On the origin of swirl-switching in 90°-bend pipe flow

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Swirl-switching is an oscillation of the Dean vortices with respect to the plane of symmetry of the curved pipe, and it has been observed in both spatially developing bent pipes[1] and infinitely curved ones[2]. There are, to the best of the authors' knowledge, several studies in the literature that investigate this phenomenon. In a recent one[1], it was shown that swirl-switching has a three-dimensional wave-like structure, albeit its cause is yet to be understood. The present work aims at understanding the physical mechanism that originates the swirl-switching. For this purpose, both linear and nonlinear direct numerical simulations (DNS) of the flow in a 90°-bend pipe are carried out using a spectral element code. The parameters governing the flow are the curvature δ, *i.e.* the ratio between the radius of the pipe cross-section and the radius of curvature of the bend, and the bulk Reynolds number Re_b, based on the bulk velocity, the diameter of the cross-section of the pipe and the kinematic viscosity. The 90°-bend flow under investigation is characterized by a curvature $\delta = 1/3$ and $Re_b = 11700$. At the first stage, a linear analysis of the turbulent mean flow is carried out, employing only the molecular viscosity, not taking into account the effect of the Reynolds stresses. The amplitude of the perturbations evolving on top of the mean flow is found to be decaying, and their spatial structure does not resemble that of the POD modes found in the previous works[1] (see Fig. 1 for a comparison).

Future work will therefore involve the use of an eddy-viscosity model in the linear analysis, to investigate the structural sensitivity of the swirl-switching modes. Moreover, a resolvent-based approach, coupled with modal decomposition techniques, will be used to investigate the input-output relationship between the swirl-switching modes and the nonlinear forcing.

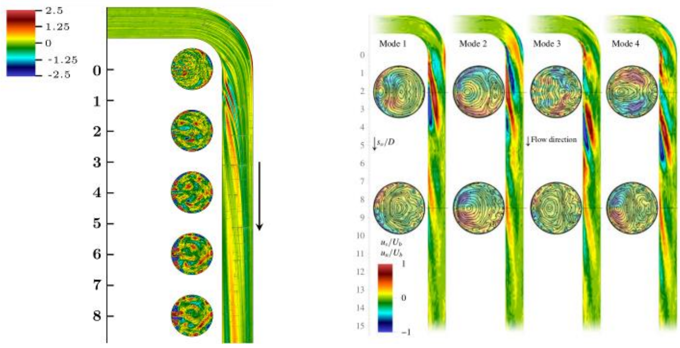

Figure 1: (left) Most unstable perturbation resulting from the linear analysis in the present work. (right) POD modes from Hufnagel et al. (2018)[1].

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[1] Hufnagel et al., *J. Fluid Mech.* **835**, 86 (2018).

[2] Noorani and Schlatter, *Int. J. Heat Fluid Flow,* **61**, 108 (2016)