Types of Pumps

Pumps come in a vast array of shapes and sizes and in a great range of designs. Here we give just a few examples of pumps from a range of different technological contexts. The presentation will generally follow a framework of progressively decreasing specific speed, N, and so will begin with high specific speed pumps from applications involving high flow rates and relatively modest head rise. Figure 1 depicts a schematic and a picture of typical axial flow pumps in which the flow emerges axially from the impeller but discharges laterally from the machine. Figure 2 shows a mixed flow pump for somewhat lower specific speeds in which

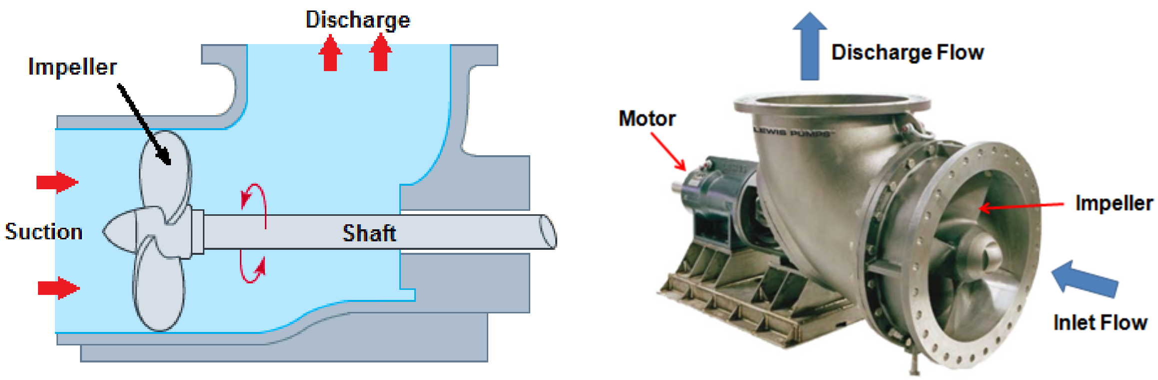

Figure 1: Schematic and picture of typical axial flow pumps.

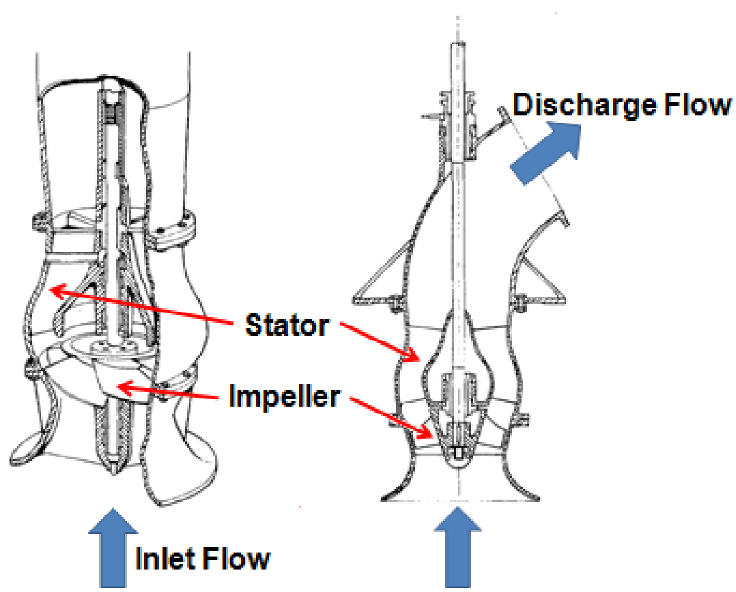

Figure 2: Typical mixed flow pump.

the discharge from the impeller has a radial component so that the head rise has a centrifugal component. Downstream of the impeller the flow returns to an axial direction and proceeds through a stator before exiting laterally from the pump.

Figures 3 and 4 show a typical centrifugal pump for low specific speeds of order $N = 1$ or less. The flow enters the pump axially (Figure 3), enters the impeller, exits the impeller radially (Figure 4) and is

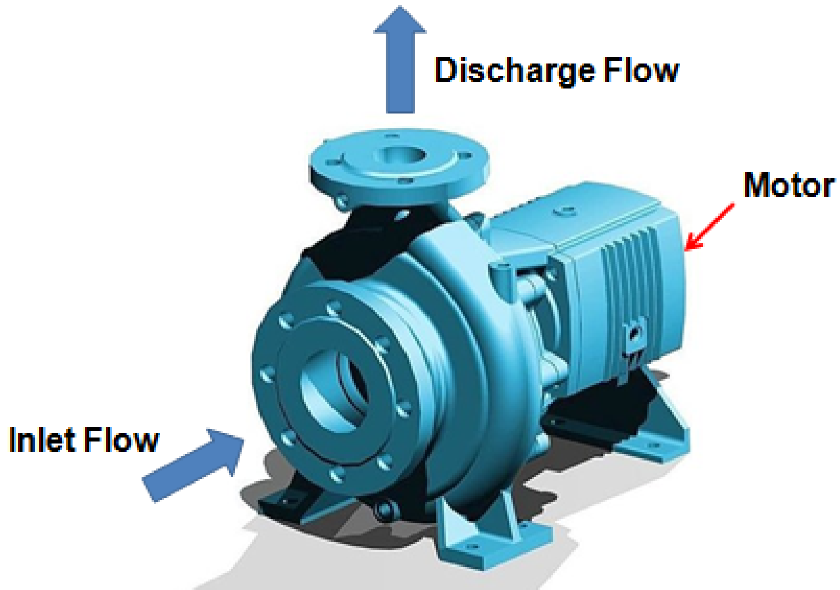

Figure 3: Typical centrifugal pump.

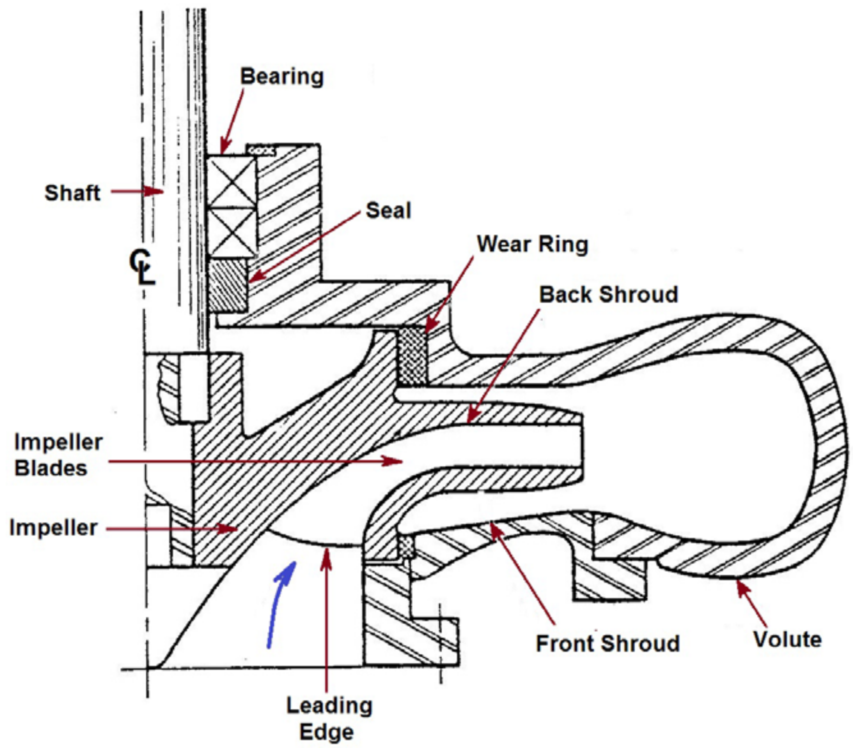

Figure 4: Components of a typical centrifugal pump.

collected in a volute (Figure 4) from which it exits in an off-central tangential direction (Figure 3). A typical centrifugal pump impeller is shown in figure 5 (left). It is a five-bladed impeller made by Byron Jackson Pump Division of Borg Warner International Products, has a discharge blade angle of 23° and a design specific speed, N_D, of 0.57. In later sections we present performance data for this impeller tested in combination with several volutes including the single exit, spiral volute shown in Figure 5 (right). That volute was designed to match that impeller in Figure 5 (left).

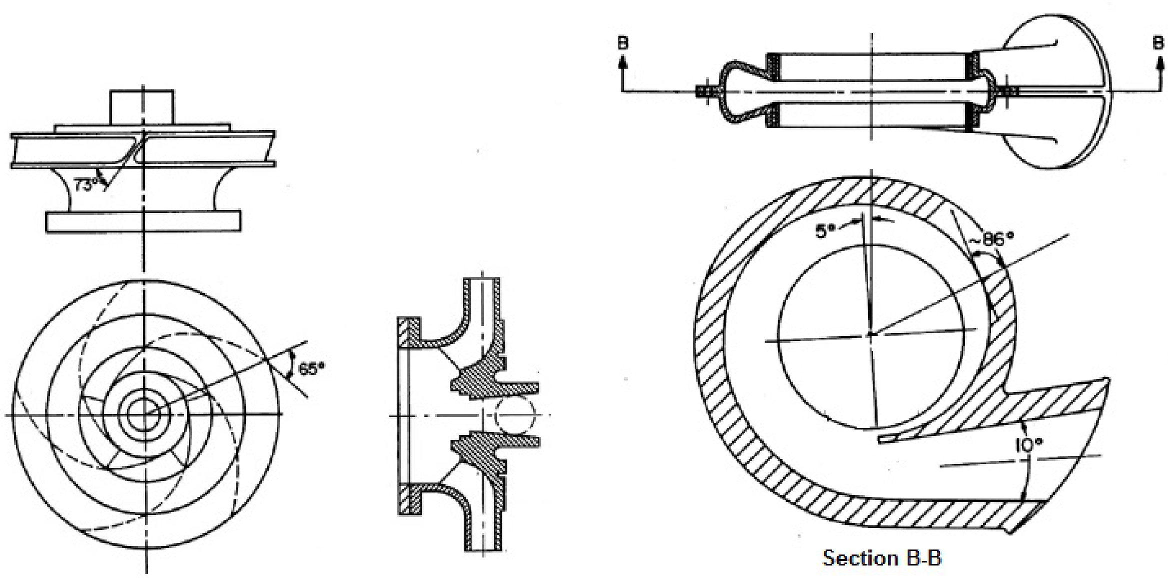

Figure 5: Typical centrifugal pump impeller (left) and volute (right).

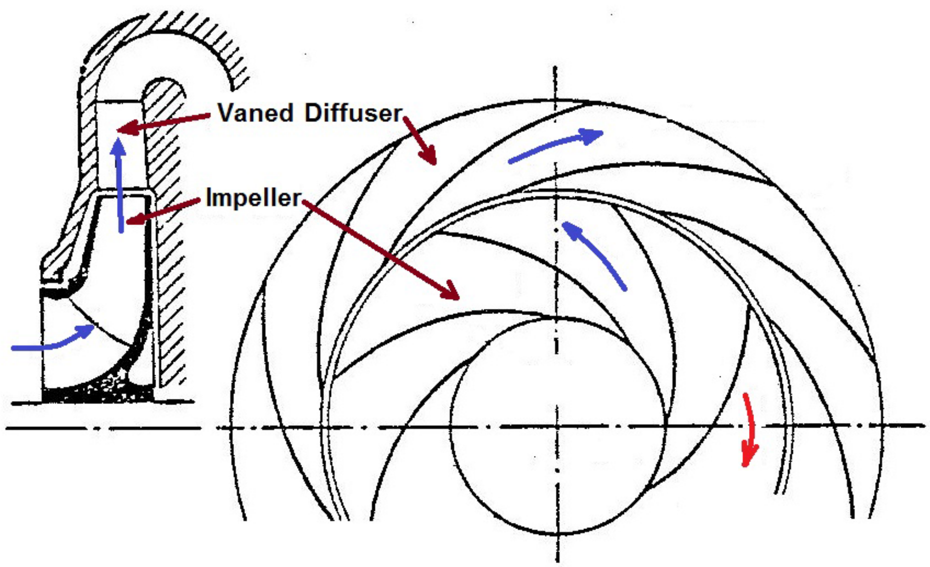

Figure 6: Typical centrifugal pump vaned diffuser.

Often a centrifugal pump is equipped with a radial vaned diffuser of the type illustrated in Figure 6. The flow exits the impeller and proceeds through the vaned diffuser before entering the volute.

When the design specific speed is below a value of about $N_D = 0.5$, it is necessary to achieve the desired head rise by using more than a single centrifugal pump stage. A typical example of such a multistage centrifugal pump is shown in Figure 7 (left). Apart from the impellers, key components include the vaned diffusers and the return passages which comprise a 180° bend, a 90° bend and the inward-flowing return section. The losses incurred in these return passages constitute a significant contribution to multistage centrifugal pump performance. As depicted in Figure 7 (right), downhole oil well pumps represent examples of multistage centrifugal pumps and often include 20 or 30 modular stages. Each rotor (impeller) stage is stacked together with a stator (diffuser and return passage) stage, the rotors being keyed to a central rotating shaft while the stators are keyed to the surrounding duct.

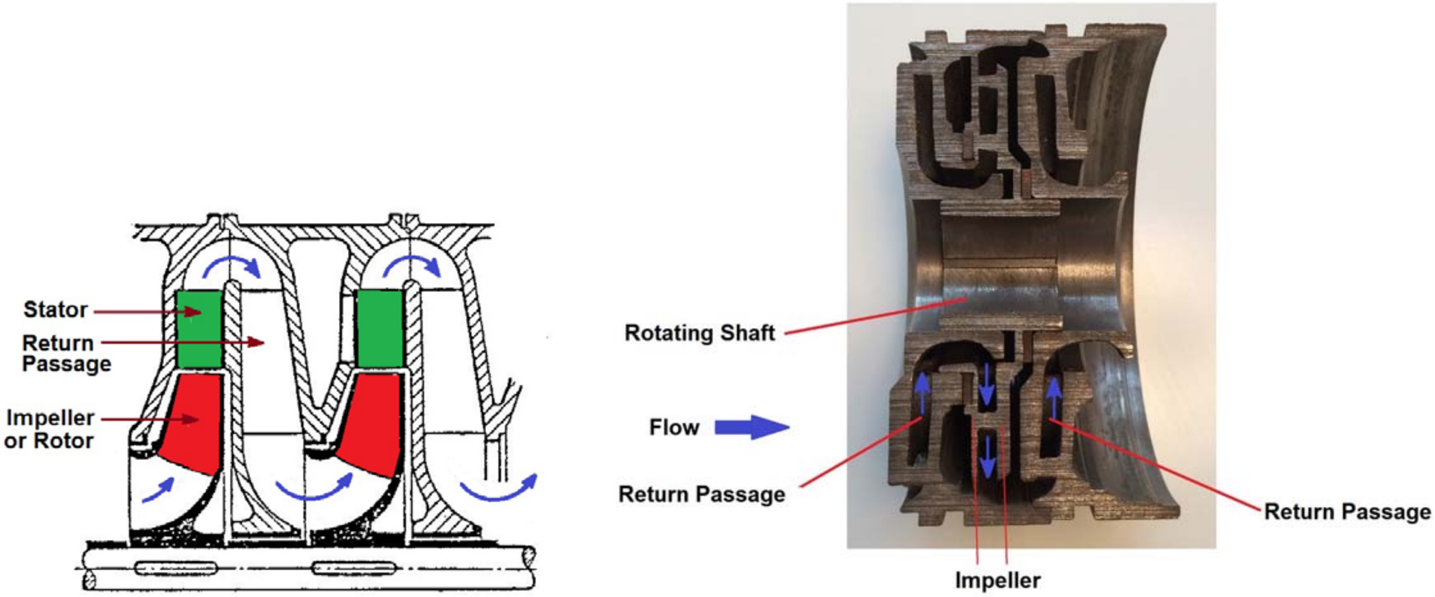

Figure 7: Left: Two-plus stages of a multistage centrifugal pump. Right: Cross-section of one and half stages of a multistage downhole oil well pump showing two return passages or stators and one impeller stage.

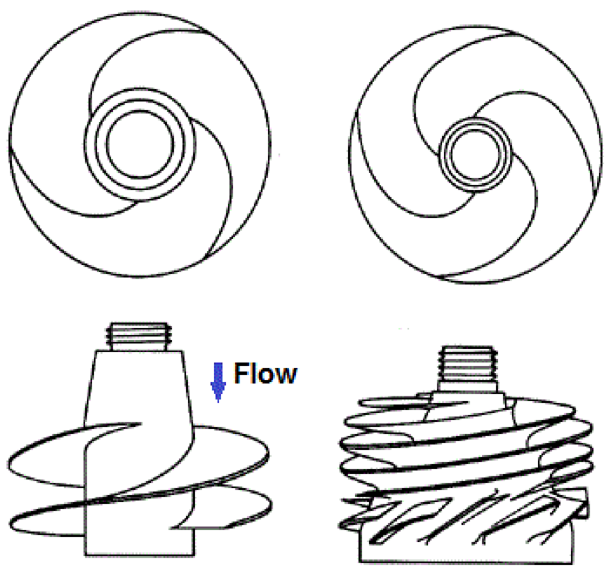

Figure 8: Two cavitating inducers: on the left a 9° helical inducer; on the right a scale model of the impeller in the SSME low pressure LOX turbopump.

When extensive cavitation cannot be avoided (for example in cryogenic rocket engine pumps), it becomes necessary to alter the pump design so that it can function with substantial cavitation. This is usually accomplished by adding an additional stage ahead to the main impeller, a stage that is commonly called a cavitating inducer or just an inducer. The strategy is to handle the incoming flow very gently with small angle of incidence so that the pressure is gradually increased to a level at which the flow can enter the following impeller without excessive cavitation. As illustrated in Figure 13, cavitating inducers are usually helical with helical angles that involve small initial angles of incidence. Sometimes the discharge flow from the inducer is at larger radial positions than the inlet (see Figure 13 (right)) and this adds a significant centrifugal component to the inducer head rise. Two particular axial flow pumps or inducers, designed to

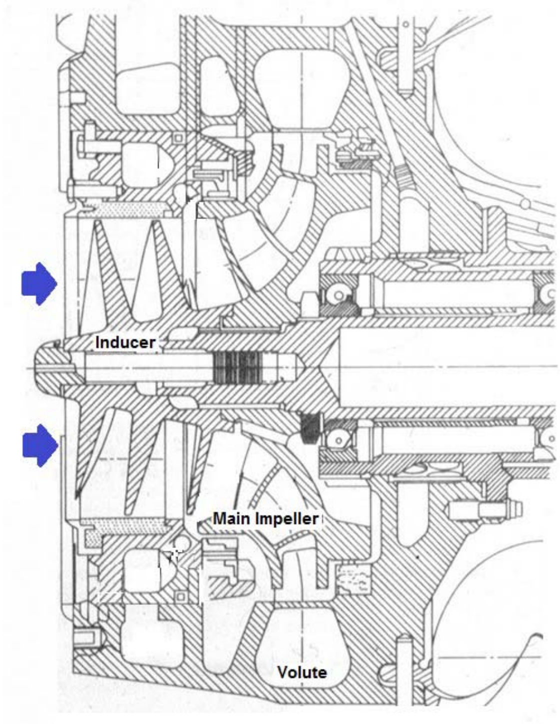

Figure 9: Left: The liquid oxygen pump in the J2 rocket engine. Right: Scale model of the low pressure liquid oxygen pump impeller in the Space Shuttle Main Engine.

function with cavitation, are shown in figure 13, namely a simple 9° helical inducer and a scale model of the low pressure liquid oxygen impeller in the Space Shuttle Main Engine (SSME) (see also Figure **??**). Performance data for both inducers is presented in later sections.

Figures 10 and 11 present examples of the rocket engine turbopumps in the Space Shuttle Main Engine (SSME) and in the Ariane V rocket; all are turbopumps, liquid cryogenic pumps driven by gas turbines powered by the same gas. The liquid oxygen pumps necessarily incorporate cavitating inducers; the liquid hydrogen pumps do not need these additional components. Note that unlike all the other liquid propelled rocket engines, the SSME has two stage pumping systems with both low- and high-pressure pumps. Earlier figures (Figure 9 (right)) illustrated the design of the low pressure turbopumps. Figure 10 includes the SSME high pressure liquid hydrogen (top) and liquid oxygen (bottom) pumps. The high pressure liquid hydrogen pump is a three-stage centrifugal pump while the high pressure liquid oxygen pump is a back-to-back single stage centrifugal pump with a single common volute.

Unlike the SSME, the Ariane V has just one hydrogen and one oxygen pump as shown in Figure 11. The hydrogen pump has an inducer followed by two centrifugal stages while the oxygen pump has an inducer followed by a single centrifugal stage.

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Turning now to compressors handling compressible gases rather than liquids, the same basic options are relevant though the increase in the density as the fluid passes through the impeller requires modified impeller geometry. This can be seen in the geometry of the typical centrifugal compressor shown in Figure 12 where, in comparison with the liquid machine, the flow passage increases less in cross-sectional area as the flow proceeds through the impeller (in order to adjust for the increase in fluid density).

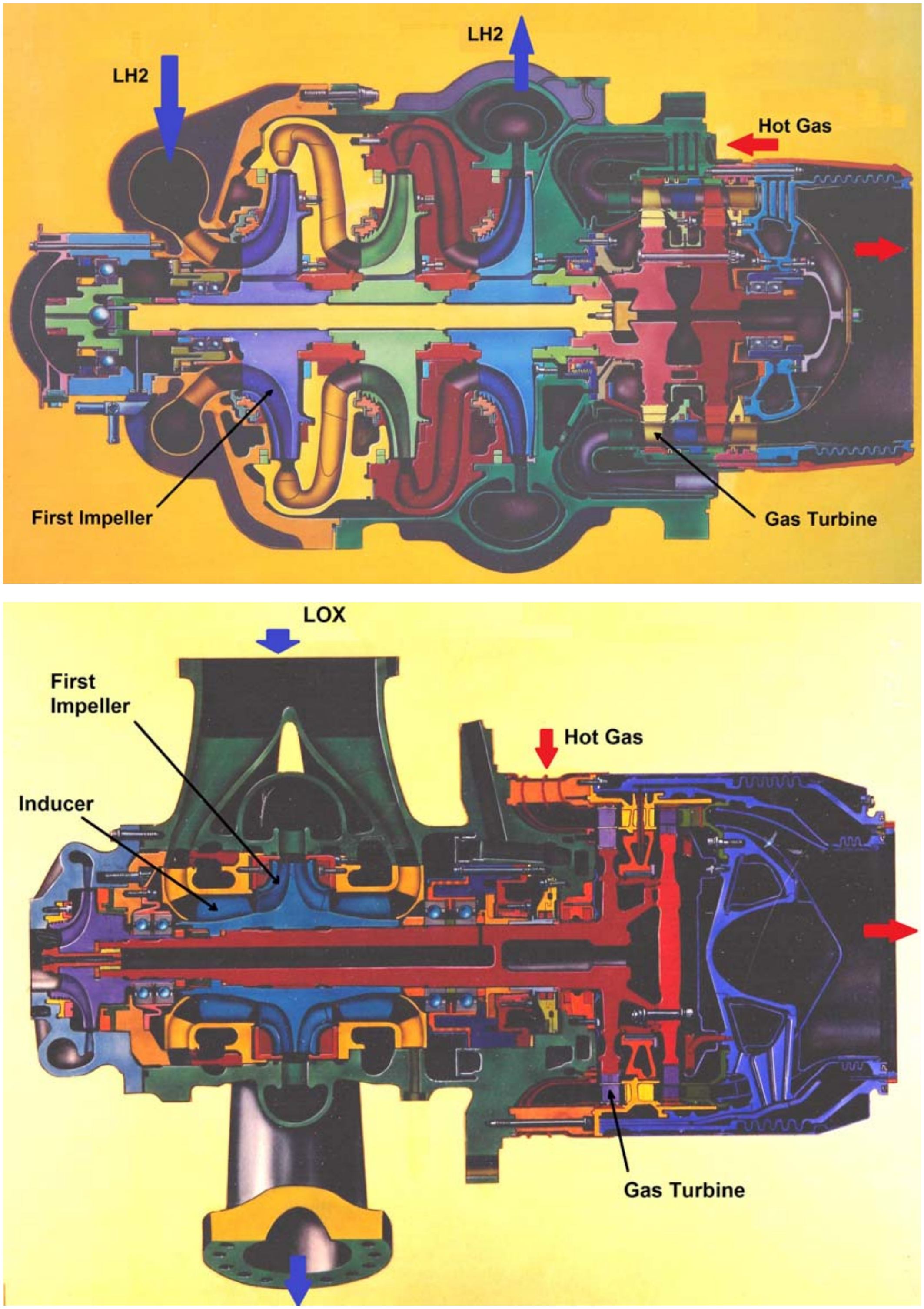

Figure 10: The high pressure liquid hydrogen (top) and liquid oxygen (bottom) pumps in the Space Shuttle Main Engine.

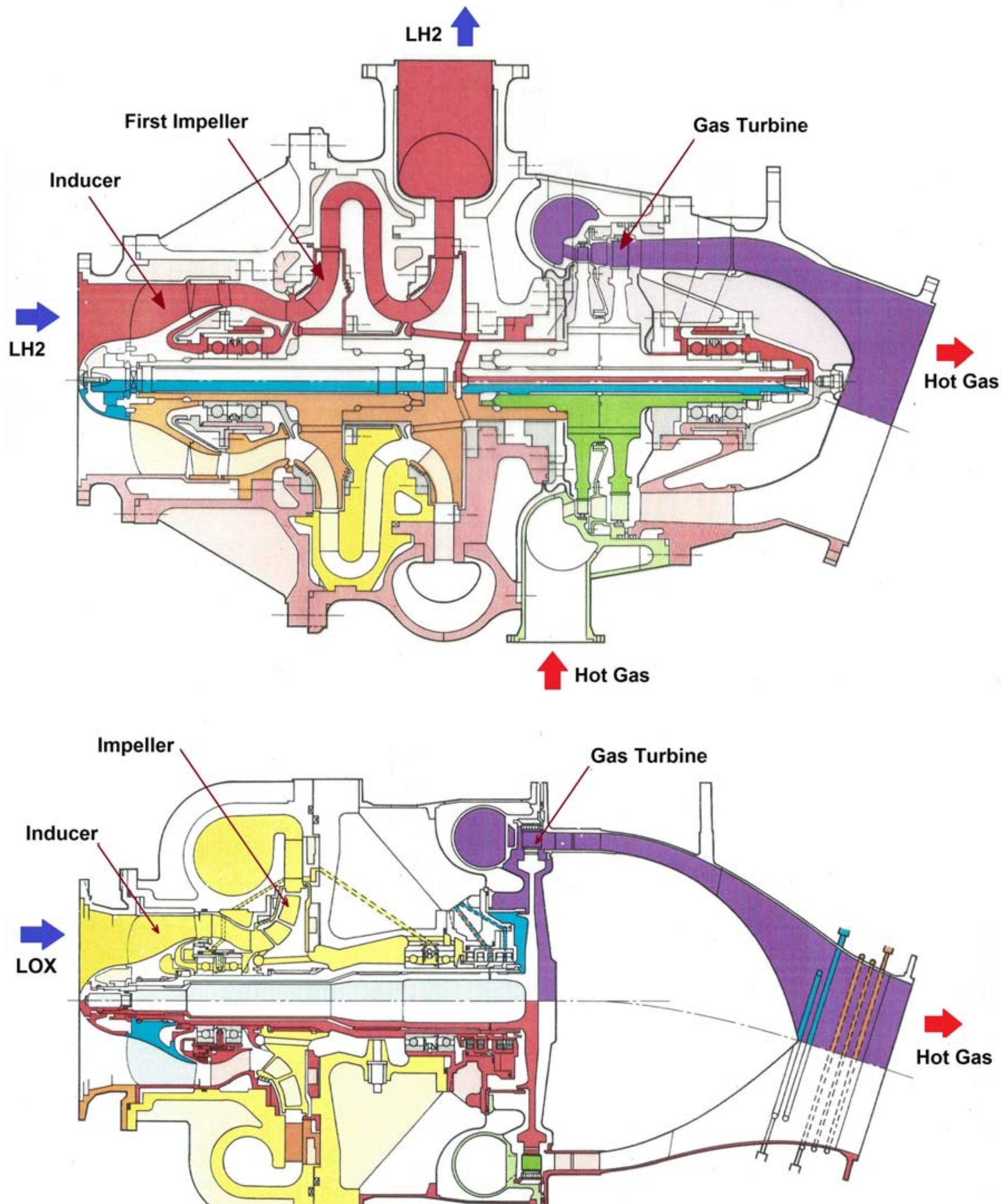

Figure 11: The liquid hydrogen (top) and liquid oxygen (bottom) pumps in the Ariane V rocket engine.

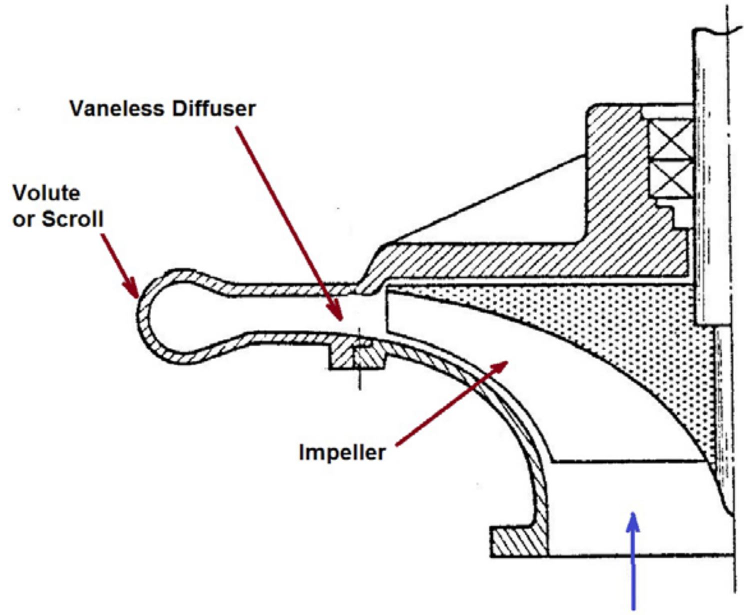

Figure 12: Typical centrifugal compressor.

Many compressors such as those in gas turbine engines are multi-stage axial machines with many rotors and stators decreasing in size as the density increases as illustrated in Figure 13.

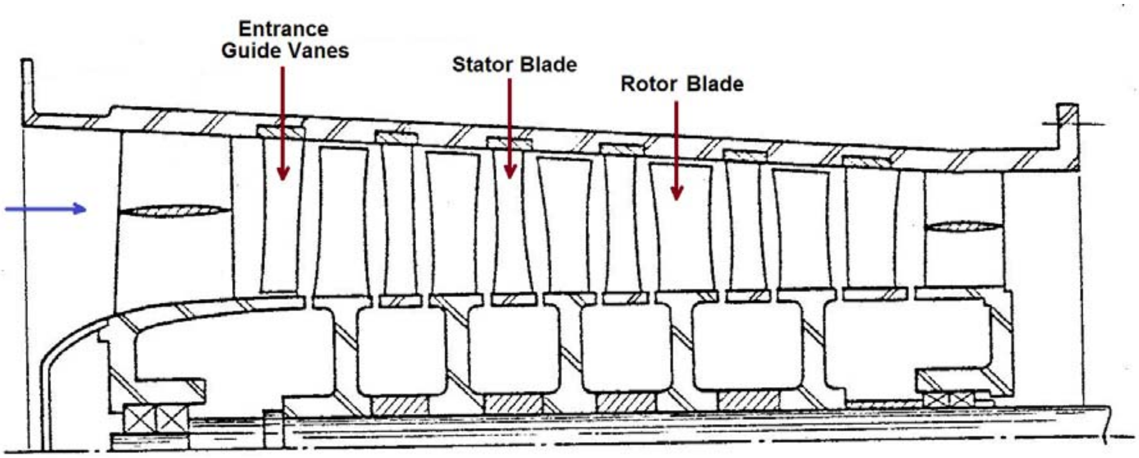

Figure 13: Typical axial compressor.

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There are, of course, other types of pumps and compressors, in particular positive displacement pumps whose advantage is that they deliver a particular flow rate relatively independent of the head rise. These, too, come in different types: many are driven by a reciprocating mechanism with passive suction and discharge valves to prevent backflow as illustrated in Figure 14. Another type is the gear pump shown in Figure 15 (left) though this could also be classified as a form of a peristaltic pump. However, the classic peristaltic pump (which mirrors the action in animal intestines) is comprised of a flexible tube which is squeezed by the action of a mechanical device that acts to move the liquid (or deformable solid/liquid) along the tube as depicted in Figure 15 (right). The great advantage of such a pump is that the liquid only contacts the tube and this has great advantages as a pump for sterile medical applications or for processes handling corrosive or dangerous liquids.

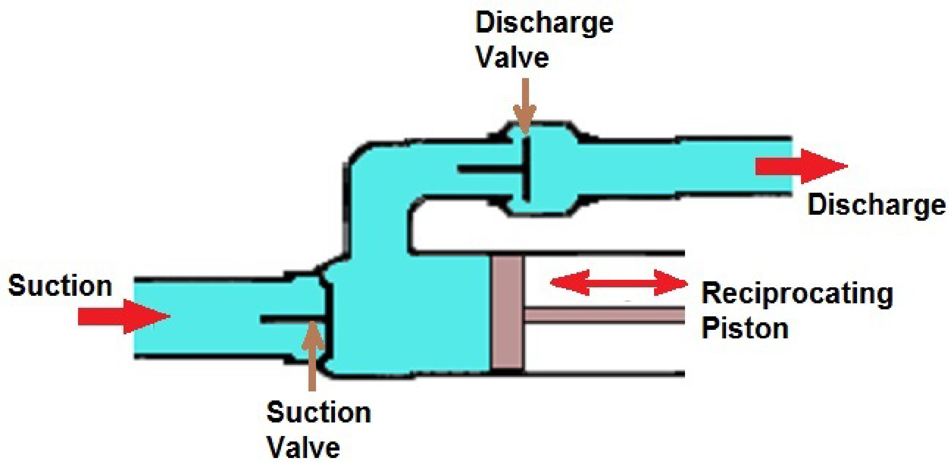

Figure 14: Schematic of a simple positive displacement pump.

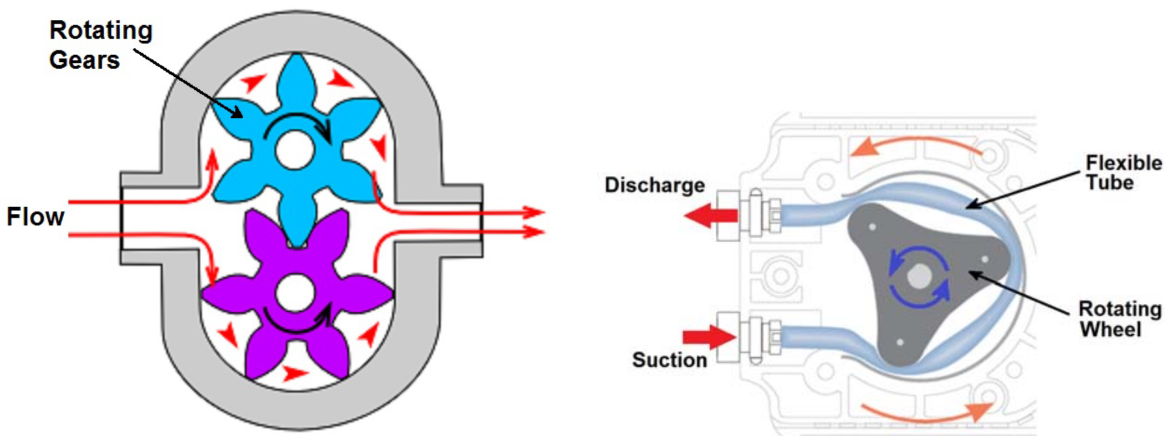

Figure 15: Left: Schematic of a typical gear pump. Right: Schematic of a typical peristaltic pump.