News & views

Fluid dynamics

Cardiac cycle inspires optimized pipe flow

Angela Busse

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 depend 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 cardiovascular system.

Most commonly, pipe flow is driven at a constant 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 when Reynolds numbers are low and becomes turbulent when Reynolds numbers are high[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 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 resulted in the flow being turbulent throughout the pipe. Next, Scarselli *et al.* applied pulsatile driving that emulated a time-dependent periodic pattern reported previously[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,

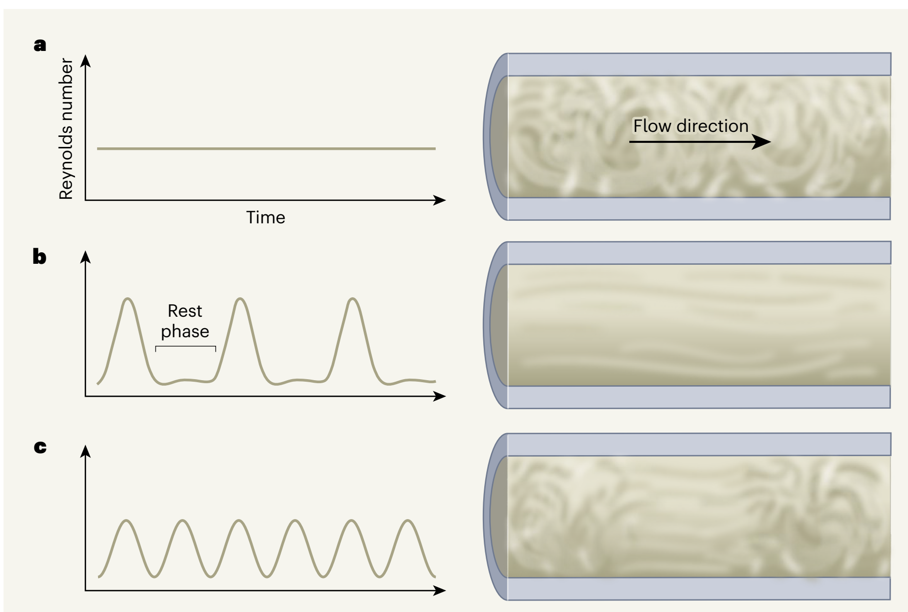

Figure 1 | Suppression of turbulence by cardiac-cycle-inspired driving. Scarselli *et al.*[2] compared different ways of driving pipe flow. **a**, A constant flow rate resulted in turbulent pipe flow. **b**, Taking inspiration from the cardiac cycle, the authors applied pulsating pipe flow with a rest 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), a dimensionless quantity that is defined as the product of the flow velocity, the 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.)

From the archive

Insect development, and an economist's will offers financial incentives for university reform.

50 years ago

Developmental Systems: Insects. Edited by S. J. Counce and C. H. Waddington — Insects have provided and will continue to provide ideal material for the study of all the processes of growth and development. Their size is such that the relations between the final form and the cells by which it is built are often wonderfully clear to the observer. This does not make the process of growth intelligible — but it constantly inspires the investigator with the feeling that given a little more knowledge everything could be understood ... Volume 2 opens with a 150-page chapter in which S. J. Counce reviews in detail "the causal analysis of insect embryogenesis" ... The succeeding section by P. A. Lawrence is less concerned with completeness than with ideas. It provides a stimulating discussion of gradients in relation to differentiation. C. M. Child battled for years for recognition of the importance of gradients — but without much success. Gradients of what? As ... Lawrence makes clear, it is possible to define the laws of gradients without knowing the true nature of the phenomenon. To discuss gradients of an imaginary something is no more and no less an invocation of the occult than is the idea of gravity — which, after nearly four hundred years, is still a useful concept.

From *Nature* 7 September 1973

150 years ago

The late Mr. John Stuart Mill has left property to the amount of 14,000*l* [£14,000]. Of this he has left to any one university in Great Britain or Ireland that shall be the first to open its degrees to women, 3,000*l*; and to the same university a further sum of 3,000*l* to endow scholarships for female students exclusively. His copyrights he bequeaths in trust to Mr. John Morley, to be applied in aid of some periodical publication which shall be open to the expression of all opinions, and which shall have all its articles signed with the names of the writers.

From *Nature* 4 September 1873

but for a pattern with a rapid acceleration followed by 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/3sfiygz), a 9% reduction in pumping power could make a considerable contribution to improving energy efficiency.

There is, however, work to be done before such savings can be realized. Scarselli *et al.* considered Reynolds numbers that are moderate compared with typical values 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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Ecology

A drowned future for coastal ecosystems

Qiang He

Tidal marshes, mangroves and coral reefs support the livelihoods of millions of people. Most of these ecosystems will be vulnerable to submergence owing to rapid sea-level rise if global warming exceeds 2 °C above pre-industrial levels. **See p.112**

Humans have gravitated towards coastlines for millennia and depend on coastal ecosystems such as tidal marshes, mangroves and coral reefs for fisheries, storm protection and recreation[1]. On page 112, Saintilan *et al.*[2] shed light on what the future under climate change might mean for these ecosystems.

The Kunming-Montreal Global Biodiversity Framework, an agreement on biodiversity conservation adopted during the 2022 United Nations Biodiversity Conference (www.cbd.int/gbf), outlines a global goal to protect at least 30% of coastal ecosystems. However, these ecosystems are increasingly threatened by rising seas, owing to global warming. Since the 1900s, the global mean sea level (GMSL) has risen by 0.20 metres, with rates reaching 3.7 millimetres per year between 2006 and 2018 (ref. 3). According to the Intergovernmental Panel on Climate Change's Sixth Assessment Report (IPCC AR6), the GMSL is projected to rise further by 2100 under global warming scenarios of 1.5–5 °C of temperature rise above pre-industrial levels, probably with a mean rise of between 0.44 m and 0.81 m above the GMSL of the 1900s and a mean rate of rise of between 4.3 mm and 11.7 mm per year[3].

How would coastal ecosystems fare in such rising sea levels? Saintilan and colleagues provide a comprehensive global-scale assessment of this crucial question and find that the thresholds beyond which sea-level rise would lead to widespread 'drowning' of coastal ecosystems might be much lower than were previously thought.

Tidal marshes, mangroves and coral reefs are ecosystems in which plants and corals accelerate the deposition of substrate material (accretion) – by affecting sediment and the accumulation of organic matter and calcium carbonate – and thus lower the depth and duration of water inundation, which in turn enables these ecosystems to persist when they encounter sea-level rise[4]. Without considering these biophysical feedback processes, early modelling studies[5,6] predicted large losses of