1st European Fluid Dynamics Conference (EFDC1)
16 – 20 September 2024, Aachen, Germany

Mean Impulse Response in a Turbulent Channel Flow

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The mean linear response of a turbulent channel flow to a small enough, impulsive (in space and time) body force is defined and measured through direct numerical simulations, by considering a forcing placed in the continuous range of wall distances from the wall to the centerline. A zero- mean, white-noise body force is used to probe the turbulent flow, and the response function is obtained efficiently by accumulating the space-time correlation between the white forcing input and the velocity field obtained as output [1]. The output is a mean impulse response function tensor $\mathscr{H}_{f_i \to u_j}$, with i, j the streamwise x, wall-normal y and spanwise z direction. Three different responses are measured, at the same Reynolds number $Re_b = 2280$, for a laminar channel flow, a true turbulent channel flow and a channel flow where the mean velocity profile has the turbulent shape but no turbulence is present, as assumed by the resolvent analysis [2] The main outcome of the analysis is that the impulse response is anisotropic. The response largely changes depending on the couple input/output, on the regime i.e. laminar, pseudo-turbulent and turbulent, on the forcing location y_f and on the wavenumbers considered. Overall the diagonal components of the tensor ($i = j$) are the largest, followed by the components involving the response in streamwise direction, i.e. $\mathscr{H}_{f_y \to u_x}$ and $\mathscr{H}_{f_z \to u_x}$. Figure 1(left) plots the isosurfaces of the response $\mathscr{H}_{f_z \to u_x}$ for the three regimes at a fixed time forcing location. The structure resembles the low and high streaks typical of the near-wall turbulent cycle for all the three regimes, although the shape and the intensity do not perfectly match. We conclude that the dynamics of the turbulent structures is partly but not entirely linear. The linear impulse response function is also analysed in its evolution in time after considering the maximum over y_f, y and wavenumbers. Figure 1(right) shows $\mathscr{H}_{f_z \to u_x}$. All the three curves highlight a transient growth with the turbulent case having the smallest peak in the response and the fastest decay of the disturbance. This is due to the turbulent diffusion overcoming the amplification phenomena.

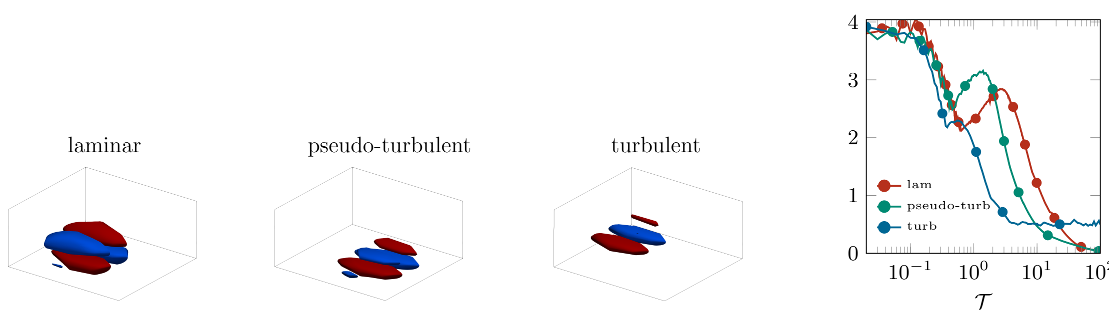

Figure 1: Left panel: isosurfaces of $+0.5$ (red) and -0.5 (blue) of the response $\mathscr{H}_{f_z \to u_x}$ for the three cases at bulk time $\mathscr{T} = 0.48$ for the forcing actuation place at $y_f = 0.1h$, with h the channel semi-height. Right panel: Absolute maxima $max(\mathscr{H}_{f_z \to u_x}(\mathscr{T}))$ over y_f, y and wavenumbers as a function of the bulk time.

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[1] Luchini et al., *Phys. Fluids.* **18** (2006).
[2] McKeon et al., *J. Fluid Mech.* **658** (2010).