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# Large Eddy Simulation of particle-laden turbulent channel flows with isotropic or non-isotropic wall roughness

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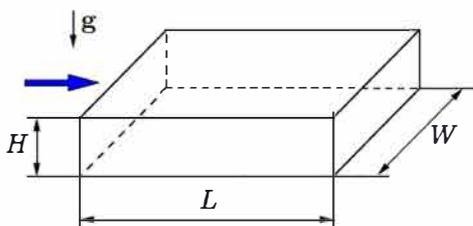
**Keywords:** Large eddy simulations, particle-laden flows, particle-wall interaction, rough wall, stochastic models

## Abstract

In particle-laden flows, particles rebound from rough wall can influence significantly properties of particle and fluid phase which can be important in number of industry processes. 2D stochastic procedures for such a rebound have been developed for representing the effect of wall roughness although such mechanism is generally 3D due to the particle incident velocity and roughness geometry. Therefore we have developed a general approach allowing to represent the 3D particle bouncing on isotropic or non-isotropic rough wall. Thus effect of the isotropic and non-isotropic roughness is evaluated using DPS/LES in horizontal channel flow. Inter-particle collisions are calculated using soft sphere model. Different LES subgrid models of pure fluid flow are examined and influence of subgrid turbulent fluid velocity on particle statistics is evaluated. Detailed information regarding particle velocity statistics are discussed with respect to wall roughness characteristics.

## 1 Simulation setup

Channel geometry (Fig. 1) and experimental setup are taken from Sommerfeld and Kussin (2004). Bulk flow velocity of air is  $U_b = 20$  m/s, and Reynolds number of flow is approximately around  $Re \approx 43,000$ . Dimensions of horizontal channel used in experiments are 6 m x 35 mm x 350 mm in streamwise, wall normal and spanwise directions. To reduce computational cost, computational domain for LES simulation is smaller: 140 mm x 35 mm x 52.5 mm.



**Figure 1:** Geometry of channel used in LES:  $L = 140$  mm,  $H = 35$  mm,  $W = 52.5$  mm.

Mesh consists of single block structured mesh of 3,067,200 cells. Number of cells in  $x$ ,  $y$ , and  $z$  direction are, respectively, 135x160x142. Cells are uniform in streamwise and spanwise direction while mesh is graded in wall normal direction, with ratio of height of cell at the center of channel and height of first cell next to the wall equal to  $r = 37$ .

Periodic boundary conditions are applied in streamwise and spanwise directions. For top and lower wall are applied no slip velocity conditions and zero Neumann pressure

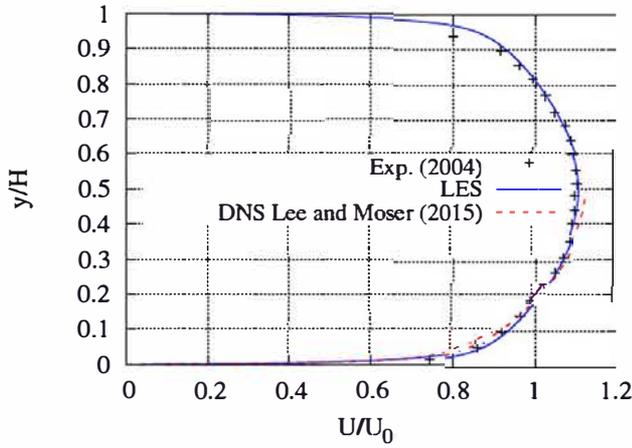
conditions. Central differencing scheme is used for space discretization and backward second order implicit scheme is used for temporal discretization. Simulations are carried out in OpenFOAM. PISO algorithm is used for pressure-velocity coupling. After approximately 50 flow-through times, when it is assumed that statistically steady state is reached, velocity is averaged in time until convergence is achieved, which is followed by spatial averaging in streamwise and spanwise direction.

## 2 Results and discussion

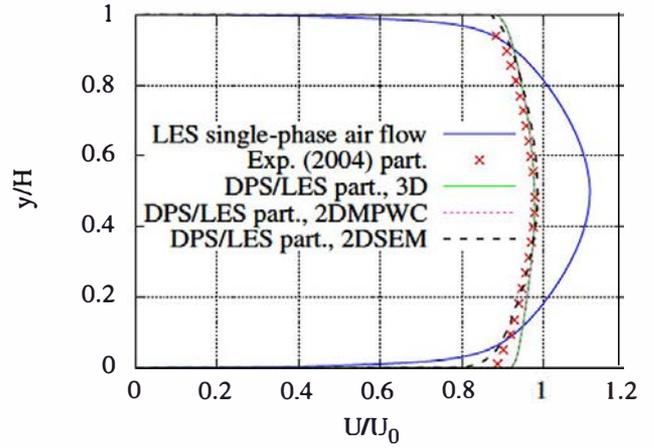
In Fig. 2a are compared results of LES for single-phase fluid flow, using Smagorinsky model with Van Driest damping near wall, results of DNS analysis of Lee and Moser (2015) and experimental results for single-phase fluid flow of Sommerfeld and Kussin (2004). Agreement is very good.

Comparison of RMS velocity fluctuations with experimental results of Sommerfeld and Kussin (2004) and results of DNS of Lee and Moser (2015) is shown in Fig. 2b. Small discrepancies between LES which could be attributed to the fact that the contribution of subgrid scales misses in shown RMS of velocity fluctuations.

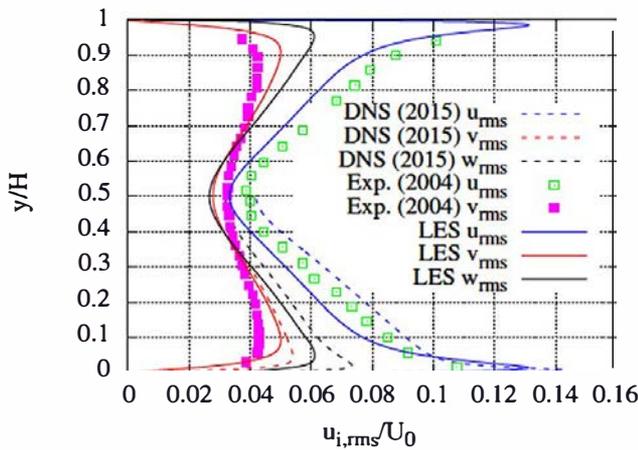
In Fig. 3a are shown particle mean velocity profiles obtained by DPS/LES with different stochastic models for particle rebound from rough wall and in Fig. 3b are shown particle RMS velocity fluctuations. In simulations, whose results are shown in Fig. 3, particles have diameter  $130 \mu\text{m}$  and mass loading ratio is 1 (ratio of mass flow of particles and mass flow of fluid). Inter-particle collisions are neglected, i.e. one-way coupling is applied. These models are com-



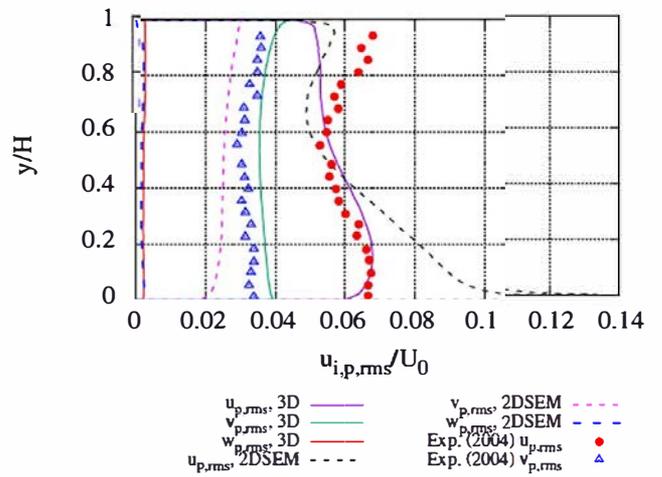
(a)



(a)



(b)



(b)

**Figure 2:** Mean velocity profile of single-phase fluid flow (Fig. a) and RMS velocity fluctuations of single-phase fluid flow (Fig. b).

pared to results of the available experimental measurements of Sommerfeld and Kussin (2004). Discrepancy between results can be due to the subgrid scale effect but also owing to the inter-particle collision effects which are not accounted for in the actual simulation, especially for transverse rms velocity fluctuation  $w_{p,rms}$  which will increase drastically due to collision redistribution effect.

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**Figure 3:** Velocity profile of single-phase fluid flow obtained with LES, particle velocity profile from experiment of Sommerfeld and Kussin (2004) and particle velocity profiles from DPS/LES simulations with different particle-wall rebound models: 3D isotropic model Radenkovic and Simonin (2018), 2D stochastic model Konan et al. (2009) (2DMPWC) and 2D shadow effect model Sommerfeld and Huber (1999) (2DSEM) (Fig. a) and particle RMS velocities (Fig. b).

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