NUMERICAL INVESTIGATIONS OF COLLIDING PARTICLES IN SPATIALLY DECAYING TURBULENCE

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Abstract Numerical studies [10, 1] show that the influence of gravity and turbulence on the motion of small and heavy particles is not a simple superposition. However, in [9] it is shown that these studies may be artificially influenced by the turbulence forcing scheme. In the present study, a new numerical setup to investigate the combined effects of gravity and turbulence on the motion and collision probability of small and heavy particles is presented, where the turbulence is only forced at the inflow and is advected through the domain by a mean flow velocity. Within a transition region the turbulence develops to a physical state which shares similarities with grid-generated turbulence in wind tunnels. In this flow, trajectories of about 43 million particles are advanced in time. It is found that for specific particle inertia the particles fall faster in a turbulent flow compared with their fall velocity in quiescent flow. These results are in agreement with the theory in [4]. Additionally, specific regions within the turbulent vortices cannot be reached by the particles as a result of the particle vortex interaction. Therewith, the particles tend to cluster outside the vortices, which is called preferential concentration. Both effects alter the particle collision probability.

INTRODUCTION

Heavy particles transported in turbulent carrier flows are important for several applications. However, quantitative physical explanations for some phenomena are still missing. This is mainly due to the large range of scales involved. In numerical simulations the dissipation range has to be fully resolved since the particle motions are mainly governed by the smallest scales of turbulence. To the authors' knowledge the highest Re_λ concerning particle-laden turbulent flows was reached in [3]. Based on these data physical explanations for the phenomena of particle clustering were found. However, the influence of gravity on the particle phase was neglected in this study. In [5] it is pointed out that the fall velocity of the heavy particle significantly shortens the particle vortex interaction time and therewith the presence of gravity alters the preferential concentration effect. This is numerically supported by [10].
All numerical studies in the literature concerning isotropic turbulence utilize the same generic periodic setup wherein the largest scales of turbulence are forced. In [9] it was recently shown that this could be problematic because the preferential concentration depends on the employed large scale forcing scheme. Therefore a completely different setup is presented.

SETUP AND FLOW PHASE

The flow field generated in this study shares similarities with grid-generated turbulence in wind tunnel experiments. A slice through the domain is shown in Fig. 1. A detailed description can be found in [6]. Only at the inflow plane synthetically generated turbulent fluctuations $\mathbf{u}'$ are added to the mean advection velocity $\mathbf{U}$ using a method following [2]. Downstream the turbulent kinetic energy k decays due to viscous damping. Figure 2 (a) shows the dissipation rate ϵ over the streamwise coordinate x in a logarithmic plot. It can be seen that ϵ is nearly constant at the inflow, but further downstream it decays with the theoretical decay exponent for grid turbulence of -2.3 [8]. All statistic volumes are located inside this region. Figure 2 (b) shows a one-dimensional velocity spectrum at the position of the first statistic volume. The -7 law of the dissipation range down to the Kolmogorov length is well resolved. The inertia range is rather small. Re_λ has a value of around 20, weakly depending on the spatial location. There is no restriction to scale up the current method to reach higher turbulent intensities besides the larger computational effort. The dependency of the results on the dissipation rate can be checked with a single computation. The turbulence decays spatially and therewith the particles are advected through areas of different turbulence intensities.

PARTICLE PHASE AND RESULTS

The particles considered here are small and heavy. Within this limit the equation of motion can be greatly simplified [7]. A total number of about 45 million particles in 20 different radii classes are advanced simultaneously in the turbulent flow described above. The particle Stokes number St is used to characterize particles in turbulent flows. Dávila and Hunt [4] suggest to rescale the St to a so-called Particle Froude number to take into account the altered interaction time between the turbulent vortices and the particle due to the gravitational settling of the particle. In Fig. 3 the difference between the averaged turbulent and the laminar falling velocities is plotted over the particle Froude number and with respect to the dissipation rate ϵ. For $F_p \sim 1$ particles fall faster, the stronger the turbulence of the carrier fluid is, because the particles preferentially pass vortices on their downward motion side. For $F_p > 40$ the effect is inversed and weaker. It fits exactly

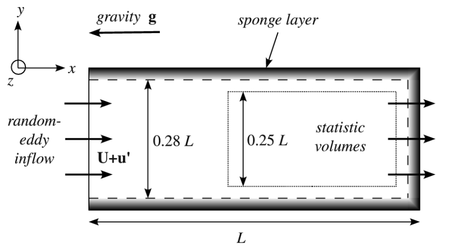

Figure 1. Sketch of the domain setup. The z and the y layout are the same.

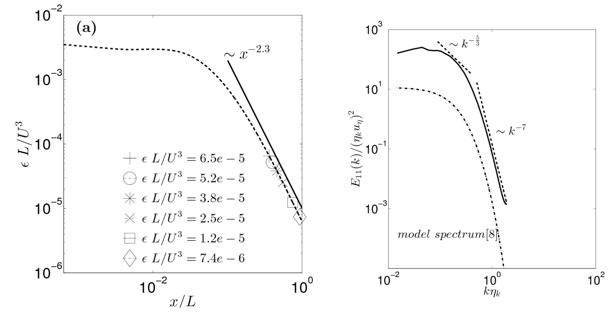

Figure 2. Flow field characterization: (a) Streamwise evolution of the turbulent kinetic energy dissipation rate ϵ. (b) One-dimensional energy spectrum of the simulated turbulence at the position of the first statistic volume.

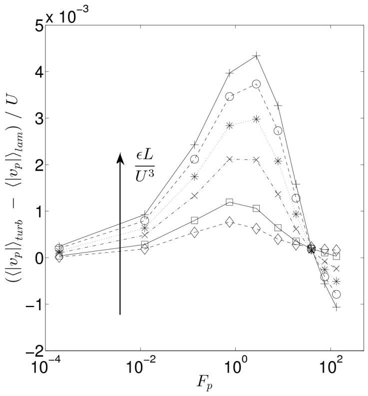

Figure 3. Difference between the averaged turbulent and the laminar falling velocities over the particle Froude number.

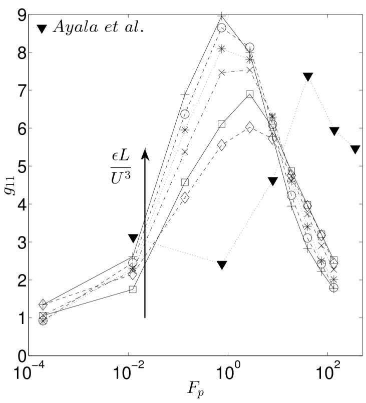

Figure 4. RDF g_{11} over the particle Froude number.

the predictions in [4]. Despite the totally different setup the same was found in [1].
Due to their inertia particles cannot reach certain areas of the vortices. In this study, this particle clustering is measured by a so called radial distribution function (RDF) g_{11} [10]. It compares the actual number of particle pairs at contact with the number expected for a normal distribution. The RDF is plotted over the particle Froude number depending on the dissipation rate in Fig. 4. From small to big particles the clustering effect gets stronger and attains its maximum value for $F_p \sim 1$ and decays after that. In contrast the position of the maximum value in [1] is at $St \sim 0.6$. At this value the strongest effect was found in [3] neglecting the influence of gravity. This is surprising because of the otherwise good quantitative agreement with the data of [1]. The differences might be originated in the spatial decay of the turbulence in this study and/or the periodicity of the domain and the large scale forcing scheme in the studies reported in the literature. However, based on the existing data it remains unclear what causes this difference and which result is physically more correct. Therefore, it is planned to numerically simulate a laboratory experiment to answer this question.

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