Description for the general public

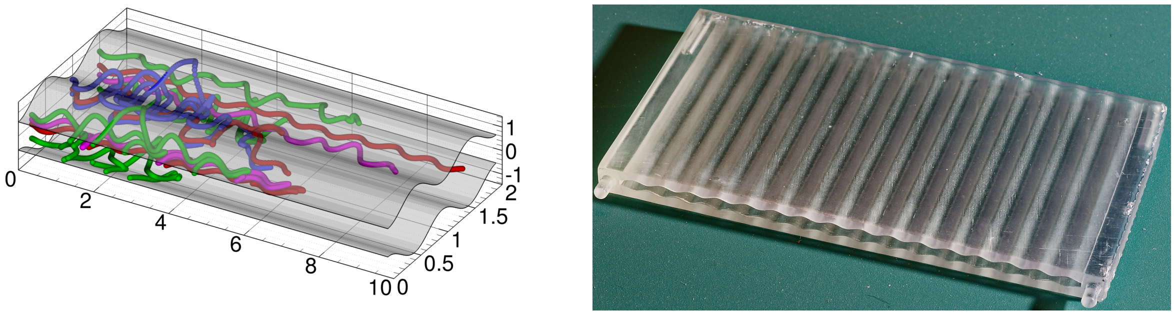
Mixing process in a stationary or slowly-moving fluid, without external actuation, it usually very sluggish. This is because the process is dominated by molecular diffusion and lacks the convective effects. A good example is the dissolution of sugar in a coffee cup, which without external forcing (mixing with a spoon) may take up to a few days.

A general approach to mixing intensification is to bring the flow to a turbulent state. Turbulization of the flow is, however, difficult to obtain in the case of slow and small scale flows, where physics is dominated by viscous phenomena. Such flows are characterized by a low Reynolds number. On the other hand, ’brutal’ turbulization can be undesirable. For example, substances suspended in a liquid may be very sensitive to rapidly fluctuating shear stresses. Partial remedy, often applied in practice, is to force the conditions of laminar mixing through onset of chaotic advection. Chaotic advection is a phenomenon in which simple laminar flows result in very complex - chaotic - motion patterns. The induction of chaos is often implemented by appropriately shaping the flow domain, often in combination with internal obstacles and vortex generators. As a consequence hydraulic loses may rise dramatically.

The scope of the current project is to look for methods that allow for the onset of chaos in laminar flows, free of external actuation of complex obstacles, such that it does not lead to a rise in hydraulic loses. The concept is to utilize natural hydrodynamic instabilities, invoked by an appropriately shaped flow geometry, which results in chaotic advection and a mixing-friendly flow topology.

Within the frame of the current project we will focus on various stability properties of flows between corrugated walls. It turns out that appropriate form of wall grooving enables amplification of small perturbation already at low values of the Reynolds number, while decreasing hydraulic resistance. It is therefore possible to intensify mixing and limit the operational costs of a flow device.

The aim of the project is to establish, both computationally as well as experimentally, necessary conditions for the instabilities to appear. We will investigate various destabilization mechanisms. Whether a given flow intensifies mixing is a difficult question to answer. One could try to analyse the kinematics of the flow by investigating relative changes of passive markers injected into this flow. Figure 1a illustrates traces formed by such markers injected continuously into the nonstationary flow at fixed positions. The flow Reynolds number is 80, and it results from spontaneous amplification of initially small perturbations. It is interesting to observe that, contrary to the low Reynolds number, the flow is sufficiently complicated, enough so that the traces of injected markers diverge along the flow. Figure 1b shows an element of the experiment assembly produced by stereolithography (SLA) i.e. 3D printing with UV-solidifing resin.



(a)

(b)

Figure 1: (a) Traces formed by continuously injecting markers into a nonstationary flow, resulting from numerical simulation of laminar flow at Reynolds 80. (b) 3D printed section of an experimental set-up.