharyya *et al.* (1993).

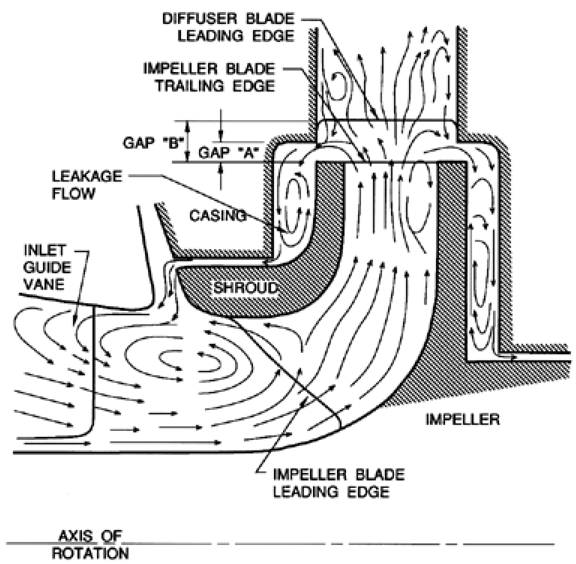

Figure 3: Schematic showing secondary flows associated with a typical centrifugal pump operating at off-design conditions (adapted from Makay 1980).

interference region existed near the casing.

Additional examples of secondary flows are given in the descriptions by Makay (1980) of typical flows through shrouded centrifugal impellers. Figure 3, which has been adapted from one of Makay's sketches, illustrates the kind of secondary flows that can occur at off-design conditions. Note, in particular, the backflow in the impeller eye of this shrouded impeller pump. This backflow may well interact in an important way with the discharge-to-suction leakage flow that is an important feature of the hydraulics of a centrifugal pump at all flow rates. As testament to the importance of the backflow, Makay cites a case in which the inlet guide vanes of a primary coolant pump in a power plant suffered structural damage due to the repeated unsteady loads caused by this backflow. Note should also be made of the secondary flows that Makay describes occurring in the vicinity of the impeller discharge.

It is also important to mention the disturbed and separated flows that can often occur in the volute of a centrifugal pump when that combination is operated at off-design flow rates (Binder and Knapp 1936,

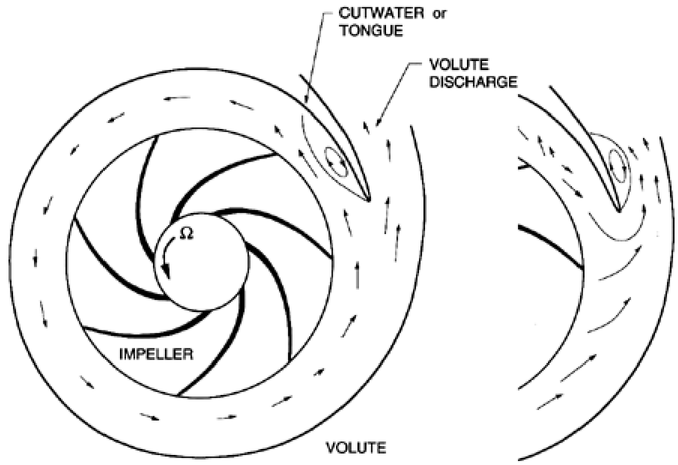

Figure 4: Schematic of a centrifugal pump with a single, vaneless volute indicating the disturbed and separated flows which can occur in the volute below (left) and above (right) the design flow rate.

Worster 1963, Lazarkiewicz and Troskolanski 1965, Johnston and Dean 1966). As described in the preceding section, and as indicated in figure 4, one of the commonest geometries is the spiral volute, designed to collect the flow discharging from an impeller in a way that would result in circumferentially uniform pressure and velocity. However, such a volute design is specific to a particular design flow coefficient. At flow rates above or below design, disturbed and separated flows can occur particularly in the vicinity of the cutwater or tongue. Some typical phenomena are sketched in figure 4 which shows separation on the inside and outside of the tongue at flow coefficients below and above design, respectively. It also indicates the flow reversal inside the tongue that can occur above design (Lazarkiewicz and Troskolanski 1965). Moreover, as Chu *et al.* (1993) have recently demonstrated, the unsteady shedding of vortices from the cutwater can be an important source of vibration and noise.