DNS INVESTIGATION OF A PARTICLE LADEN COMPRESSIBLE TURBULENT BOUNDARY LAYER ON AN INCLINED PLATE USING A TWO-WAY COUPLING

Arne Heinrich[1], Flavia Cavalcanti Miranda [1] & Jörn Sesterhenn [1]
[1]*Technische Universität Berlin, Berlin, Germany*

Abstract In this paper we present a numerical study of a high speed compressible turbulent boundary layer with particles in suspension on an inclined surface. We compare this situation with the not-inclined, horizontal case. The well-known streaks with particle agglomeration develop in both cases, but in the inclined case additional clustering is observed with roughly the same spacing in streamwise direction.

INTRODUCTION AND NUMERICAL FRAMEWORK

Particles in wall bounded turbulent flows are frequently found from environmental systems to industrial processes. Such flows are characterized by complex interactions between the turbulent structures and the solid phase. Examples in natural processes are pyroclastic avalanches from volcanoes, snow avalanches, or sandstorms; in industrial applications we have e.g. fluidized beds and pneumatic transport of powders. Most computations of those flows e.g. by Soldati [4] or more recently [2] are incompressible. Compressible computations do exist, e.g. [5], but are not intended to resolve turbulent structures and particle agglomeration.

Close to the wall, particles segregate due the turbulent structures like sweeps and ejections and cluster inhomogenously. Particles in those flows do not distribute randomly, but cluster in straining regions. For the boundary layer this means they cluster along low speed streaks, forming very long stripes of high and low particle density. This effect was described by Soldati [4] and can be seen in the top of Fig. 2 or Fig. 3. In the former, raw particles, in latter figure the particle density are shown.

In the present contribution, we show results of a compressible boundary layer flow at $Ma = 0.8$ and $Re_\delta = 1000$ on an inclined plate under $22°$. Scales are resolved down to the Kolmogorov range. The Froude number of the flow is $Fr = 2$ at a Stokes–number close to unity. At the inlet an overall of $\mathcal{O}(10^6)$ particles are injected randomly. Lacking better data, we introduce the particles with fluid velocity.

The aim of this work is to investigate the difference of the inclined to the horizontal plate. The inclination angle and Froude number are chosen resembling [5], who compute a pyroclastic avalanche on a volcanic slope.

The numerical framework is a high order compact, primitive variable scheme in a characteristic formulation [3]. The time integration was performed by an exponential integration based on Krylov subspaces.The particles were treated Lagrangian, using a two way coupling, also bouncing off the wall and are integrated by a Runge-Kutta method of fourth order.

We force the turbulent boundary layer with a Lund–type recycling method adapted for compressible flows [1]. Our computational domain is essentially 45δ long, (not measuring a sponge region at the exit), 6δ high and 3δ in the spanwise direction, which is treated periodically. The particles are not recycled but rather injected at the inlet and leave the domain for good at the outlet.

RESULTS

Particles agglomerate different under influence of a inclined gravity as observed in the bottom of Figs 1– 3 respectively.

Fig. 1 shows a the particles in a longitudinal cross–section of the boundary layer. The top picture shows the flat, non–inclined plate, no gravity acting. (The non-inclined case with gravity look similar and confirms that gravity is essentially negligible in the non–inclined case.) The lower picture represents the inclined case. The latter has a less homogeneous appearance than the former.

This is more apparent and easier to describe in the top view of Fig. 2 at a height of a few wall units. In the top picture, one can observe the familiar streaky structure, which looks indistinguishable from the incompressible computations by Soldati [4]. Marked difference can be found in the bottom picture from the inclined plate. The streaks still exist, but streamwise patches of particle–agglomerations are observed. Essentially the same information is depicted more ostensible in Fig. 3. Here particles are counted in boxes with side length of a few wall units and a local particle density is computed.

In order to establish the associated length scale, we used a Fourier transform of fluid velocities and particle density in spanwise and streamwise direction. (In the latter, a hamming window is employed.) The visual effect can clearly be corroborated and the streamwise length scale turns out to be slightly larger than the streak spacing. Whether this is intrinsically so or depends on Reynolds, Stokes or Froude number is not clear yet and makes forthcoming computations necessary.

A longer computational domain or particle recycling seems necessary as well, since at the very end of the computational domain, a slug of particles is formed, and we do need to answer the question whether similar wave patterns tend to form regularly and travel downstream.

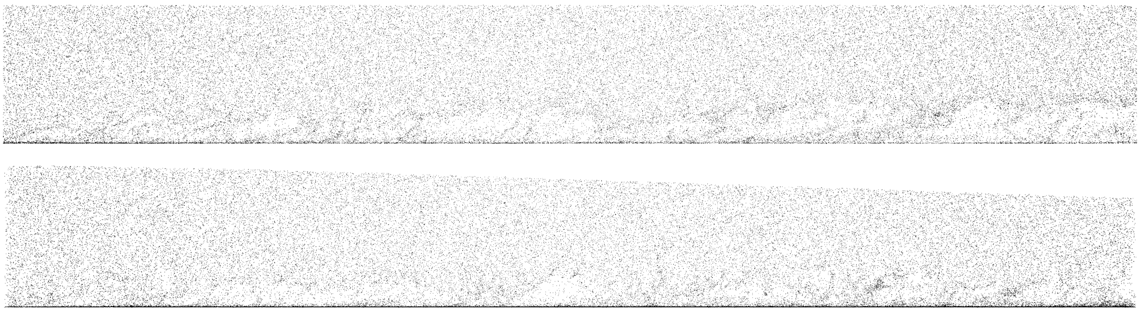

Figure 1. Cross section of particles in the x-y plane. Top: straight plane, bottom: oblique plane

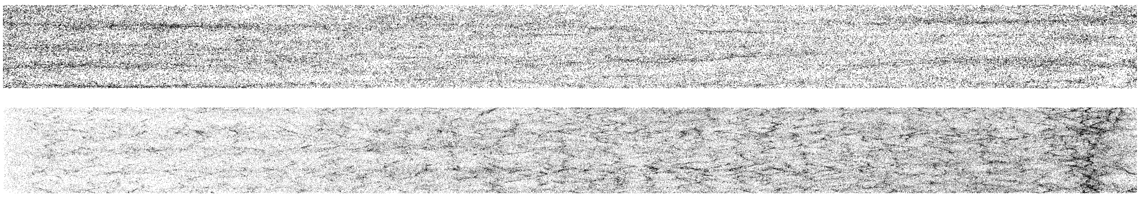

Figure 2. Top view (x-z plane) of particles in the boundary layer. Top: straight plane, bottom: oblique plane

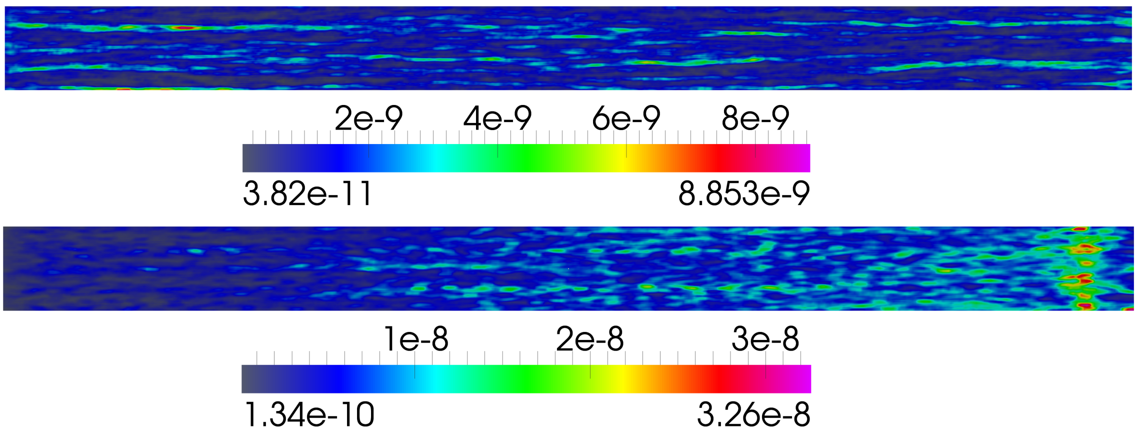

Figure 3. Top view (x-z plane) of the particle density. Top: straight plane, bottom: oblique plane

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