Transitional and turbulent bent pipes

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Abstract:
In this talk, we discuss a number of different aspects of the transitional and turbulent flow in bent pipes, obtained at KTH using numerical simulations using the spectral-element code Nek5000. This flow is characterised by the appearance of so-called Dean vortices, which arise due to the action of the centrifugal force in the bend. We start with studying the stability properties of the toroidal pipe (*i.e.* an infinitely bent pipe without inflow or outflow); an extensive linear stability analysis shows that for all curvatures $\delta > 0$, exponentially growing waves can be found, at a bulk Reynolds number of about 4000. The resulting neutral stability curve [4] is shown in Figure 1, and will be compared to previous DNS and experiments.

When increasing the Reynolds number, the flow in a torus at low curvature goes through an interesting region where the measured pressure drop is in fact lower than for a straight pipe with the same bulk flow rate, and at times even lower than the laminar (steady) flow; we refer to these states as substraight and sublaminar drag [2]. For the latter case, we use POD analysis to explain the phenomenon.

When further increasing the Reynolds number, the fully turbulent regime [1] is reached. In this parameter regime, the so-called swirl switching, *i.e.* the periodic dominance of one Dean cell over the other, has been observed in experiments. We will use our numerical simulations to contribute to the understanding of the swirl switching: In a first step, we consider a toroidal pipe, and establish that even in the absence of upstream large-scale structures dominant frequencies resembling swirl switching can be observed [3]. In order to be able to directly compare to experimental studies, we also consider a spatially developing bent pipe [5], in particular a 90° bent pipe with fully developed turbulent inflow, see Figure 2. Extensive POD analysis, both in two-dimensional planes and full three dimensions, reveals the travelling-wave nature of the swirl switching. We compare our POD results to previous experiments, and highlight the importance of using the full velocity snapshots in order to extract correct modes, and thus a low-order description of the phenomenon.

References

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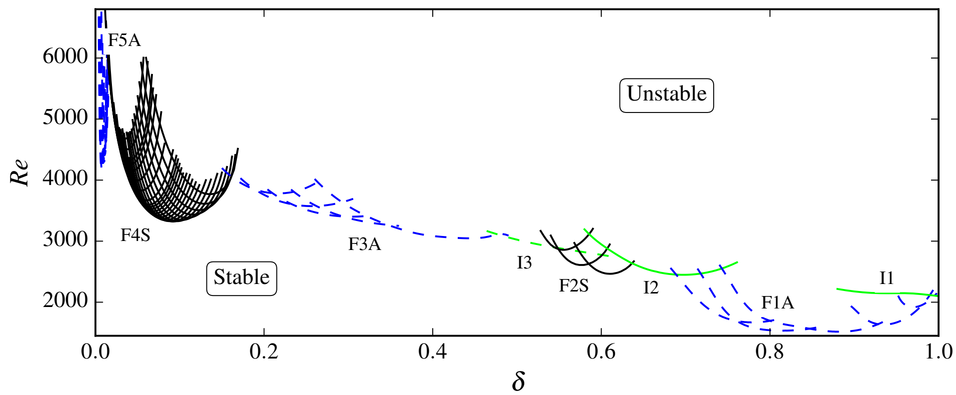

Figure 1: *Neutral curve in the* $\delta - Re$ *plane.* $\delta \in [0.002, 1]$*. Each line corresponds to the neutral curve of one mode. The neutral curve for the flow is formed by the envelope of the lines. Five families (black and blue) and three isolated modes (green) are marked by labels. Symmetric modes are indicated with continuous lines while antisymmetric modes are represented with dashed lines. Note that the curves are not interpolated, i.e. they are segments connecting computed solutions with* $\Delta\delta = \mathcal{O}(10^{-3})$*. The uncertainty on the Reynolds number is* $\pm 10^{-4}\%$*. Taken from Ref. [4].*

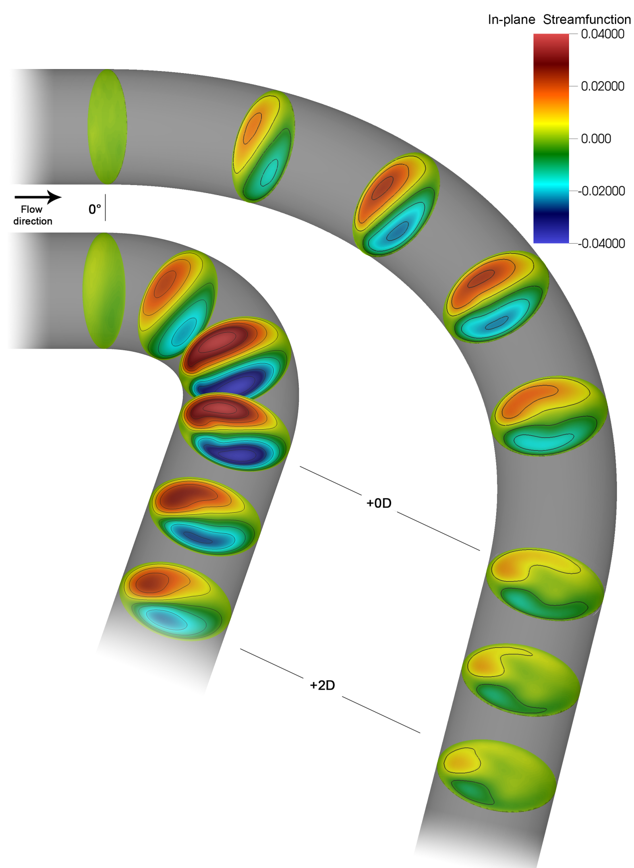

Figure 2: *Formation of Dean vortices in the spatially developing* $90°$ *bent pipe, visualised by in-plane streamfunction (*$Re_b = U_b D/\nu = 11700$*) (Left)* $\delta = 0.3$*, (right)* $\delta = 0.1$*. Taken from Ref. [5].*