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Direct Numerical Simulation of turbulent Non-Newtonain flow in a rod-roughened channel

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Abstract — Direct numerical simulation are performed for fully-developed flow of power law fluids in a planar channel with rod-roughened walls. Validation is initially performed by investigation the case of Newtonian flow (power index of 1) and comparing with literature data. The results showed that the velocity profile in wall coordinates has a negative shift (to lower values of u+) consistent with the increased drag even for the shear-thinning fluids. However, the overall log law is higher than the Newtonian case because of shear thinning effect.

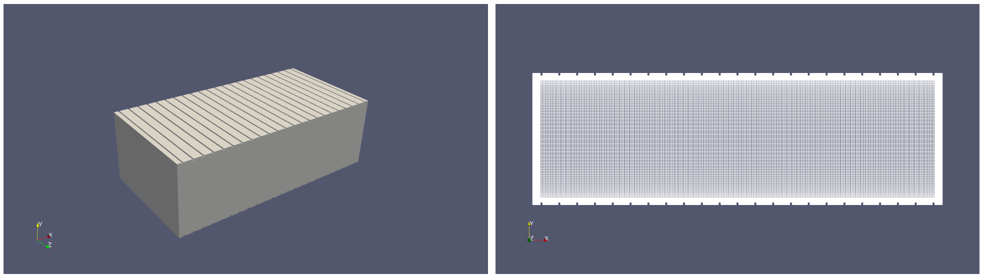
1. Introduction

All ducts have some sort of wall roughness and when the roughness exceeds some size it has an impact on the flow characteristics and increase friction, as is well known. Hence, it is of utmost importance to be able to predict the flow behaviour in roughened ducts and the physics of its flow. Performing experiments on roughened ducts is not easy becasue of the need to control well the flow conditions, wall roughness and of the inherent inhomogeneity of wall turbulence (Ashrafian 2004). Therefore the development of accurate numerical method and of fast computaional resource have turned the direct numerical simulation (DNS), and large eddy simulation (LES), of such flows reliable alternatives. Since DNS considers all flow scales from the kolmogorov dissipative scales to the large scales imposed by geometry, which contains most kinetic energy of flow, it can capture accurately all physical mechanisms which are needed to understand this flow. Wood et al. (1975), Grass et al. (1993), Djenidi et al. (1999) and Antonia et al. (2001) are some of the works on the effect of roughness on turbulent boundary layer and associated mechanisms.

Several methods have been developed impose roughness, such as immersed boundary method (Nimwegen, 2010) or the detailed geometric description of the roughness. However, even though real roughness tends to have an irregular shape, it is often represented by some regular form. All these works focused only on Newtonian fluid flows, and very little is known when the rheology is non-Newtonian, as far as we are aware of. Some researchers applied an array of transverse bars (Jimenez, 2004), others modelling it using sin functions Bhaganagar et al.(2008) or other forms such as the square rods Ashrafian et al. (2004) In this work, we study the roughness effect on channel flow of Generalized Newtonian Fluids in which the viscosity function is described by the power law. The roughness is regular as represented by rod squares as wall boundary condition.

2. Problem Definition

The geometry of is the planar channel as shown in figure 1. The three dimensional domain size is $(2\pi,2,\pi)$ and equal distanced-block shaped roughness elements, with heights of 0.034 applied at both. The roughness is K-type (the cavity width is larger than the height). With the detailed roughness represented exactly, the condition is applied and for this purpose a utility was developed to generate the required mesh,



(a) roughed channel (b) Girds of domain

Figure 1: Schematic of computational domain

The viscosity of the Generilized Newtoninan fluid is given by power law model is considered ($\eta = K\dot{\gamma}^{(}n - 1)$). Where K is the consistency index and n stands for power index. For $n = 1$ the Newtonian fluid is recovered, while for $n < 1$ the fluid is shear-thinning. In this study flow indices 1, 0.75 and 0.5 are considered.

3. Results and Discussion

Our preliminary results are shown in Fig. 2. The mean velocity profile for one Newtonian case and one shear-thinning flow are plotted. Also the law of the wall is shown for the Newtonian case (in presence of the roughness function), which verifies the accuracy of our simulations. As expected by introducing the roughness, the velocity profile moves downward even for the shear-thinning fluids. however, due to shear thinning the overall log law is higher than the Newtonian case.

One of the goals of the present study is to find the functional form of this roughness function for the power-law fluids.

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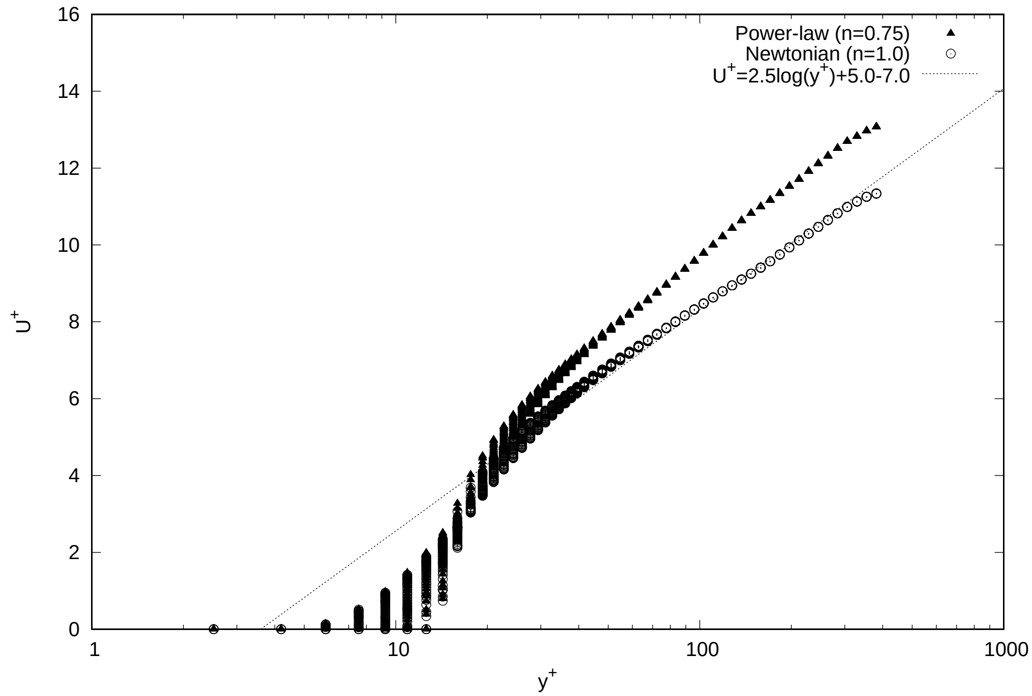

Figure 2: Mean velocity profile for Newtonian and power-law flow with Re=395 in duct with roughened wall.

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