OPTIMAL FORCING TO DESTABILISE TURBULENCE IN A PIPE FLOW

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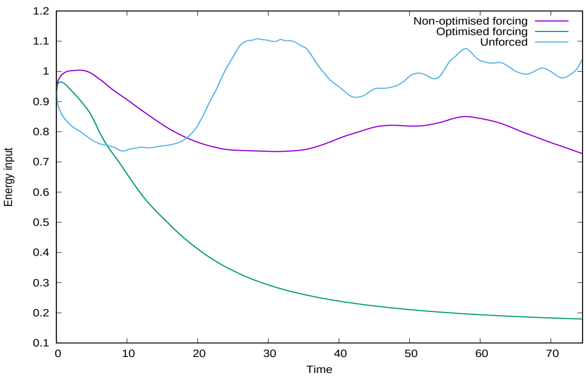
Recent experiments [1, 2] in pipe flow have shown that flattening the turbulent streamwise velocity profile destablises the turbulence so that the flow relaminarises. The flattening of the mean profile was obtained in the experiments by inserting a baffle in the core of the pipe. As a first step towards capturing this phenomenon theoretically, Marensi *et al.* (2019) [3] performed direct numerical simulations of pipe flows where the presence of the baffle was modelled by adding an artificial body force to the Navier-Stokes equations. The forcing was designed to mimic the drag experienced by the baffle as a linear damping, and the nonlinear stability of the laminar state was measured by the size of the energy of typical disturbances needed to trigger transition. With this simple form for the baffle, Marensi *et al.* (2019) [3] were able to predict enhanced nonlinear stability of the laminar state and significant drag reductions, both laminar and turbulent.

In an effort to push forward these encouraging first results, we construct a new fully nonlinear optimisation problem, whereby the 'minimal forcing', i.e. the forcing characterised by the lowest amplitude or the minimum work done against the flow, is sought to just destabilise the turbulence. Starting from a turbulent velocity field at $Re = 3000$ and suitable initial guesses for the forcing, an optimisation algorithm is developed that is able to optimise the forcing so that the flow relaminarises. The energy input, defined as the sum of the viscous dissipation and the work done by the forcing, is significantly reduced, as shown in the left graph of figure 1. The resulting optimal forcing, obtained with a variety of different initial guesses and for both short and long pipes, shows a strong radial localisation close to the wall, is axisymmetric and tend to be fairly independent of the streamwise direction too, at least for a short pipe. To better understand the optimal streamwise shape/modulation of the forcing, we use an analytical fitting for the optimal radial profile of the forcing and perform a parametric study on the effect of the streamwise extent of the baffle. In the long-pipe case we find that the energy input is minimised when the baffle is localised. Such 'optimal' forcing is shown in the right graph of figure 1. It is hoped that with this study we will be able to provide insights and guidelines to the experiments on how to exploit this promising direction of flow control in the most efficient way.



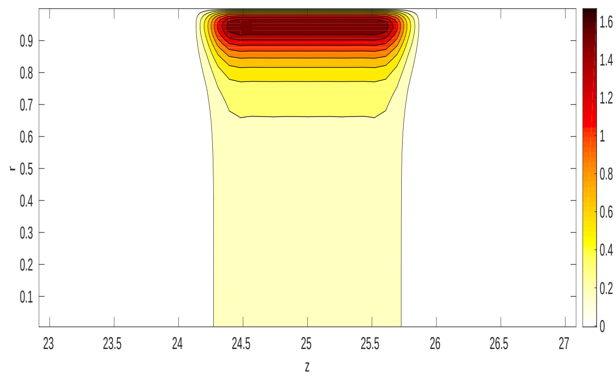


Figure 1. Left: Time series of the energy input with the optimised and non-optimised forcing and in the unforced case. Right: Cross section in the $r - z$ plane of the 'optimal' forcing in the long-pipe case obtained from the parametric study on the streamwise extent of the baffle using an analytical fitting for the radial profile of the forcing. The coordinates are non-dimensionalised with the radius of the pipe and only a streamwise section of the pipe is shown for visualisation reasons.

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References

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