# Turbulence in pulsatile pipe flow

## Turbulent puff dynamics in pulsatile pipe fow

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## In Short

- Turbulence in pulsatile pipe flow first appears as localized turbulent puffs.
- Here we study the effect of the shape of the pulsation on turbulence.
- We look for the waveform that is more/less detrimental for turbulence survivability in the transitional regime.

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Pulsatile pipe flow is ubiquitous in industrial and biological applications. For instance, in our cardiovascular vessels, blood flows at a pulsatile bulk velocity, i.e. with a mean and one or more periodic components. However the presence of turbulence in pulsatile pipe flow is usually undesired. Coming back to our earlier example, the presence of turbulence in blood flow has been linked with the development of cardiovascular diseases. Thus there is a need to understand how turbulence behaves in pulsatile pipe flow to avoid this and other detrimental effects.

In the limit of no oscillatory component, i.e. steady driven pipe flow, the presence of turbulence is determined by the Reynolds number $Re$. This non-dimensional number was first proposed by Reynolds, 1, and compares the inertia and viscous forces in the flow. At a sufficiently high $Re$ turbulence first appears in the form of localised turbulent puffs. It is at $Re \geq 2050$ when puffs can survive for infinite times 2. As $Re$ further increases turbulence appears axially localized in puffs or longer slugs that, at a sufficiently high $Re$, can fill the whole pipe with turbulence.

In the case of pulsatile pipe flow, turbulence will depend not only on $Re$ but also on the frequency and shape of the pulsation. This opens up a huge parametric space, that has recently started to be explored. Studies have mainly focused on pulsatile pipe flow at $Re \approx 2050$ with one oscillatory component. Simulations and experiments show that, only at high enough frequencies and for oscillatory parts whose amplitude is smaller than the mean component, turbulent puffs survive at $Re \approx 2000$. For other cases, i.e. lower frequencies and/or higher amplitudes, $Re$ must increase for puffs to survive 3.

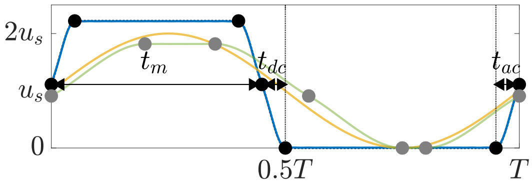

***Figure 1:*** *Example of three bulk velocities in our project. In blue one with small $t_m$, $t_{dc}$ and $t_{ac}$. In green with higher $t_m$, $t_{dc}$ and $t_{ac}$. In yellow a single harmonic sine wave pulsation.*

Different to steady pipe flow, pulsatile pipe flow is susceptible to intermittent transition. As observed in experiments, geometric defects can trigger sudden bursts of turbulence for $Re$ as low as $Re = 800$ at certain frequencies and amplitudes 4. These bursts start as helical structures that appear in the flow, that then collapse and trigger turbulence. The mechanisms behind the growth of these helical instabilities are different to the ones typically found in puffs in steady pipe flow. The helical instability depends on the frequency of the pulsation and its waveform. For some cases, they can grow exponentially and quickly trigger turbulence. It is still unclear whether puffs can take advantage of these mechanisms in pulsatile pipe flow too or not 5.

In this project we study the effect the pulsation shape has on turbulence dynamics in pulsatile pipe flow. We know that some shapes will be more likely to trigger the helical instability than others, but it is the interest of the project to determine which ones will be more or less detrimental for turbulence survivability.

To that end we perform Direct Numerical Simulations of pipe flow at $Re = 2000$. We perform simulations of pipe flow driven at different bulk velocities. In order to define the bulk velocities we follow these steps. We first set the position of six points (black or grey dots in figure 1) to represent the "skeleton" of the pulsation. Their position is controlled by the relative times $t_{ac}$, $t_{dc}$ and $t_m$, which are our control parameters. We then define a spline that captures the position of these points (using a pchip interpolation) in a smooth manner. We finally fit the spline using 30 Fourier modes.

Among all the possible combinations, we select 8 different cases, each with different bulk velocities (or different $t_{ac}$, $t_{dc}$ and $t_m$). For each case we perform a set of simulations where we trigger turbulence. We want to study turbulence survivability and turbulence dynamics using the results from the sets of simulations of each case. It is the ultimate goal of the project to define trends and characteristics that could lead to a future project on turbulence control using the pulsation waveform.

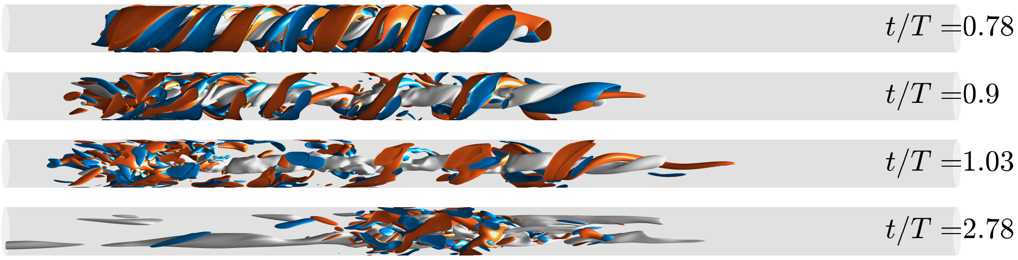

***Figure 2:*** *DNS of a helical instability as it triggers a long-living puff in a pulsatile pipe flow at* $Re = 2000$.

## WWW

`http://www.zarm.uni-bremen.de`

## More Information

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## Funding

DFG FOR 2688, Grant AV 120/6-1