



**HAL**  
open science

# DSMC of fully developed turbulent particle-laden channel flow with non-elastic frictional wall bouncing

Pascal Fede, Olivier Simonin

► **To cite this version:**

Pascal Fede, Olivier Simonin. DSMC of fully developed turbulent particle-laden channel flow with non-elastic frictional wall bouncing. 10th International Conference on Multiphase Flow (ICMF 2019), May 2019, Rio de Janeiro, Brazil. hal-03624069

**HAL Id: hal-03624069**

**<https://hal.science/hal-03624069v1>**

Submitted on 30 Mar 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



## Open Archive Toulouse Archive Ouverte

OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible

This is an author's version published in: <http://oatao.univ-toulouse.fr/26722>

**To cite this version:**

Fede, Pascal and Simonin, Olivier DSMC of fully developed turbulent particle-laden channel flow with non-elastic frictional wall bouncing. (2019) In: 10th International Conference on Multiphase Flow, 19 May 2019 - 24 May 2019 (Rio de Janeiro, Brazil). (Unpublished)

Any correspondence concerning this service should be sent to the repository administrator: [tech-oatao@listes-diff.inp-toulouse.fr](mailto:tech-oatao@listes-diff.inp-toulouse.fr)

# DSMC of fully developed turbulent particle-laden channel flow with non-elastic frictional wall bouncing

Pascal Fede, Olivier Simonin

Institut de Mécanique des Fluides de Toulouse (IMFT), Université de Toulouse, CNRS, Toulouse, France

Allée du Professeur Camille Soula, Toulouse, 31400, France

pascal fede@imft.fr

**Keywords:** DSMC, frictional wall bouncing

## Abstract

Direct Simulation Monte Carlo (DSMC) have been used to predict the statistics of solid particles transported by a fully developed turbulent channel flow. The particle inertia was large allowing to neglect the turbulent dispersion by the fluid motion. However, the particle volume fraction is sufficient large for observing an effect of the inter-particle collisions on the particle dynamics. In contrast, the solid mass loading remains low so that the modification of the fluid phase by the presence of the particles is neglected. In a previous study we showed that DSMC provided accurate statistics of the particulate phase but in the near-wall region the deterministic simulation by Discrete Element Method (DEM) exhibit an increase of the particle concentration. Such an effect, called wall shelter effect, is not taken into account in standard DSMC. Here we introduce a new Monte Carlo algorithm for taking into account the wall shelter effect by a direct modification of the collision kernel and we compare the results to another method based on the addition of a wall-force. The effects of non-elastic and frictional bouncing with walls are also investigated.

## Introduction

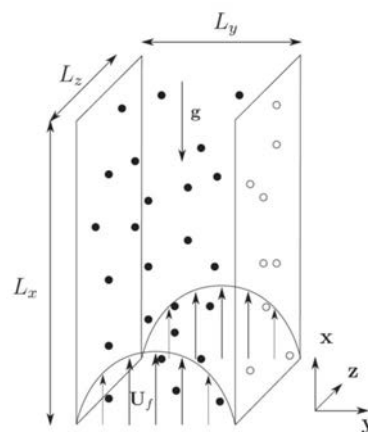
Particle-laden flows are found in a wide range of practical applications from geophysical flows (sediment transport, pyroclastic flow, volcano ashes dispersion ...) to industrial applications (solid fuel combustor, catalytic reactor) and passing by medical applications (medicament aerosol inhalation). Even if many complex phenomena take place in particle-laden turbulent flows, the current study put the focus on the inter-particle collisions and particle bouncing with smooth frictional walls.

Basically several methods can be found to perform numerical simulations of particle-laden flow differing in terms of accuracy and computational cost. Stochastic Lagrangian algorithm is one of those methods and consists in the Lagrangian tracking of numerical particles (called parcels) and in the using of Direct Simulation Monte Carlo (DSMC) for taking into account the inter-particle collisions (Sommerfeld, 2001).

Recently, following the results obtained by Sakiz (1999) with Discrete Element Method (DEM), Fede & Simonin (2018) showed that DSMC fails to account for the wall shelter effect due to the wall-normal unbalanced inter-particle collisions influence induced by the presence of the wall. The authors proposed to add a wall-force for taking into account the wall shelter effect. The wall-force model being derived from the moment approach and then require some closure model. In the present study we propose a new algorithm for taking into account the wall shelter effect by a direct modification of the collision kernel in the near-wall region. The effect of the wall-boundary condition is also analyzed by using such an algorithm.

## Configuration and numerical method

The configuration is a fully developed turbulent channel flow. The domain is periodical in  $x$ - and  $z$ -direction. Two walls are placed on  $y$ -direction (see Figure 1). The fluid velocity profile is imposed and comes from a previous numerical simulation with a  $k - \varepsilon$  model.



**Figure 1:** Configuration where  $L_x = 240\text{mm}$ ,  $L_y = 40\text{mm}$  and  $L_z = 32\text{mm}$  (From Fede & Simonin, 2018)

The particles are assumed spherical with a diameter  $d_p$  and with a large particle-to-fluid density ratio. In such a framework, only the drag force and the gravity are acting on the particles motion,

$$\frac{d\mathbf{u}_p}{dt} = -\frac{\mathbf{u}_p - \mathbf{u}_{f@p}}{\tau_p} + \mathbf{g} \quad (1)$$

where  $\mathbf{u}_p$  is the particle velocity,  $\mathbf{u}_{f@p}$  the fluid velocity,  $\mathbf{g}$  the gravity and  $\tau_p$  the particle relaxation timescale.

When two particles  $p$  and  $q$  collide their velocities are changed by using the hard-sphere model

$$\mathbf{u}_p^* = \mathbf{u}_p + \frac{1 + e_c}{2} (\mathbf{w} \cdot \mathbf{k}) \mathbf{k} \quad (2)$$

$$\mathbf{u}_q^* = \mathbf{u}_q - \frac{1 + e_c}{2} (\mathbf{w} \cdot \mathbf{k}) \mathbf{k} \quad (3)$$

where  $\mathbf{w} = \mathbf{u}_p - \mathbf{u}_q$  is the relative velocity,  $\mathbf{k}$  the unit vector linking the centers of the two particles and  $e_c$  the normal restitution coefficient.

### Direct Simulation Monte Carlo (DSMC)

The DSMC approach is based on a statistical description of the gas-particle turbulent flows. The dispersed phase is described by the Probability Density Function (PDF)  $f_p(\mathbf{c}_p, \mathbf{x}; t)$ . In such a framework, it is possible to obtain a Boltzmann-like transport equation

$$\frac{\partial f_p}{\partial t} + c_{p,i} \frac{\partial f_p}{\partial x_i} + \frac{\partial}{\partial c_{p,i}} \left[ \left\langle \frac{du_{p,i}}{dt} \middle| \mathbf{c}_p \right\rangle f_p \right] = \left( \frac{\partial f_p}{\partial t} \right)_{col} \quad (4)$$

where the right-hand-side is the modification of the PDF by inter-particle collisions. In Eq. (4),  $\mathbf{c}_p$  is a realization of the particle velocity and  $\frac{du_{p,i}}{dt}$  is the force, per unit of mass, experienced by the particles. In DSMC the PDF is approximated by a sum of Dirac. In such an approximation, the particles are represented by numerical particles, also called parcels, where each parcel represent  $\omega_i$  real particles. Stochastic Lagrangian simulation contains two steps. First a free-flight step where the left-hand-side of Eq. (4) is solved and a second step for the collision operator. The standard Monte Carlo (MC) algorithm can be described as:

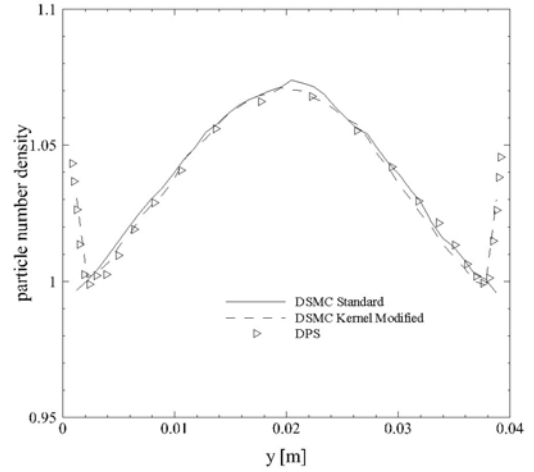
1. the parcels are randomly paired and the probability of collision is computed for each pair.
2. A rejection method is used to determine the occurrence of the collision or not.
3. If the collision occurs an impact vector ( $\mathbf{k}$ ) is randomly built and the parcel velocity are modified according to Eqs. (2) & (3).

In the new algorithm the third step is modified. Using the random impact vector, the virtual position of the colliding particle is computed and if such a position is not in the computational domain the velocity of the paired particle is not modified.

### Results and Discussion

Figure 2 shows the mean particle density number obtained by DEM (Sakiz & Simonin, 1998), by standard DSMC and by the new algorithm. The case corresponds to particle with a diameter of  $1500\mu\text{m}$ , a density of  $1032 \text{ kg/m}^3$  and the bulk solid volume fraction is  $\bar{\alpha}_p =$

$1.4 \times 10^{-2}$ .



**Figure 2:** Normalized mean particle number density across the channel for  $e_c = 1$ ,  $e_w = 1$  and  $\mu_w = 0$ .

As shown by Figure 2, in the near-wall region we can observe an increase of the mean particle number density. Such a wall shelter effect comes from the wall-normal unbalanced inter-particle collisions induced by the presence of the wall. It can be observed that the new algorithm is able to take into account this effect just by a direct modification of the algorithm and without addition of model as proposed by Fede & Simonin (2018).

### Conclusions

A new algorithm is introduced for taking into account the wall shelter effect. The results are compared to DEM and to DSMC predictions using a wall force for modelling the wall shelter effect. The study also investigates the effects of the non-elastic and frictional bouncing in particle-laden turbulent flows.

### References

- Fede, P., Simonin, O., Villedieu, P. Monte-Carlo simulation of colliding particles or coalescing droplets transported by a turbulent flow in the framework of a joint fluid-particle pdf approach. *Int. J. Multiphase Flow*, Vol 74, 165–183 (2015).
- Fede, P., Simonin, O. Direct Simulation Monte-Carlo predictions of coarse elastic particle statistics in fully developed turbulent channel flows: Comparison with deterministic discrete particle simulation results and moment closure assumptions. *Int. J. of Multiphase Flow*, 25-42, (2018).
- Sakiz, M.; Simonin, O. Continuum modelling and Lagrangian simulation of the turbulent transport of particle kinetic stresses in a vertical gas-solid channel flow, *Proc. 3rd ICMF* (1998).
- Sommerfeld, M. Validation of a stochastic lagrangian modelling approach for inter-particle collisions in homogeneous isotropic turbulence. *Int. J. Multiphase Flow* 27, 1829-1858, (2001).