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# Direct numerical simulation of a turbulent Couette-Poiseuille flow, part 2: Large- and very-large-scale motions

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ABSTRACT

A direct numerical simulation dataset of a fully developed turbulent Couette-Poiseuille flow is analyzed to investigate the spatial organization of streamwise velocity-fluctuating $u$-structures on large and very large scales. Instantaneous and statistical flow fields show that negative-$u$ structures with a small scale on a stationary bottom wall grow throughout the centerline due to the continuous positive mean shear, and they penetrate to the opposite moving wall. The development of an initial vortical structure related to negative-$u$ structures on the bottom wall into a large-scale hairpin vortex packet with new hairpin vortices, which are created upstream and close to the wall, is consistent with the auto-generation process in a Poiseuille flow (Zhou *et al.*, *J. Fluid Mech.*, vol. 387, 1999, pp. 353–396). Although the initial vortical structure associated with positive-$u$ structures on the top wall also grows toward the bottom wall, the spatial development of the structure is less coherent with weak strength due to the reduced mean shear near the top wall, resulting in less turbulent energy on the top wall. The continuous growth of the structures from a wall to the opposite wall explains the enhanced wall-normal transport of the streamwise turbulent kinetic energy near the centerline. Finally, an inspection of the time-evolving instantaneous fields and conditional averaged flow fields for the streamwise growth of a very long structure near the centerline exhibits that a streamwise concatenation of adjacent large-scale $u$-structures creates a very-large-scale structure near the channel centerline.

## 1. Introduction

For several decades, turbulent pure Couette flows or Couette-Poiseuille flows have received much attention in the area of fluid mechanics because such flows are present whenever a wall moves toward the flow direction (e.g., turbulent bearing films). These flows are known to be beneficial because they are characterized by more efficient diffusion and less resistance than pure Poiseuille (i.e., pipe/channel) flows (Orlandi et al., 2015). Because the fundamental mechanisms of heat and momentum transfers are mostly affected by the dynamics of turbulent coherent structures, research on structures in Couette-Poiseuille flows will improve our understanding of turbulent structures in pure Poiseuille flows.

### 1.1. Turbulent Poiseuille and boundary layer flows

Experimental and numerical studies have reported that large-scale motions (LSMs) and very-large-scale motions (VLSMs) contribute significantly to the generation and transport of the streamwise turbulent kinetic energy and the Reynolds shear stress in turbulent Poiseuille flows and turbulent boundary layer (TBL) flows. Falco (1977) first identified LSMs as a generalization of the bulges in a turbulent/non-turbulent interface that were known to occur at the edges of turbulent boundary layer flows with streamwise lengths of 1–3$\delta$ (Kovasznay et al., 1970; Adrian et al., 2000), where $\delta$ is the appropriate outer length scale in the channel, pipe and boundary layer flows without distinction. The largest, outermost hairpin packets in the hierarchy are known to resemble LSMs. In a direct numerical simulation (DNS) study of a turbulent channel flow at a low Reynolds number, Zhou et al. (1999) found that if an initial vortical structure, similar to a hairpin vortex, is sufficiently strong in a mean turbulent field, the evolution of the initial structure generates new hairpin vortices both upstream and downstream of the primary hairpin vortex, creating a hairpin vortex packet. Experimental studies of the spatial organization patterns of hairpin vortex packets in wall-bounded turbulent flows have shown that hairpin vortices are often aligned in the streamwise direction, creating an elongated low-momentum region

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