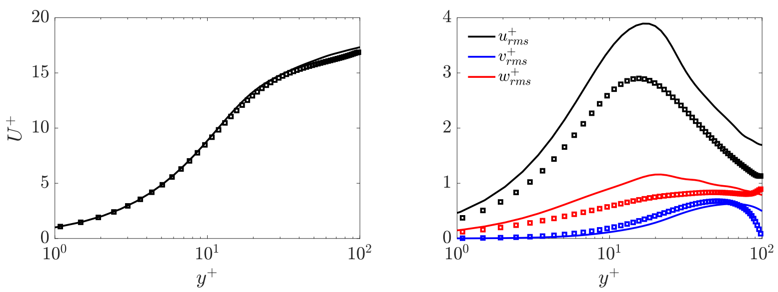
Reduced-order models of turbulent channel flow

Igor A. Maia[*], Petrônio A. S. Nogueira[†], André V. G. Cavalieri[‡]

We present reduced-order models (ROMs) for turbulent channel flow, derived through Galerkin projections of the incompressible Navier-Stokes (NS) equations onto suitable bases of spatial functions. Two choices of basis are tested: i) controllability modes of the linearised NS system; and ii) balanced modes. The projections are truncated to a few streamwise and spanwise wavenumbers, and we explore ROMs with a few hundred degrees of freedom, therefore much smaller than the full NS system. Similar models have been developed recently for Waleffe and Couette flow [1] [2], and have been shown to reproduce key aspects of nonlinear dynamics of wall-bounded turbulence. The present work is an extension of these models to channel flows.

The configuration is an open channel, with free-slip boundary conditions on the open surface. ROMs were obtained for a domain with streamwise and spanwise extents of $L_x = 2\pi$ and $L_z = \pi$, respectively. Direct numerical simulation (DNS) results, obtained for the same flow configuration using the code *channelflow*, are used as a reference to assess the accuracy of the model. Figure 1 shows mean and rms velocity profiles computed with a ROM obtained using 360 controllability modes, for a Reynolds number of $Re_\tau = 100$. The flow statistics computed with the ROM are found to be in reasonable agreement with the DNS, showing that the ROM is suitable to represent, to a large extent, the nonlinear dynamics of turbulence in the channel, despite the much lower number of degrees of freedom. This opens up possibilites to use them for understanding nonlinear dynamics and self-sustaining processes in wall-bounded turbulence and also to derive control laws.



(a) Mean-flow profiles (b) RMS velocity profiles

Figure 1: Flow statistics, computed for a ROM obtained with 360 controllability modes and $Re_\tau = 100$, and compared to DNS results.

---

[*]Divisão de Engenharia Aeroespacial, Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil

[†]Department of Mechanical and Aerospace Engineering, Laboratory for Turbulence Research in Aerospace and Combustion, Monash University, Clayton, Australia

[‡]Divisão de Engenharia Aeroespacial, Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil

[1]A. V. G. Cavalieri, *Phys. Rev. Fluids.*, **18**, 034610, (2021)

[2]A. V. G. Cavalieri and P. A. S. Nogueira, *Phys. Rev. Fluids.*, **7**, L102601, (2022)