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News & views

Fluid dynamics

Cardiac cycle inspires optimized pipe flow

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Pulsatile driving of pipe flow that imitates waveforms measured in the human aorta has been shown to suppress turbulence and increase the energy efficiency of the transport of fluids in pipes. **See p.71**

Modern civilization depends on the transport of liquid and gases in systems of pipes, just as humans are dependent on the transport of blood through arteries and veins[1]. As fluids move through pipes, they encounter friction due to the interaction between the fluid and the pipe wall. At low flow rates, the flow is laminar — smooth and predictable — and the power requirements for pumping it are comparatively low. However, laminar flow is difficult to achieve and in most pipe systems the flow is turbulent, that is, it exhibits irregular motions that occur over a wide range of length and timescales. These turbulent fluctuations increase resistance, resulting in higher pumping costs compared with laminar flow. So, how can we keep pipe flow as smooth as possible? On page 71, Scarselli *et al.*[2] report a strategy that is inspired by the pipe system closest to our hearts, the cardio-vascular system.

Most commonly, pipe flow is driven at a constant flow rate. By contrast, pulsating pipe flows have a time-dependent flow rate, which is the combination of a non-zero average flow rate with a periodic component. The blood flow in the human aorta is an example of a pulsating pipe flow because the heart operates cyclically[3]. During the first part of the cardiac cycle, blood is pumped out of the heart; in the second part, no blood is ejected and the heart rests. As a result, blood flow in the aorta is highly time dependent. At its peak, it reaches flow rates at which — under steady conditions — pipe flow would be fully turbulent. Nevertheless, in healthy humans, aortic blood flow manages to avoid high levels of turbulence and associated damage to the cardiovascular system.

The key parameter that governs the behaviour of pipe flows is the Reynolds number (Re), which is calculated by multiplying the flow velocity by the internal diameter of the pipe and the density of the fluid and then dividing the result by the dynamic viscosity of the fluid. The Reynolds number is named after Osborne Reynolds, who found in 1883 that steady pipe flow is in a laminar state for low Reynolds numbers and becomes turbulent for high Reynolds numbers[4].

Scarselli and colleagues used experiments and simulations to investigate how pulsatile driving, mimicking the cardiac cycle, can be used to suppress turbulence in pipe flows. In their initial experiments, the authors considered three different driving conditions and compared them at the same instantaneous Reynolds number (Re = 2,800). In the first case, the flow was driven at a rate that was not time dependent (Fig. 1a). This case resulted in the flow being turbulent throughout the pipe. Next, Scarselli *et al.* applied pulsatile driving that emulated a time-dependent periodic pattern reported[5] for part of the human aorta (Fig. 1b). Under these conditions the flow was fully laminar. In the third case, the authors tested similar pulsatile driving to the second case, but removed the rest phase, and found that the flow remained largely turbulent (Fig. 1c). This demonstrates that the rest phase is key for suppressing turbulence.

In the main part of their study, the authors investigated whether cardiac-cycle-inspired driving also yields benefits at higher Reynolds numbers and whether overall power savings can be obtained by driving the pipe flow. By varying the properties of the pulsating waveform, they were able to compare the power savings that can be achieved for different pulsatile flow patterns. Not all pulsating waveforms yielded power benefits, but for a pattern with a rapid acceleration followed by

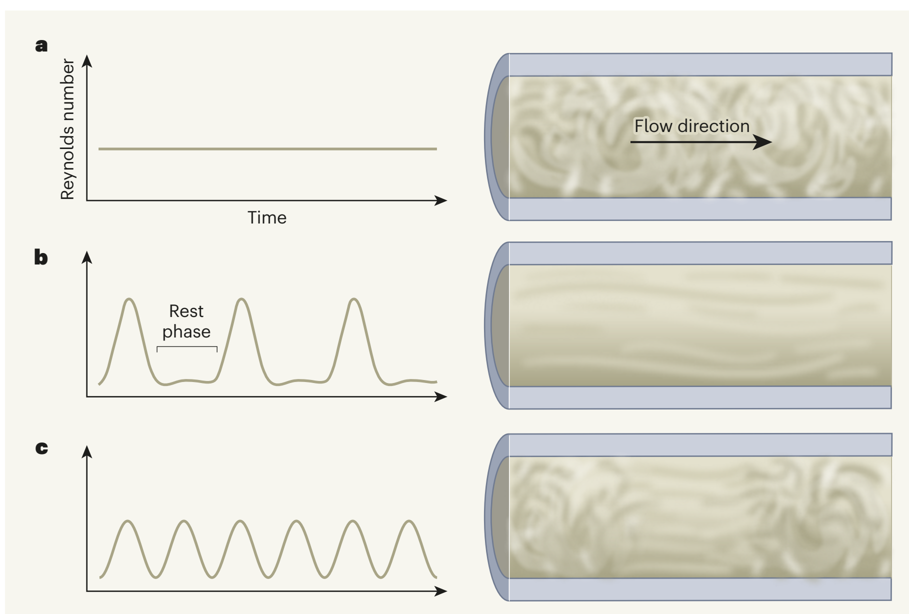

Figure 1 | Suppression of turbulence by cardiac-cycle-inspired driving. Scarselli *et al.*[2] compared different ways of driving pipe flow. **a**, A constant flow rate resulted in turbulent pipe flow. **b**, Taking inspiration from the cardiac cycle, the authors applied pulsating pipe flow with a rest phase, and found that this suppressed turbulence. **c**, A similar pulsating pattern with the rest phase removed generated a flow that remained largely turbulent. The visualizations show snapshots of the flow at the same instantaneous Reynolds number (2,800), which is a dimensionless quantity that is defined as the product of the flow velocity, internal diameter of the pipe and the density of the fluid divided by the dynamic viscosity of the fluid. (Adapted from Fig. 1 of ref. 2.)

a gentler deceleration and a rest phase, Scarselli and co-workers reported a substantial power saving of 9% compared with steadily driven pipe flow. Considering that the pumping of fluids has been estimated to account for almost 15% of the total energy consumption in the European Union (see go.nature.com/3sf1ygz), a 9% reduction in pumping power could make a considerable contribution to improving energy efficiency.

There is, however, still work to be done before such savings can be realized. Scarselli *et al*. considered Reynolds numbers that are moderate compared with typical values found in many industrial pipe-flow applications. Thus, it needs to be established whether their approach can be extended to higher Reynolds numbers. Furthermore, Scarselli and colleagues' study focused on flow in a straight pipe section, which is the standard configuration for investigating the fundamental properties of pipe flow. However, pipe systems contain many other elements, such as bends, branches, junctions, expansions and contractions. Similar elements also occur in the human cardiovascular system. Therefore, it would be of high interest to investigate whether Scarselli and colleagues' optimal pulsating waveforms could yield similar benefits for more complex configurations, representative of full industrial and biological applications of pipe systems.

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