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Statistics of Particle Suspensions in Turbulent Channel Flow

Lihao Zhao* and Helge I. Andersson

Fluids Engineering Division, Department of Energy and Process Engineering, Norwegian University of Science and Technology, 7491 Trondheim, Norway.

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Abstract. Particle dynamics in a turbulent channel flow is considered. The effects of particle concentration and Reynolds number on the particle velocity statistics are investigated. Four different particle response times, τ^+=1, 5, 30 and 100, are examined for three different Reynolds numbers, Re_*=200, 360 and 790 (based on channel height and friction velocity). The particle concentration evolves with time and statistics obtained during three different sampling periods might be distinctly different. The mean and fluctuating particle velocities are substantially affected both by the particle response time and by the Reynolds number of the flow.

AMS subject classifications: 76T15, 76F10, 76F65

Key words: Spherical particles, DNS, turbulence, sampling, Reynolds number effects.

1 Introduction

Solid spherical particles suspended in fluid turbulence are commonly encountered both in nature and industry, e.g. in sand storms, pollution in the atmosphere, in pneumatic transport and so on. The study of particles suspended in a carrier fluid has been an active area of research during several decades along with the development of computer resources and experiment technologies [1,2]. It is commonly known that inertial particles will not follow the flow totally passive. Due to the inertial effect, there is a certain amount of slip velocity between particles and the local fluid flow. In other words, the inertial solid particles have a tendency to concentrate around locally calm regions [1]. In the channel flow case, for example, the particles tend to accumulate in the near-wall region and the greater the inertia of particles, the longer time is needed to achieve a steady state of the particle concentration. Several investigations have focused on the particle deposition and

*Corresponding author. *Email addresses:* `lihao.zhao@ntnu.no` (L. H. Zhao), `helge.i.andersson@ntnu.no` (H. I. Andersson)

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particle preferential concentration in wall turbulence or homogenous turbulence, see for instance Pedinotti *et al*. [2], Soltani and Ahmadi [3], Marchioli and Soldati [4], Narayanan *et al*. [5] and Picciotto *et al*. [6]. To obtain better understanding of particle transport and particle velocity statistics, several studies were reported by Marchioli and Soldati [4], Kulick *et al*. [7]. and Geashchenko *et al*. [8].

Depending on the particle volume fraction, there are several ways to make the coupling between the particle phase and the fluid phase, i.e. as one-way, two-way or four-way coupling, as defined by Elghobashi [9]. With *one-way* coupling, e.g. [4, 6], the particles are driven by the local flow, but there is no feedback effect from particles on the fluid. This approach is suitable for sufficiently dilute suspension flows when the particle volume fraction is small. *Two-way* coupling means interactions between the particle phase and the fluid phase based on Newtons third law, while *four-way* coupling not only considers the interaction between particles and fluid, but also includes the effect of inter-collisions among the particles themselves. Several investigations with two-way coupling, like Squires and Eaton [10] and Elgobashi and Truesdell [11] in homogeneous turbulence, Pan and Banerjee [12] and Zhao *et al*. [13] in wall-bounded turbulence, focus on the modulations of turbulence by the presence of particles. The present work is confined to one-way coupling as we assume a dilute suspension of the particles in the carrier fluid and focuses on the Reynolds number effect on the particle transport and particle depositions.

During the last two decades direct numerical simulations (DNSs) have become a powerful tool in the research of turbulent flow of particle suspensions, for example DNS simulations of particle-laden homogeneous and isotropic turbulence [10, 11] and also of particulate turbulent channel flow [2–4, 12, 13]. However, all these simulations were carried out at fairly low Reynolds numbers, most likely due to limitations of the available computer capacity.

In the present investigation a dilute suspension of solid particles in a turbulent channel flow is simulated with an Eulerian-Lagrangian approach where the fluid flow is obtained by means of DNS. In Section 2, the treatment of the flow and the particles is described. Results for four different particle categories are presented and compared in Section 3.1 for one particular Reynolds number whereas results for three different Reynolds numbers are presented in Section 3.3. The highest Reynolds number considered is substantially higher than in earlier DNS studies of particle-laden channel flows [2–6, 12, 13]. The major findings are discussed and summarized in Section 4, notably in view of the influence of the particle concentration on the velocity statistics.

2 Mathematical modeling and computational details

In the present work we consider the motion of tiny spherical particles in a turbulent plane channel flow. The equations governing the flow field and particle motion are simultaneously integrated forward in time. The flow solver and the particle treatment is the same as that used by Mortensen *et al*. [14, 15].