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Data-driven modeling of the transition across equilibrium states in plane Couette flow

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We present a low-dimensional reduced order model for one of the well studied canonical shear flows, plane Couette flow. Above a certain Reynolds number, this flow admits nontrivial equilibrium solutions, which can be viewed as fixed points in the phase space of velocity fields. Besides equilibria, other distinguished solutions (such as periodic orbits or traveling waves) have also been discovered. Together, these simple invariant flows are called exact coherent states (ECSs).

These ECSs are the building blocks that organize general, more complicated flows. As a result, significant effort has been made to discover and model ECSs. Several reduced order models have been proposed to capture the ECSs and the connecting orbits between them. Examples include truncated modal projections of the governing Navier Stokes equations [1], or, more recently, methods motivated by machine learning [2]. While projection based approaches are able to capture relevant ECSs, it is a priori unclear how many modes need to be considered. On the other hand, popular data-driven methods, such as Dynamic Mode Decomposition (DMD), cannot describe coexisting ECSs [2].

Spectral submanifolds (SSMs) theory offers an alternative for reduced order modeling. Recently, these invariant manifolds were extracted purely from measurement data [3]. Here we apply these results to construct SSMs of simple ECSs of Couette flow.

We show that certain scalar functions of the flow can successfully parametrize the most important SSMs. These scalar functions are the rate of energy input and output and hence have direct physical relevance. The low-dimensional SSMs we extract from data serve as connections between the coexisting fixed point ECSs. By restricting the dynamics to these SSMs, we obtain accurate reduced order models, which then capture all asymptotic states of the full Navier Stokes equations.

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