International Conference on *Fundamentals*, *Experiments*, *Numeric* and *Applications*

Particles in turbulence

March 16, 2011 - March 18, 2011 University of Potsdam (Germany)

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Program of the conference Particles in turbulence 2011 International Conference on Fundamentals, Experiments, Numeric and Applications
16-18 March 2011, Potsdam, Germany http://mp0806.cineca.it/potsdam

Program version 3

Registration will take place on 15 March 2011 from 17:00 to 19:00

16 March 2011 - Conference day 1

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Particle advection by an intermittent deterministic field

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Abstract: The advection of particles in a turbulent flow are considered in terms of simplified flow. Recent works concern turbulent flows from direct numerical simulations and random flow fields. In this contribution we use a deterministic, but chaotic, and intermittent flow to investigate in detail the statistical properties of the particle motion.

Breakup of particles in turbulent flows with application to spray painting

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Abstract: The breakup of liquid paint in spray devices in industry-scale painting is modeled and simulated. In the automotive industry the Electrostatic Rotary Bell Sprayer (ERBS) technique is frequently used. Paint is injected at the center of a rotating bell and forms a film on the inside of the bell. The atomization takes place when the paint enters the surrounding air. The paint droplets are charged and guided towards the target by a combination of aerodynamic and electrostatic forces acting upon them. The paint exits from the bell into the air in the form of filaments spiraling outwards. As the air flow in the vicinity of the bell is turbulent, the filaments are randomly forced, and Rayleigh-Taylor and Kelvin-Helmholtz instabilities are excited. Pieces of paint are broken off which then undergo one or more secondary breakup events, forming successively smaller droplets. The process ends when the new droplets are small enough to withstand the external forces without breaking up further. The stability criterion can be expressed as a critical Weber number, We_c, where the dimensionless Weber number relates the dynamic pressure to the surface tension. It is evaluated as We = rho_g*u_r^2*d/sigma, where rho_g is the density of the surrounding gas, u_r is the relative velocity of the particle with respect to the air, d is the particle diameter and sigma is the surface tension coefficient. For the paint We_c is estimated to 12. The resulting size and velocity distributions are extracted and compared to measurements. The aim of the project is to be able to significantly reduce the number of costly near-bell spray measurements for different applicators and process settings. In order to achieve this, models of the breakup involving the physical parameters of the paint and surrounding air are developed which will be presented.

Stratified turbulence ensemble

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Abstract: A generalization of the Kraichnan velocity ensemble accommodating the effects of (neutral, stably) stratified turbulence is proposed. A notable difference to isotropic turbulence is the deviation of the vertical energy spectrum (~k^-3) from the usual Kolmogorov-Obukhov scaling (~k^-5/3) due to gravity and the boundary condition on the surface. Due to strong stratification effects the density is not a constant and needs to be included in the ensemble as a random scalar field. Consistency with the mass conservation law then implies among other things that 1) the density profile is exponentially decreasing w.r.t height, and 2) that the density statistics has a finite correlation time, which may have important consequences for clustering of inertial particles. Applications for passive scalar and tracer/inertial particle s tatistics will be considered.

Breakup of small particles driven by local dissipation

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Abstract: Breakup of suspended particles and particle aggregates is a crucial phenomenon in many natural and engineered systems. It plays a substantial role in the processing of colloidal materials [1,2] and in the treatment of (waste)water. Moreover, it affects the release of aerosols from technical facilities [3] and it influences the formation of marine snow in tidal waters [4]. Here, we consider the breakup of small (point-wise) particles in homogeneous turbulence. When the flow is diluted or when particle inertia is small such that energetic collision can be neglected, breakup is governed by viscous stresses acting on the particle which depend on the local dissipation. Furthermore, assuming that breakup occurs instantaneously when the viscous stress exceeds a threshold value (that depends on the particle properties, i.e., its size [5]) we arrive at a picture where the macroscopic breakup rate (defined as the rate of change of the number of particles per unit volume [6]) is given by the frequency the particles sample spots of intense dissipation, i.e., values of the dissipation that lead to viscous stresses larger than the threshold value. In this contribution we present a model that translates the above picture in an explicit expression for the breakage rate [7]. This 'definition' of the breakage rate contains the joint probability of the dissipation and the time derivative of the dissipation. A simple closure is proposed that reduces the latter to the single probability of the dissipation. The resulting model is compared with the breakage rate obtained from analyzing real Lagrangian trajectories taken from our database of numerical simulations. [1] D. Xie, H. Wu, A. Zaccone, L. Braun. H. Chen, M. Morbidelli, Soft Matter 6 (2010) 2692 [2] J.J. Derksen, D. Eskin, Ind. Eng. Chem. Res. 49 (2010) 106333 [3] T. Lind, Y. Ammar, A. Dehbi, S. Guntay, Nuc. Eng. Des. 240 (2010) 2046 [4] J.C. Zahnow, U. Feudel, Nonlin. Processes Geophys. 17 (2010) 715 [5] A. Zaccone, M. Soos, M. Lattuada, H. Wu, M. U. Babler, M. Morbidelli, Phys. Rev. E 79 (2009) 061401 [6] M.U. Babler, M. Morbidelli, J. Baldyga, J. Fluid Mech. 612 (2008) 261 [7] V.I. Loginov, J. Appl. Mech. Tech. Phys. 26 (1985) 509

Size effects in the dynamics of large particles in turbulent flows

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We investigate the two-way coupling between a particle and an incompressible fluid flow maintained in a high-Reynolds-number turbulent regime. In order to attack this problem, we make use of a direct numerical method that combines a Fourier pseudo-spectral solver for the fluid with an immersed-boundary technique to impose the no-slip boundary condition on the surface of the particle. Benchmarking of the code is performed by measuring the drag and lift coefficients and the torque-free rotation rate of a spherical particle in various configurations of the carrier flow. Such studies show a good agreement with experimental and numerical measurements from other groups, and validate the code. A study of the turbulent wake downstream a fixed sphere is also reported. The mean velocity deficit is shown to behave as the inverse of the distance from the particle, as predicted from classical similarity analysis. This law is reinterpreted in terms of the principle of "permanence of large eddies" that relates infrared asymptotic self-similarity to the law of decay of energy in homogeneous turbulence. We finally present results of this method applied to freely moving particles in a developed turbulent flow and show that the interaction with the fluid is determined by a turbulent boundary layer where usual regimes of boundary turbulence can be observed (viscous, intermediate and logarithmic layers). A striking result is that the sphere has a finite interaction radius that is determined by the size of this turbulent boundary.

Droplet dynamics in phase separation of binary mixtures under slow cooling

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Abstract: In demixing experiments of binary fluids long lasting oscillations of the droplet density were observed [1]. The phase separation under slow cooling occurs in consecutive bursts of massive nucleation of droplets that alternate with quiescent periods. We propose a reactive-flow model of this phenomenon [2] which explicitly takes into account the background convection generated by the fluid. The model combines the spatio-temporal evolution of the supersaturation field with the dynamics (advection, coagulation) of the droplets. It allows us to study how the period of the oscillations depends on different control parameters, in particular advection, cooling, and diffusion. [1] J. Vollmer, G.K. Auernhammer, and D. Vollmer, Minimal Model for Phase Separation under Slow Cooling, Phys. Rev. Lett. 98, 115701 (2007) [2] I.J. Benczik and J. Vollmer, A reactive-flow model of phase separation in fluid binary mixtures with continuously ramped temperature, EPL 91, 360003 (2010)

Turbulent pair dispersion of inertial particles

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Abstract: The relative dispersion of pairs of inertial point particles in incompressible, homogeneous, and isotropic turbulence is studied by means of direct numerical simulations at two values of the Taylor-scale Reynolds number Re ~ 200, 400; corresponding to resolutions of 512 and 2048 grid points per direction, respectively. The evolution of both heavy and light particle pairs is analysed at varying the particle Stokes number and the fluid-to-particle density ratio. For particles much heavier than the fluid, the range of available Stokes numbers, $0.1 < St < 70$. For heavy particles, it is found that turbulent dispersion is schematically governed by two temporal regimes. The first is dominated by the presence, at large Stoke s numbers, of small-scale caustics in the particle velocity statistics, and it lasts until heavy particle velocities have relaxed towards the underlying flow velocities. At such large scales, a second regime starts where heavy particles separate as tracers particles would do. As a consequence, at increasing inertia, a larger transient stage is observed, and the Richardson diffusion of simple tracers is recovered only at large times and large scales. In the case of light particles with high density ratios, strong small-scale clustering leads to a considerable fraction of pairs that do not separate at all, although the mean separation increases with time. This effect strongly alters the shape of the probability density function of light particle separations.

Results from the Göttingen Turbulence Facility

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We report on experimental results from the Göttingen high-pressure turbulence facility. The first set of experiments was conducted in the recently completed variable density turbulence tunnel. In this tunnel, the kinematic viscosity can be varied by a factor of 100 by using air or sulfur hexafluoride at pressures up to 15 bar. We report measurements of the streamwise and spanwise velocity fluctuations in decaying wind tunnel turbulence behind a passive grid at Taylor microscale Reynolds number up $R_\lambda = 1700$. We compare with the work by Mydlarsk and Warhaft[1], who used an active grid to reach $R_\lambda \approx 730$ and studied the deviations from the $k^{-5/3}$ Kolmogorv scaling in energy spectra as a function of Reynolds number. Our data for a passive grid agree well with that from the active grid measurements. We also report measurements of the normalized energy dissipation $A = \varepsilon L/u^3$.

We then report results from a second experiment on the heat transport, as expressed by the Nusselt number Nu, in turbulent Rayleigh-Bénard convection in a cylindrical sample of aspect ratio $\Gamma \equiv D/L = 0.50$ ($D = 1.12$ m is the diameter and $L = 2.24$ m the height) in the Rayleigh-number range $10^{12} < Ra < 10^{15}$ and for a Prandtl number $Pr \simeq 0.86$ [2,3]. The top and bottom plates of the convection cell were made of copper, and the sidewall was made of Plexiglas. The pressure vessel, and with it the sample cell, was filled with a suitable gas, usually sulfur hexafluoride at pressures up to 19 bars; this gas served as the convection fluid. At these large Ra the results were exceptionally sensitive to details of the experiment. Near $Ra = 10^{15}$ the Nusselt number could be caused to vary over the range $3500 < Nu < 5800$ by minor changes in the apparatus or operating procedure.

[1] Mydlarksi, L., Warhaft, Z.: Passive scalar statistics in high-Péclet-number grid turbulence. J. Fluid Mech. 358:135–175, 1998.
[2] Ahlers, G., Funfschilling, D., and Bodenschatz, E.: Transitions in heat transport by turbulent convection for $Pr = 0.8$ and $10^{11} \leq Ra \leq 10^{15}$. New J. Phys. 11:123001 (18p), 2009.
[3] Ahlers, G., Funfschilling, D., and Bodenschatz, E.: Lecture at the Euromech Colloquium in Les Houches, see www.hirac4.cnrs.fr/HIRAC4_-Talks_files/Ahlers.pdf, Jan. 27 2010.

Non-local closure model for particle dispersion tensors in a turbulent boundary layer

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Abstract: A non-local closure model for the pdf kinetic equation particle dispersion tensors is presented. The closure model accounts for the effects of turbulence inhomogeneity (and anisotropy) and elastic particle-wall collisions on the dispersion tensors, for particles dispersing under the influence of drag, added mass and gravitational forcing. In addition, the new closure formulation provides a general closure for the so called `kappa' dispersion tensor (the dispersion tensor which describes a convective acceleration experienced by the particles due to the fluid turbulence inhomogeneity); general in the sense that it is not limited to small Stokes number particles. The closure modelling is tested against data obtained from particle tracking in a 2D inhomogeneous kinematically simulated flow field, al ong with comparisons to the alternative local homogeneous approximations to the dispersion tensors.

Direct numerical simulation of sustained homogeneous turbulence interacting with finite size resolved particles.

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Abstract: The fluid-particle statistical models, as the Mesoscopic Eulerian Formalism, call for assumptions to be accomplished. When the particles are immersed in a turbulent flow, one assumption is always required: the diameter of the particles have to be smaller than the smallest turbulent length scale of the fluid flow. The present work aims at estimating the error brought by these models when taking the limit of this assumption. In order to confront the previous models, a simulation of an homogeneous isotropic turbulence with finite size particles is presented. The present approach is to make a direct numerical simulation of the Navier-Stokes equations in their one fluid formulation for particulate two-phase flows. In order to force the solid behavior within the nodes belonging to the particle, a penalty method is implemented: the viscosity associated to these nodes is one thousand times the fluid one. Then, an augmented Lagrangian method is used to resolve the flow while keeping the incompressibility. At this step, the flow is known inside the particles (solid motion) and around them. With the velocity of the particles, new positions are computed in a Lagrangian way and the spherical particle shape is projected onto the flow grid to build the solid fraction in each cell. Lubrication and collision models between particles are implemented to avoid overlapping between particles and to include the effect of the unresolved lubrication film. To choose the parameters of the simulation, it is necessary to take into account four numerical constraints. First, as have been shown by some previous validations, the present approach agrees with physical experiments using more than 4 grid points per particle radii. Nevertheless, for the present simulations, 8 grid points per radii are used. In addition, and to ensure that the turbulence is well resolved, the mesh size is determined by the Kolmogorov length scale. As can be deduced, in our simulations, the particle radii are 16 times the Kolmogorov length scale. Another constraint is that, in our periodic box, 8 integral length scale per direction have to be accounted for. Finally, because of the size of the actual parallel computers, we cannot exceed more than 512 x 512 x 512 nodes without loosing the numerical speed-up. The first case presented uses 256 x 256 x 256 mesh points. As an example for this first case, the solid volume ratio is 1%. The particle density is twice the fluid one. The Reynolds number based on the Taylor microscale is 40. The ratio of the particle time constant to Kolmogorov time scale is around 28. Those simulations will provide new correlations that could be used to better understand the phenomena of particles in turbulent flows when the particles are bigger than the turbulence length scale.

Impact of trailing wake drag on the statistical properties and dynamics of finite-sized particle in turbulence

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Abstract: We study by means of an Eulerian-Lagrangian model the statistical properties of velocity and acceleration of a neutrally-buoyant finite-sized particle in a turbulent flow statistically homogeneous and isotropic. The particle equation of motion, beside added mass and steady Stokes drag, keeps into account the unsteady Stokes drag force - known as Basset-Boussinesq history force - and the non-Stokesian drag based on Schiller-Naumann parametrization, together with the finite-size Faxen corrections. We show that while drag forces have always minor effects on the acceleration statistics, their role is important on the velocity behavior. We propose also that the scaling relations for the particle velocity variance as a function of its size, which have been first detected in fully resolved simulations, does not originate from inertial-scale properties of the background turbulent flow but it is likely to arise from the non-Stokesian component of the drag produced by the wake behind the particle. Furthermore, by means of comparison with fully resolved simulations, we show that the Faxen correction to the added mass has a dominant role in the particle acceleration statistics even for particle with size in the inertial range.

Intermittency in the velocity distribution of heavy particles in turbulence

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Abstract: The results of high resolution numerical simulations on the statistical properties of the relative velocity of heavy particles will be reported. In particular, we will show that the statistics is highly intermittent. Indeed, when particles are separated by distances within the viscous subrange, the competition between quiet regular regions and multi-valued caustics leads to a quasi bifractal behavior of the particle velocity structure functions, with high-order moments bringing the statistical signature of caustics. Contrastingly, for particles separated by inertial-range distances, the velocity-difference statistics is characterized in terms of a local Holder exponent, which is a function of the scale-dependent parti cle Stokes number only.

The LES/PDF method for turbulent two phase flows

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Abstract: In the last two decades, Large eddy simulation (LES) has been widely used in turbulence simulation with interesting results in many situations. This development has caused a corresponding effort in the proposition of models of those scales that are not resolved in LES approach, that is subgrid scales (SGS). In this sense, the probability density function (PDF) approach has proven useful for large eddy simulation of turbulent reacting flows. Recently, interest in SGS modelling has grown also for turbulent two-phase flows. We present the rigorous formalism for the LES/PDF of turbulent two-phase flows. In this methodology, the effects of the unresolved subgrid scales are taken into account by considering the joint probability density function of particle position, particle velocity and fluid velocity seen by particles. Relations between Lagrangian and Eulerian pdfs are pointed out. An exact transport equation is derived for the PDF in which the effects of the SGS convection appear in closed form. The unclosed terms in this transport equation are modeled. A system of stochastic differential equations (SDEs) which yields statistically equivalent results to the modeled PDF transport equation is constructed. These SDEs are solved numerically by a Lagrangian Monte Carlo procedure. The LES/PDF results are compared with those obtained without SGS closures. These results are also analyzed via a priori and a posteriori comparisons with results obtained by direct numerical simulation and/or experiments.

Lagrangian velocity, acceleration and vorticity autocorrelations in rotating turbulence

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Abstract: The influence of the Earth background rotation on oceanic and atmospheric currents, as well as the effects of a rapid rotation on the flow inside industrial machineries like mixers, turbines, and compressors, are typical examples of fluid flows affected by rotation. Rotating turbulence has often been studied by means of numerical simulations and analytical models, but the experimental data available is scarce and purely of Eulerian nature. In the present study, experiments on continuously forced turbulence subjected to different background rotation rates are performed by means of 3D Particle Tracking Velocimetry. The data collected is processed in the Lagrangian frame, as well as in the Eulerian one. The background rotation is confirmed to indu ce 2-dimensionalisation of the velocity field, and the large-scales are dominated by stable counter-rotating vertical tubes of vorticity. The auto- correlation coefficients along particle trajectories of velocity, acceleration and vorticity components have been explored, and in this talk the effects of rotation on the Lagrangian temporal scales of the flow will be discussed.

The inverse Smoluchowski problem for cluster-cluster aggregation

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Abstract: The time evolution of the cluster size distribution for a system of aggregating particles can often be described by the Smoluchowski coagulation equation once the collision kernel appropriate to a given physical system is known. Even in circumstances in which the micro-physics is well understood, however, calculating the resulting collision kernel can be challenging. In this talk, we will discuss the corresponding inverse problem: given numerical or experimental measurements of the time evolution of the cluster-size distribution, what information can be extracted about the underlying collision kernel? This problem is very ill-posed in the sense that a straightforward discretisation results in a set of equations which are hugely under-determined. Nevertheless, with appropriate regularisation, reasonable answers can be extracted - at least in the idealised cases which we have studied. We argue that such an inverse approach has the potential to be a useful complementary tool in studying aggregation phenomena with complex underlying transport mechanisms such as turbulence where the micro-physics is difficult to understand.

DNS experiments on the two-way fluid-particle interaction in the settling of heavy particles in homogeneous turbulence including Reynolds number effects.

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Abstract: Experimental and numerical studies showed that heavy particles settle faster in homogeneous turbulence than in still fluid under the effects of two physical mechanisms: the preferential concentration and the preferential sweeping [1]. However, quantitative discrepancies are observed between the experiments [2][3] and the numerical simulations [4] so that further investigation is still required to better understand the increase of the settling rate. In particular, the two-way fluid-particle interactions (two-way coupling) may influence the particle settling velocity. The present numerical study focuses on investigating these two-way coupling effects by making use of direct numerical simulation (DNS) to resolve the carrier fluid phase and the Lagrangian point-particle approximation to model the particle phase.
The modulation of the settling rate but as well of the fluid by the two-way coupling is analysed for a decaying and a forced homogeneous turbulence with the aim to assess how far the forcing scheme (used to maintain stationary the turbulence in the forced flow) can alter the numerical results. The results include also Reynolds number effects by considering a low and a high Reynolds number of turbulence, $R_\lambda=40$ and 130 (with R_λ the Reynolds number based on the Taylor length scale). For the high Reynolds number flow comparisons with experiments are presented.

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Synchronization of hydrodynamically coupled colloidal particles

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At a microscopic scale, hydrodynamic interactions introduce an effective coupling between particles and bodies moving in fluids. Such coupling can be fundamental in understanding the dynamics of microscopic systems like cilia, flagella and artificial micropums. As a simple model of synchronization of eucariotic cilia, we study , both numerically and analytically, a system of colloidal particles immersed in a fluid and moved by oscillating potentials.

Particle interactions with near-wall coherent structures in low Re turbulent channel flow

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Abstract: The purpose of this study is to assess the modifications of quasi-streamwise vortices in the near-wall region of particle-laden turbulent channel flow due to the momentum exchange between the phases. For this reason, several instantaneous flow fields, produced by direct numerical simulation of particle-laden flows with inter-phase momentum exchange, are conditionally sampled to extract the dominant coherent structures. The obtained quasi-streamwise vortices can serve as models to address the major changes due to inter-phase momentum exchange. For all cases, the size of particles is smaller than the Kolmogorov length scale and the grid spacing, the latter being small enough to adequately resolve the smaller length scales of the fluid flow. The particl e feedback effect on the flow of the carrier phase is taken into account by a point-force model. Results are obtained for particle ensembles with four response times in simulations at an average particle mass fraction of $\varphi m=0.2$ with and without streamwise gravity and elastic interparticle collisions. The size of the conditionally averaged quasi-streamwise vortices is increased in the presence of particles. It is larger for particles with the smallest inertia studied, which is partly due to their locally non-uniform spatial distribution. The organized fluid motions induced by the quasi-streamwise vortices are attenuated due to the inter-phase momentum exchange. Both streamwise gravity and interparticle collisions result in an additional augmentation of the size of coherent structures and in more pronounced changes in the surrounding fluid flow. The conditional sampling indicates that a torque of opposite sign to the rotation of the ensemble-averaged quasi-streamwise vort ex is created by the particles. The streamwise vorticity of the structures is decreased directly by the action of particles, resulting in a reduction of the fluid pressure magnitude. The latter influences the redistribution of kinetic energy from the streamwise to the other components of the fluid velocity and, thus, affecting also the features of near-wall fluid turbulence indirectly.

Formation of Large-scale and Small-Scale Inhomogeneities of Inertial Particles in Temperature-Stratified Turbulent Flows

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Abstract: We analyze the phenomenon of turbulent thermal diffusion that causes the non-diffusive streaming of aerosols in the direction of the mean heat flux and results in formation of large-scale aerosol layers in the vicinity of the temperature inversions. We discuss the theory of the effect of turbulent thermal diffusion and describe laboratory experiments which confirmed the existence of the effect. We provide an insight into the existence of this phenomenon in the atmosphere and its potential impact onto aerosol distribution. We applied the theory of turbulent thermal diffusion to analyze the GOMOS aerosol observations near the tropopause and explained the shape of aerosol vertical profiles with elevated concentrations located almost symmetrically to the absolute temperature profile. We found an agreement between the theoretical predictions and the observations of the aerosol concentration and mean temperature profiles in the vicinity of the tropopause. These measurements in combination with the theoretical dependence of the turbulent thermal diffusion ratio on the turbulent diffusion yield an independent method for determining the coefficient of turbulent diffusion at the tropopause. We derived practically applicable formulations for dispersion of pollutants taking into account the phenomenon of turbulent thermal diffusion and preliminarily assessed the effects of turbulent thermal diffusion in modern dispersion models. In particular, we performed the numerical simulations of the sensitivity of the lower-troposphere vertical profiles of the aerosol concentration to the phenomenon of turbulent thermal diffusion. We found a regular upward forcing of the aerosols caused by turbulent thermal diffusion in the lower troposphere whereby heavier particles are affected stronger than the light aerosols.
We have predicted theoretically and detected in laboratory experiments a new type of particle clustering (namely, tangling clustering of inertial particles) in a stably stratified turbulence with imposed mean vertical temperature gradient. In this stratified turbulence a spatial distribution of the mean particle number density is nonuniform due to the phenomenon of turbulent thermal diffusion, i.e., the inertial particles are accumulated in the vicinity of the minimum of the mean temperature of the surrounding fluid, and a non-zero gradient of the mean particle number density is formed. It causes generation of fluctuations of the particle number density by tangling of the large-scale gradient by velocity fluctuations. In addition, the mean temperature gradient produces the temperature fluctuations by tangling of the large-scale gradient by velocity fluctuations. The anisotropic temperature fluctuations contribute to the two-point correlation function of the divergence of the particle velocity field, i.e., they increase the rate of formation of the particle clusters in small scales. We have demonstrated that in the laboratory stratified turbulence this tangling clustering is much more effective than a pure inertial clustering (preferential concentration) that has been observed in isothermal turbulence. In particular, in our experiments in oscillating grid isothermal turbulence in air without imposed mean temperature gradient, the inertial clustering is very weak for solid particles with the diameter of the order of 10 microns, and Reynolds numbers based on turbulent length scale and

root-mean-square velocity, Re=250. In the experiments the correlation function for the inertial clustering in isothermal turbulence is much smaller than that for the tangling clustering in non- isothermal turbulence. The size of the tangling clusters is of the order of several Kolmogorov length scales. Our theoretical predictions are in a good agreement with the obtained experimental results.

Aggregation and fragmentation of marine aggregates in random flows

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Marine aggregates are an important integral part of the biogeochemical cycles in the ocean. Besides their inorganic kernel they are composed of organic material in form of algae and bacteria. These biological components are responsible for the seasonal variation of the size distributions observed in the open ocean and in tidal areas. Due to the production of transparent exopolymers by the algae the internal properties of the aggregates change in summer. Moreover, the structure of marine aggregates is not spherical but fractal-like due to the attached algae. Different modeling approaches are possible to obtain the evolution of size distributions of marine aggregates such as size-class based and distribution-based models. We present an individual based model which takes each aggregate explicitly into account. The basic equations describing the dynamics of these inertial particles are the Maxey-Riley equations. We consider aggregation and fragmentation of these particles in random flows. The collision of the particles leads to aggregation and larger aggregates are formed. These can in turn fragment due to shear forces in the flow. Fragmentation can take place when the shear forces in the flow become larger than the binding forces of the aggregate. We find that the combination of aggregation and fragmentation leads to an asymptotic steady state for the size distribution of the aggregates which depends crucially on the considered mechanism of fragmentation. We discuss the dependence of the final size distributions on the properties of the aggregates as well as of the flow.

Perspectives in the study of behavior of inertial particles in real turbulence

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Abstract: In recent decade it has become possible to derive several analytic results for the behavior of inertial particles in real turbulence. The results do not involve modeling of turbulence but rather some natural assumptions on the flow like smoothness. We will give a coherent review of the existing results including recent ones and discuss the possible development of the area in the future.

European High Performance Computing for Science: the PRACE project

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Abstract: The European Commission identified High Performance Computing as a strategic priority for Europe. The size and the cost of the related research infrastructures is steadily increasing insomuch as, today, the most advanced computing facilities can be conceived only on trans-national or even continental basis, with a joint contribution of a number of different member states. A first effort in this direction was represented by DEISA, the Distributed European Infrastructure for Supercomputing Appliications (http://www.deisa.eu/). Today, the European path toward petascale and, in a further perspective, exascale computing is represented by the PRACE project (Partnership for Advanced Computing in Europe, http://www.prace-project.eu/). PRACE's goal is to provide Europe with world-class systems for high-end science and to strengthen European scientific and industrial competitiveness. PRACE will maintain a pan-European HPC service consisting of up to six top of the line systems (Tier-0) well integrated into the European HPC ecosystem. Top class scientific projects, based on numerical applications, are supported by periodic calls. In the first call (june 2010), ten research projects have been awarded access to the PRACE infrastructure. In total 321.4 Million compute core hours were granted. We will give an overview of the roadmap and the main features of the PRACE e-infrastructure. In particular, we will highlight the perspectives for science and for a new generation of large scale research cases. Our use case is related to cosmology and its challenges, providing an example of state-of-the-art numerical application, the computational requirements and the solutions adopted for the huge data volume produced, which led to the realization of one of the largest simulated galaxy cluster public archives: the IRA-CINECA archive (http://data.cineca.it). Finally, the possible developments (and issues) on petascale computing systems will be presented.

Flow around finite-size neutrally buoyant Lagrangian particles in fully developed turbulence

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Abstract: By using an innovating technique based on Lagrangian Particle Tracking (LPT), we have been able to follow the motion of finite-size neutrally buoyant particles together with the trajectories of tracer particles in the surrounding fluid. The particles we study have diameters of about 200 times the dissipative scale of the flow, and their density is almost that of the fluid. The experiments are conduced in a von Karman swirling water flow at Taylor microscale Reynolds numbers up to 500. By measuring the full motion of the big particles (translation and rotation), we are able to "sit" in their frame of reference and measure the flow properties around them. We will report experimental results on the flow properties and its correlations with the big particle trajectories in this Lagrangian frame.

Growth of cloud droplets and raindrops in turbulent clouds

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Formation of rain in warm ice-free clouds involves diffusional and collisional growth of cloud droplets and drizzle/rain drops. These processes are traditionally referred to as the warm-rain processes (in contrast to precipitation formation processes involving ice phase). Turbulence is often argued to play a significant role in warm-rain processes through affecting the diffusional growth of cloud droplets (and thus leading to the broadening of the droplet spectrum, an aspect important for the onset of gravitational collisions) or growth through the collision/coalescence. This presentation will introduce the cloud physics context for the particle in turbulence problem and provide a brief overview of recent observational and modeling studies concerning the role of turbulence in warm-rain processes.

The effects of back-reaction on turbulence modulation in shear flows

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Abstract: The dynamics of heavy particles is addressed in a homogeneous shear flow in the two-way coupling regime. A large scale anisotropic velocity field influences the formation of particles aggregates (clusters) up to the smallest scales. The clusters are characterized by a preferential spatial organization induced by the coherent large scales motions. In anisotropic flows a complete description of particle clustering is achieved by considering the Angular Distribution Function (ADF) which parameterize the probability to find two particles in terms of their separation and direction. This observable might be employed to measure the residual anisotropy of particles pairs at each scale separation. For particles which present small scale clustering, as the scale separation is reduced, the anisotropy level of the clusters increases to eventually saturate at small scales. This means that the particle distribution at small scales is singular and anisotropic. In this contribution we consider the effect of the back-reaction of the disperse phase on the carrier fluid. Due to small scale clustering the back-reaction field is localized on those sets where particles accumulate and an highly anisotropic forcing active on the smallest scales is expected. In case of considerable coupling effects, turbulence would be directly stirred in a range of scales usually characterized by isotropy recovery. For increasing mass loads (ratio between the mass of the disperse phase and the fluid) we show that the Stokes drag intercepts energy from the classical cascade to pump part of the intercepted energy back in the fluid at small scales. In addition, we observe a definite change in the spectral distribution of the turbulent shear stress which provides the scale-by-scale energy production and allows to identify the range of scales directly affected by the anisotropic forcing (its integral amounts to the Reynolds stress). The range of scales affected by anisotropic production is progressively enlarged as the momentum exchange between the disperse phase and the carrier flow becomes relevant. In fact, the Stokes drag removes energy from the normal stresses reducing velocity variances to force the shear stresses i.e. the anisotropic motions. In this conditions doubts are cast on the possible use of standard sub-grid models for LES which are typically based on the small scale isotropy recovery assumption.

Preferential concentration of water droplets in homogeneous and isotropic turbulence

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Abstract: We present an investigation of the preferential concentration of water droplets within a gas volume of homogeneous and isotropic turbulence without mean flow, often referred to as a “box of turbulence”. The generation of the gas flow is produced by 8 arrays of synthetic jets which are placed at the vertices of a cubic frame and aim at the cube center. By balancing the intensity of each array the desired flow conditions are attained at the center of the cube. Poly-disperse water droplets produced by an air-assist atomizer are introduced into the flow. The size distribution of the water droplets is measured by means of Phase Doppler Anemometry. We quantify the droplet dispersion in the flow of interest in terms of the mean droplet size and droplet size spread.The preferential concentration is evaluated with three methods, as follows : (a) Radial Distribution function; (b) Cell counting method, where a grid with fixed size is applied on a plane through the box and the particles are counted in each cell; (c) Voronoi analysis. The results from the three methods will be compared for different spray characteristics.

Advection of tracer particles in the free atmosphere

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Abstract: Investigating the spreading of air pollutants in the free atmosphere is a question of importance. The atmospheric flows play an important role in the transport of tracer particles and dispersion of air pollutants (e.g. from volcanic eruptions). Far from the surface, air masses are transported approximately on two-dimensional surfaces, therefore we first carried out simulations of passively advected tracer particles on these surfaces using ERA-Interim wind fields. In order to characterize the advection, we determined the effective fractal dimensions of the pollutant clouds. The effective dimensions increase over time and tend to 2 corresponding to a perfect mixing. We also investigated the average homogenization time of an initially localized cloud within a hemisphere as a function of the initial geographic location of the cloud. This time is of the order of a month and has seasonal dependence. We also calculated the three-dimensional trajectories of aerosol particles by taking their terminal velocity into account. In this case the deposition of the particles was also studied. Some of the above-mentioned quantities were compared with those of the two-dimensional advection. The spreading of gases and aerosol particles produced by volcanic eruptions were studied too. The results of our simulations and the satellite images show great similarity.

Experimental model studies of passive tracer dispersal in geostrophic turbulence

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Abstract: In our laboratory experiment we examined the dye advection processes in the geostrophic turbulence. The rotating annulus with differential heating is the classical laboratory model of the midlatitude atmospheric flow. In the different experiments the temperature contrast was changed and fluorescent dye is used as passive tracer. The dye dispersion is evaluated by digital image processing. Two quantities are determined to characterize dye dispersion: the maximal zonal extent of the dye cloud measured by the central angle and the total number of pixels above a contrast threshold. We looked for connection between these quantities and the temperature contrast. We found if the temperature contrast is larger, the dye encompasses f aster. We experienced the angle of the zonal extent is close to linear in time and there is a linear dependence between the fitted slope and the temperature contrast.

Entrainment studies in a shearless mixing layer through direct numerical simulation

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Abstract: Entrainment, that is the drawing in of external fluid by a turbulent flow, is ubiquitous to both industrial and natural turbulent processes. This mechanism is particularly important in atmospheric clouds, where the entrainment of dry air by turbulence can determine whether clouds will precipitate or not. Inertial particle entrainment has been studied primarily in relatively complex flows, such as jets, wakes, and channel flows, rendering the identification and isolation of key physical processes difficult (Eaton & Fessler, 1994). We create a simple shearless mixing layer and parameterize our simulations to decouple the individual effects of turbulence, Reynolds number, particle inertia, and gravity on the entrainment process. We then advance the flow temporal ly in decaying turbulence by means of direct numerical simulation (DNS). By analyzing particle concentrations, velocities, and distributions, we find that particle statistics are affected strongly by the relative turbulence levels between the mixing layers. Our results show that without the influence of gravity, over the range of Stokes numbers present in cumulus clouds, particle concentration statistics are essentially independent of the dissipation scale Stokes number. The DNS data agrees with results from wind-tunnel experiments with close parametric overlap (Gerashchenko et al., in press). We anticipate that a better understanding of the role of gravity and turbulence on inertial particle entrainment will lead to improved cloud evolution predictions and more accurate climate models. Sponsored by the U.S. NSF.

Batchelor scaling in the atmosphere

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Abstract: We have analyzed tracer pair dispersion in the atmosphere by means of ECMWF reanalysis wind fields. Since the spatial resolution is limited, we fixed the minimal initial separation larger than the grid size, in order to study the dynamics of flow at scales where flow structures are represented properly. We tested pair separation both at constant pressure and potential temperature levels, and obtained the same statistics. The essential finding is that pair separation follows Batchelor scaling for two-three days (that is the distance grows linearly with time), however the prefactor is different from 3d isotrope turbulence: it scales rather by an exponent of 5/3 instead of the theoretically predicted value of 2/3. Further tests are in progress to clarify the difference from theory.

Applying a new drag and lift correlation for particle deposition

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Abstract: Most of the Lagrangian particle tracking simulations for wall bounded flows use the "point particle approach", and employ standard drag coefficient C_D and lift coeffienct C_L correlation for uniform flow and linear shear flow in a free stream, respectively. This method is deficient when applied to particle deposition on a boundary wall, since the presence of the wall has significant modifying effects on the near-wall drag coefficient C_D and lift coefficient C_L values. Recently published research shows that actual C_D values maybe up to 70% higher than given by the standard Stokes drag correlations, whilst lift coefficients are not only influenced by linear shear, as in the Saffman model, but also by particle translation and wall proximity. In the present paper, the effects of wall proximity modified C_D and C_L on particle deposition modelling in turbulent boundary layers are investigated, both independently and in combination. The deposition model used in this investigation includes a conventional discrete random walk (DRW) model, a new discret random walk model simulating the influence of turbulent structures, and a continuous random walk (Langevin) model.

Lagrangian Statistics in 2D and 3D Turbulence - Differences and Similarities

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Abstract: In recent years the Lagrangian description of turbulent flows has attracted much interest. Especially the statistical properties of velocity increments in three-dimensional turbulence have been in the focus of experimental, numerical and analytical investigations. In the first part of the talk we present detailed numerical investigations of Lagrangian tracer particles in the inverse energy cascade of two-dimensional turbulence [1]. Thereby we focus on the shape and scaling properties of the probability distribution functions for the velocity increments. Furthermore we compare them to the Eulerian case and the Lagrangian increment statistics in three dimensional turbulence. Motivated by our observations we address the important question of translating increment statistics from the Eulerian to the Lagrangian frame of reference [2,3]. The second part concentrates on the investigation of the Lagrangian single-particle acceleration statistics in two and three dimensions. In this context we examine the Markovian properties of the acceleration statistics which are of great importance for Lagrangian turbulence modeling. [1] O. Kamps and R. Friedrich, Lagrangian statistics in forced two-dimensional turbulence, Phys. Rev. E 78, 036321 [2] O. Kamps, R. Friedrich, and R. Grauer, Exact relation between Eulerian and Lagrangian velocity increment statistics, Phys. Rev. E 79, 066301 (2009) [3] H Homann, O Kamps, R Friedrich, R Grauer, Bridging from Eulerian to Lagrangian statistics in 3D hydro- and magnetohydrodynamic turbulent flows, New Journal of Physics 11, 073020

Particle dispersion in homogeneous MHD shear flow

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Abstract: Direct numerical simulations are performed to examine particle dispersion in the homogeneous turbulent flow under the influence of mean shear and an externally applied magnetic field. Both the shear and the magnetic field are uniform. The applied magnetic field is aligned with the direction normal to the plane of the mean shear. Results are presented for three values of the ratio, M, of the mean shear time scale tau_shear to the Joule time scale tau_m. We find that the dispersed-phase structural anisotropy deviates noticeably from the velocity field structure. The dispersed-phase anisotropy is determined by M and by the magnetic Reynolds number Re_m. We use the concept of Dispersed Phase Structure Dimensionality (DPSD) to characterize the anisotropy of the spatial clustering of the particles.

Postulated Nuclear Accidents: Evaluating Radioactive Releases with Special Emphasis on Particulates

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Any credible analysis of the potential release of contamination arising from postulated (i.e., very-low probability) accidents calls for a highly-multidisciplinary analytical capability. The context of the problem requiring analysis is illustrated by focusing on water-cooled reactors which comprise the most widely-used power-generation technology in the world. An overview of the analytical approach that has essentially been developed over the last three decades is provided; it is seen that phenomena involving radiochemistry, thermal hydraulics and aerosol physics are highly coupled. It is shown that the interaction of turbulence and particles is a complex aspect of a multifaceted problem presenting numerous challenges. Examples of aspects specifically involving particulate matter include aerosol agglomeration, dry deposition, pool scrubbing, aerosol resuspension and dispersal. Finally, some outstanding difficulties are mentioned.

Statistics of dispersed phase in LES of heated channel flow

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Abstract: Two-phase, non-isothermal turbulent flow with the dispersed phase is modelled with the Large Eddy Simulation (LES) approach for fluid, one-way coupled with the equations of particle evolution. The channel is heated at both walls and isoflux boundary conditions are applied for fluid. Particle velocity and thermal statistics are computed. Of particular interest are profiles of the particle r.m.s. fluctuating temperature over the channel and the PDF of particle temperature in the near-wall region. We intend to compare our findings with available DNS reference data for particle-laden, heated channel flow [Jaszczur M. & Portela L., In: Quality and Reliability of LES, Springer 2008]. Moreover, an open issue in LES is the influence of non-resolved (residual) scales of fluid velocity and temperature fields on particles. In the contribution, we apply a stochastic model of subfilter particle dispersion [Pozorski J. & Apte S.V., Int.J.Multiphase Flow, 2009] that aims at reconstructing the residual fluid velocity and analyse its impact on particle thermal statistics.

Virtual particle transport in turbulent MHD Kolmogorov flow

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Abstract: The Kolmogorov flow is obtained by the introduction a spatially periodic forcing in the Navier-Stokes turbulence. The forcing is oriented in one direction and its spatial variations are along a direction perpendicular to it, typically fx= A sin (ky) and fy=fz=0. Such a forcing introduces a mean sheared flow, similar to the one observed in the channel flow. However, since the flow can develop in absence of solid boundary, it can be simulated in a three-dimensional periodic box using accurate pseudo spectral codes. Large direct numeric simulations of turbulent Magneto-hydrodynamic (MHD) Kolmogorov flows have been performed. The flows exhibit relatively stable large scale structures that are inhomogenous and anisotropic. Furthermore, an external magnetic field can be imposed to modify the shape of these structures. These simulations provide not only a direct access of the time and space variation of both the fluid velocity and the magnetic fields, but also to the electric field through Ohm's law. The evolution of various ensembles of trajectories in these turbulent MHD fields is studied. Charged particle trajectories (CPT) are influenced by the Lorentz force due to the electric and magnetic fields and, possibly, by a drag force caused by the difference between the particle and the fluid velocities. If the magnetic field is locally intense, the trajectories are essentially following the direction of the magnetic field with their parallel velocity, up to a number of drifts due to the electric field and to inhomogeneities in the magnetic field. The particles are then following guiding center trajectories. Two different approximations for the guiding center trajectories have been considered. In the first one (GC1), the trajectories are obtained by assuming that the velocity is constant in amplitude and always directed along the magnetic field. In the second approximation (GC2) the influence of the first drift term has been added. Finally, we have also recorded the velocit y field lines (VFL) and the magnetic field lines (MFL). In these two cases, the trajectories are obtained by assuming that the particle velocity is given respectively by the fluid velocity and by the magnetic field. For all these trajectories mean squared displacements and velocity and acceleration probability density functions are reported.

New experimental set-up to analyse cryogenic flows by visualisation

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Abstract: Flow visualisation techniques have been recently used at very low temperatures for the investigation of various liquid helium flows, e.g. see [1, 2]. Quantitative techniques, such as PIV (Particle Image Velocimetry) and PTV (Particle Tracking Velocimetry), have been indeed proven very fruitful in many scientific and industrial areas of research during the last decades e.g. see [3]. However, such a promising experimental approach is still in its infancy in the analysis of cryogenic flows and the ways to optimise it are yet to be fully investigated due to a number of technical and fundamental difficulties, e.g. the optical access to the helium bath and choice of suitable tracer particles. The topic is briefly discussed and special emphasis is given to future developments. More precisely, the models developed to characterise the unique properties of liquid 4He are introduced. The description of superfluid helium as a quantum fluid is specifically addressed as it is very relevant for the implementation of flow visualisation techniques at low temperatures. For example, the complex interactions between tracer particles, quantised vortices and macroscopic eddies in cryogenic flows are far from being completely understood and novel experiments are required to verify the current theoretical understanding of these coupled phenomena, e.g. see [4, 5]. Past experiments on various liquid helium flows and their results are reviewed also to highlight the difficulties in cryogenic flow visualisation. Future developments are then proposed to overcome such difficulties and obtain an improvement in the understanding of the underlying physics by using the PIV and PTV techniques. Details are specifically given on the implementation of such promising experimental tools at the Charles University in Prague, where the first laboratory in Europe for flow visualisation at low temperatures is currently being established. The apparatus consists of the following parts. A custom-made low-loss cryostat equipped with five sets of 25 mm diameter widows that minimise the heat input into the helium bath, enabling horizontal as well as vertical optical access, was designed and manufactured. A seeding system with a fast computer-controlled valve to supply the helium bath with the desired amount of hydrogen and deuterium micron-sized solid tracers was also built. These low-temperature related parts are to be used with a 5 W continuous wave solid state laser, fast digital camera (ca. 6200 fps) and relevant hardware and software to implement the PIV and PTV techniques for cryogenic flows. Our facility is being designed to perform novel experiments, that is, not to be just a copy of existing systems but to be potentially capable of obtaining new results. For example, the much faster camera will most likely allow a more detailed analysis of cryogenic flows' dynamics, compared to previous studies. As already mentioned, the complex interactions between tracer particles, quantised vortices and macroscopic eddies could be studied experimentally in unprecedented detail and, for example, the theoretical models that predict the conditions for particles' trapping into vortices verified. This may also have an impact on the study of turbulent multiphase flows, which is a very active field of research in classical fluid mechanics. However, a number of technical difficulties have to be tackled. For

example, even though the set-up was carefully designed, the seeding system needs to be tested at low temperatures and tuned in order to obtain the most suitable tracers. Besides, the flow visualization equipment is currently being tested on various water flows and the first results at low temperatures are expected in the coming months. [1] GP Bewley, DP Lathrop and KR Sreenivasan, 2006: Visualisation of quantized vortices, Nature 441, 588 [2] T Zhang and SW Van Sciver, 2005: Large-scale turbulent flow around a cylinder in counterflow superfluid 4He (He II), Nature Phys 1, 36-38 [3] M Raffel, CE Willert, ST Werely and J Kompenhans, 2007: Particle image velocimetry – a practical guide, Springer [4] YA Sergeev and CF Barenghi, 2009: Particles-vortex interactions and flow visualisation in 4He, J Low Temp Phys 157, 429-475 [5] SW Van Sciver and CF Barenghi, 2009: Visualisation of quantum turbulence, Progress in Low Temperature Physics: Quantum Turbulence (Edited by M Tsubota and WP Halperin), Springer, 247-303

On the role of gravity for heavy particles turbulent dynamics

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Abstract: We present some recent results from Direct numerical Simulation of inertial particles turbulent dynamics, under the influence of gravity. We will concentrate on the interplay between preferential concentration and gravity effects.

LBM of turbulent convection laden with inertial particles

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Abstract: A Lattice Boltzmann Method (LBM) coupled with Lagrangian particle tracking is employed, in this work, to investigate the behaviour of inertial particles in a turbulent Rayleigh-Bénard convection cell. In particular, we focus on the effects of inertia and gravity on particle resuspension and clustering at the wall. It is well known from the literature that particle behavior is mainly controlled by particle inertia which defines how faithfully a particle will follow fluid flow or temperature structures. This results in an inhomogeneous particle dispersion in the domain characterized by the presence of concentration fluctuations in specific regions of the flow. A strong correlation between the presence of sheetlike and mushroom type of structures at the wall and particle behavior has been found and analysed in detail. Different grid resolutions, at the same Rayleigh number, have been tested to have a better insight on the impact of the filtering action exerted by the grid on particle trajectories and consequently on particle resuspension. Mean and higher order statistics on particle and fluid velocity and temperature fields are also presented.

Torque scaling in turbulent Taylor-Couette flow with co- and counter-rotating cylinders

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Abstract: Taylor-Couette flow -- the flow between two coaxial rotating cylinders -- is the paradigmatical case for flow in closed systems. Here We analyze the global transport properties of turbulent Taylor-Couette flow in the strongly turbulent regime for independently rotating outer and inner cylinder, reaching Reynolds numbers of the inner and outer cylinder of $Re_i = 2 \times 10^6$ and $Re_o = \pm 1.4 \times 10^6$, respectively. For all Re_i, Re_o, the dimensionless torque G scales as a function of the Taylor number Ta (which is proportional to the square of the difference between the angular velocities of the inner and outer cylinder) with an universal effective scaling law $G \propto Ta^{0.88}$, corresponding to $Nu_\omega \propto Ta^{0.38}$ for the Nusselt number characterizing the vorticity transport from the inner to the outer cylinder. The transport is most efficient for the counter-rotating case along the diagonal in phase space with $\omega_o \approx -0.4 \omega_i$. -- We will also report on recent results on bubbly drag reduction in this system.

Velocity gradient dynamics

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Abstract: The two dimensional space spanned by the velocity gradient invariants Q and R is expanded to three dimensions by the decomposition of R into its strain production and enstrophy production terms. The {Q;R} space is a planar projection of the new 3d representation. The Lagrangian evolution of the velocity gradient tensor is studied via conditional mean trajectories (CMT). We observe a pronounced cyclic evolution that is almost perpendicular to the Q-R plane.

Long-term measurements of aerosol particle fluxes and deposition velocities over a tall vegetation canopy

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Abstract: Aerosol particle dry deposition is driven by meteorological conditions as well as by strong functional dependence on particle size. The current study aims to understand seasonal differences in size-averaged deposition velocities over a pine forest. Long period of measurements was used to study dependence of particle deposition velocities on size from 10 nm to 1 microm. Particle fluxes have been obtained by eddy covariance (EC) technique applied together wi th condensational particle counter. Size differentiation is performed by means of statistical analysis and modelling approach utilizing the concurrent particle size spectra measurements. Theoretical particle deposition model including Brownian diffusion, interception and turbophoresis mechanisms was applied to analyse the results. Minimum of deposition velocity occurred at around 100 nm and steep increase at larger sizes was observed. Winter time observations were dominated by bi-modal size-distributions and deposition velocities were qualitatively well described by model while the quantitative difference of 30% remained on seasonal average level. It appeared that larger than 200 nm particles contributed to elevated average deposition values in winter. We also showed that using geometric mean diameter in interpretation of size dependence of deposition velocities in case of size-integrated flux measurements can introduce bias in results. Further research is needed to understand seasonally different driving variables for deposition velocities preferably involving direct size-resolved flux measurements.

Distribution of relative velocities in turbulent aerosols

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Abstract: We compute the distribution of relative velocities for a one-dimensional model of heavy particles suspended in a turbulent flow, quantifying the caustic contribution to the moments of relative velocities. We argue that the same principles determine the corresponding caustic contribution in two and three spatial dimensions. We discuss how the presence of an inertial range in fully developed turbulence affects the collision velocities. Our conclusions are in agreement with numerical simulations of particles suspended in a randomly mixing flow in two dimensions, and with published results of direct numerical simulations of particles in turbulent flows.

Voronoï analysis of inertial particles clustering in turbulent flows

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Abstract: Study of inertial particles laden flows is relevant to many industrial and environmental issues, but it is also of fundamental interest. Since the obtention of the equations governing the particles dynamics have only been approached in some limited situations, different experimental investigations focus on the single particle problem by measuring the Lagrangian acceleration in order to get insight on the relevant forces acting on the particle. In the many particle case, a striking feature is the tendency to preferential concentration that has been observed for long and is still studied experimentally and numerically. An other interesting feature is the enhancement of the settling velocity of the particles in turbulent flows. Since the explanation of this phenomenon through the existence of clusters has been proposed by Aliseda and co-workers, different authors tried to quantify and characterise this clustering numerically. Nevertheless, the "ki nematic" simulations used neglect most of the forces acting on the particles that may play an important role in the particles dynamics and experimental investigations are required. Do clusters exist as a whole in these flows? How do they form? What is there structure and how does this structure evolve with time? Which effect do they have on the single particle dynamics? Here are some questions that have to be answered. To date, the preferential concentration/cluster problem has been studied with global tools such as box counting methods, pair correlation function estimation or topological indicators. Nevertheless, such tools do not allow the required simultaneous dynamical study of the Lagrangian dynamics of the particles and of the local concentration field. In a recent publication, we have proposed to use Voronoï tessellations that give a measure of the local concentration field at the inter-particles length scale. This experimental study has not only allowed recovering former results with a single tool (preferential concentration reaches a maximum for Stokes numbers around unity, clusters show not to have any typical length scale and their geometry exhibits fractal structure) but has also pointed unexpected behaviours regarding concentration within dense areas. Here, we extend that study to formerly analysed numerical data in order to compare results obtained in an experimental wind tunnel and in a 3D homogeneous isotropic turbulence DNS.

Nonlinear Algebraic Reynolds Stress Model for Two-Phase Turbulent Flows Laden with Small Heavy Particles

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Abstract: The algebraic Reynolds stress model for two-phase flows taking into account particles feedback on turbulence was developed based on the existing explicit and self-consistent algebraic Reynolds stress models for single-phase turbulent flows. It was combined with the diffusion-inertia model of transport and dispersion of low-inertial particles in turbulent flow developed by the authors earlier. The model is valid for two-phase flows with particles relaxation time no more than the turbulence time macroscale. In the case of the homogeneous shear flow full solution of the system of differential equations for all the Reynolds stress components was obtained and compared with DNS results, showing the adequately description of particles influence on the turbulence anisotropy and intensity. The obtained results are also in a good agreement with experimental data in straight tube.

Elastic collisions of inertial particles.

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Abstract: We investigate, by means of numerical simulations, the effects of elastic collisions on the clustering of inertial particles transported by chaotic flows. We show that the interplay between the dissipative dynamics of inertial particles and elastic collisions originates a novel clustering regime, characterized by the presence of sticky elastic collisions. In the limit of small Stokes number we discuss a theoretical model which allows to capture the main features of such events and to understand their effects on the power-law behavior of the probability distribution functions of inter-particle distance.

DNS analysis of local flow topology in a particle-laden turbulent channel flow

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Abstract: The results of point-particle Eulerian-Lagrangian DNS calculations of dilute particle-laden turbulent channel flow are used to study the effect of the particles on the local flow topology. It is found that in the viscous sublayer the flow becomes increasingly more two-dimensional as the two-way coupling effect (due to interaction between particles and fluid flow) increases with increasing particle load. Beyond the viscous sublayer the modifications in flow topology are not strongly related to the preferential concentration of particles in the flow field, which is in contrast to previous channel flow simulations. The effect of particles on the turbulent flow beyond the viscous sublayer is mostly a result of the overall changing near-wall dynamics of the fluid flow.

The effect of gas fluctuations on the particles distribution in two-phase round jets

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Abstract: Two-phase gas-particle free round jets have a widely use in different practical applications. In two-phase jets play significant role effect of the gas phase on the particle motion. The meaning have as interactions between phases as turbulence of gas phase. It is explain the great interest of investigators to processes which took place in such objects. The numerical model for describing the process of spreading dispersed phase in two-phase free jet using Euler/Euler approach was adjusted. In the model take into account the effect of velocity fluctuations of dispersed phase on the particle motion and can correctly predict the value of axial particle pulsations which bigger then gas pulsations in the same direction. The calculation of the two-phase gas-droplets jet with the variation of droplets concentration and diameter was produced. The predicted results describe sufficiently adequate the experiments and computations data for round two-phase jets with varied of inlet conditions. During variation of the particle size the base types of dispersed phase distributions ("cord-effect" - the increase of droplets mass concentration in axis region, periodic concentration profile and intensive scattering of particles in inlet sections) was shown. The adding of dispersed phase with little size produces considerable reduction of the gas turbulence (about 2 times). For large particles the turbulence generation effect observed due to separating the particle vicinity flow. This work supported by the Russian Found Basic Research(grant № 09-02-00929) and by the President's Fund for Young PhD Scientists (Grant No. MK-504.2010.8).

Time scales, persistence, and dynamic mutiscaling in two-dimensional, homogeneous, isotropic fluid turbulence

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Abstract: We present a natural framework for studying the persistence problem in two-dimensional fluid turbulence by using the Okubo-Weiss parameter to distinguish between vortical and extensional regions. We then use a direct numerical simulation (DNS) of the two-dimensional (2D), incompressible Navier-Stokes (NS) equation with Ekman friction to study probability distribution functions (PDFs) of the persistence times of vortical and extensional regions by employing both Eulerian and Lagrangian measurements. We find that, in the Eulerian case, the persistence-time PDFs have exponential tails; by contrast, this PDF for Lagrangian particles, in vortical regions, has a power-law tail with an exponent that is approximately 2.9. Furthermore, we show how different ways of extracting time scales from time-dependent vorticity structure functions lead to different dynamic-multiscaling exponents; these are related to equal-time multiscaling exponents by different classes of bridge relations. We check this explicitly, for quasi-Lagrangian and Eulerian structure functions, by using detailed DNSs of statistically steady turbulence in the 2D incompressible NS equation with Ekman friction.

Discrete population dynamics in presence of turbulence

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Abstract: We study the growth of colonies at the frontiers of population expansions and fixation of a variant gene in presence of a fluid environment. To capture the number fluctuations of the populations we use the discrete models of population dynamics [1,2] with spatial extensions. We first present the benchmark results for 0- and 1-dimensions in absence of flow and review some earlier results on population dynamics in presence of turbulence [3]. Finally we show that the presence of a compressible, advecting flow field leads to a faster fixation of population in comparison to the case where flow is absent. [1] C.R. Doering, C. Mueller, and P. Smereka, Physica A, vol. 325, 243 (2003). [2] K.S. Korolev, M. Avlund, O. Hallatschek, D.R. Nelson, Rev. Mod. Phys., vol. 82, 1691 (2010). [3] P. Perlekar, R. Benzi, D. Nelson, and F. Toschi, Phys. Rev. Lett., vol. 105, 144501 (2010).

Particle Clustering in Turbulent Premixed Flames

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Abstract: Dynamics of inertial particles in reacting flows is crucial in many applications, e.g. solid-propellant rockets, reciprocating engines, soot transport or PIV measurements. Our aim is to investigate the particle behavior in a premixed reacting turbulent jet in the flamelet regime. For this purpose an Eulerian DNS of a turbulent Bunsen-flame at Re_D=U_0 D/nu=6000 coupled with Lagrangian tracking of inertial particles is described. Several particle populations with different inertia are evolved assuming low concentration, small spherical shape and density much greater than the fluid one. We focus on the interaction between particles and turbulent flame front, neglecting gravity and thermophoretic forces. The relevant parameter controlling the process is the Stokes number based on flame front features, to be called the flamelet Stokes number. Small scale clustering of inertial particles will be shown to peak in the flame brush--the region spanned by the instantaneous flame front. In addition, we present a model for the prediction of the clustering intensity of tiny particles in terms of the mean progress variable and thermal properties of the flames. Comparison with DNS data and targeted experiments confirms the model able to capture most of the physics involved in the clustering process.

Towards an anisotropic stochastic dispersion model for LES of particle-laden turbulent flows

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Abstract: An open issue in the Large Eddy Simulations (LES) of turbulent flows is the influence of non-resolved (residual) scales of fluid velocity on particles. Various model proposals have recently been developed, including approximate deconvolution, fractal interpolation, and stochastic processes of the diffusion type. A stochastic model of subfilter particle dispersion, based on the Langevin-type equation for residual fluid velocity seen by particles has been proposed and assessed in homogeneous isotropic turbulence [Pozorski J. & Apte S.V., Int.J.Multiphase Flow, 2009]. Another piece of work for wall-bounded flows has put into evidence some drawbacks of the model in the near-wall region, due to its isotropic nature [Pozorski J.& Luniewski M., In: Quality and Reliability of LES, Springer 2008]. In the present contribution, we estimate the components of residual fluid velocity and apply them in an anisotropic Langevin model for the fluid along particle trajectories. The approach is believed to improve modelling of particle dynamics in turbulent flows (in particular: in the near-wall regions) and to provide a better prediction of particle wall deposition.

Lagrangian statistics of light particles in turbulence

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Abstract: We study the Lagrangian velocity and acceleration statistics of light particles (micro-bubbles) in homogeneous isotropic turbulence. The trajectories of the micro-bubbles are obtained using 3D Particle Tracking Velocimetry (PTV) experiments in the Twente water tunnel at different Re. The micro-bubble size is comparable to the Kolmogorov length scale of the flow and the corresponding St is close to O(0.01). The velocity PDFs of the 3 velocity components (x, y and z) show a robust Gaussian profile, which is independent of Re. It is found that the micro-bubble acceleration PDF has stretched exponential tails and shows similar intermittency as fluid tracers. The velocity and acceleration decorrelation time increases with increasing Re. Preliminary results on the Lagrangian statistics of inertial bubbles with St ~ O(1) will also be presented.

Statistical properties of the coarse-grained velocity gradient tensor in turbulence

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Abstract: In order to get insight on the properties of the velocity gradient tensor, and of its "coarse-grained" generalization, we study and solve a simplified model, enabling to understand and predict the properties of the velocity gradient tensor at different scales . The determination of its solutions requires refined Monte-Carlo methods developed to sample effectively a very inhomogeneous space of configuration. We fully characterize the properties of the velocity gradient tensor as a function of the coarse-graining scale. While the model correctly reproduces some essential properties of turbulence, our study demonstrates that some improvements are necessary. NB: the subject of the presentation may significantly deviate from the abstract here.

Particle Resuspension Modeling in Turbulent Flows

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Abstract: The work presented is concerned with the way small particles attached to a surface are resuspended when exposed to a turbulent flow. The process is important in a number of environmental and industrial processes. Of particular concern to this work is the release of radioactive particles from the primary circuit of an LWR as a consequence of a loss of coolant accident (LOCA). In this particular case the focus is on small particles < 5 microns in size, where the principal force holding the particle onto a surface is derived from van der Waals inter molecular forces. In general even for nominally very smooth adhering surfaces there exists a very broad spread in the adhesive forces. Here we develop and assess an improved version of the Rock'n Roll model [1] based on a statistical approach to resuspension which gives rise to a resuspension rate constant for the release of particles from a potent ial well due the action of the fluctuating aerodynamic force du to the turbulence. The analogy is with desorption of molecules from a surface in which the variance of the fluctuating aerodynamic force is the analogue of temperature. In this work we improve on the model by using measurements of the statistical fluctuations of both the stream wise fluid velocity and acceleration close to the wall from an LES of turbulent channel flow (see Fig 1.), translating those measurements into the statistical moment of the drag force acting on the particle attached to the surface. The original model assumes that aerodynamic forces and their time derivative are uncorrelated and have a Gaussian distribution. In so doing we examine the influence of non Gaussian forces on the resuspension rate. As a general conclusion, resuspension rate in this modified Rock n roll model is increased due to the high intermittency of the fluid velocity fluctuation (See Fig 2.) Whilst this has a significan t effect on long term resuspension rates, the short term resuspension (fraction resuspended in say 1 sec) although greater is not significantly greater (< 10%) owing to the very large spread in adhesive forces.

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A-priori reconstruction and characterization of an ideal correction for particle motion in LES velocity fields

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Abstract: One issue associated with the use of Large-Eddy Simulation (LES) to study the dispersion of small inertial particles in turbulent flow is the accuracy with which particle statistics and concentration can be reproduced. The motion of particles in LES fields may differ significantly from that observed in experiments or Direct Numerical Simulation (DNS) because the force acting on particles is not well estimated when only the filtered fl uid velocity is available, and because errors accumulate in time leading to progressive trajectories divergence. We identify herein an ideal correction (IC) such that the trajectories of individual inertial particles moving in a-priori LES fields in turbulent channel flow coincide with the particle trajectories in a DNS. The objective is to characterize PDF and statistical moments of IC to possibly identify a stochastic process approximating IC, to be eventually used as closure model for the particle motion equations.

Experimental study of relative velocity statistics of inertial particles in isotropic turbulence.

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Abstract: The collisions of heavy particles in turbulence is a subject of considerable interest, mainly for its implications on the theory of rain formation in atmospheric clouds. Current works suggest that in isotropic turbulence, the collision rate of particles can be computed from the statistics of particle relative velocities and of particle clustering (the radial distribution function). We present experimental data taken in isotropic turbulence in air at Reynolds numbers up to 400 (based on the Taylor scale), where the Kolmogorov length scale was about 150 microns. The particles were liquid droplets about 20 microns in diameter. Our study focuses on relative particles statistics but also includes results pertaining to the radial distribution function where needed. Specifically, we study particle relative velocity statistics for separations within dissipative scales, and how they depend on basic flow parameters including the Stokes number and the Reynolds number.

Vortex filaments in turbulence: a Lagrangian viewpoint

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Abstract: The statistical properties of coherent, small-scale structures are analyzed by looking at the trapping events of light particles inside vortex filaments. We study the properties of particles attracting set, measuring its fractal dimension and the Cramér's function of finite time Lyapunov exponents. We discuss a method to estimate the vortex life-times by studying the moment of inertia of bunches of particles, showing the presence of an exponential lifetime distribution, with events up to the integral time-scale.

The simulation of lagrangian particles in EM driven recirculated turbulent flows

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Abstract: Electromagnetically (EM) driven recirculated turbulent flows appear in different applications of magnetohydrodynamics, such as induction heating and melting of metals. The melt flow in induction furnaces is formed by Lorentz forces and usually consists of several main recirculated vortices. The particle transport problem in such flows is associated with the industrial problems of impurity deposition on the wall of furnace and homogenization of alloying particles. Experimental measurement of particle motion processes in the flow of metal melt is very difficult and even impossible, thus it is very important to solve this problem in the terms of mathematical modeling. The widespread concentration approach is inapplicable for particles in EM field because EM force can not be easy implemented in concentration equation. For this reason Lagrangian approach was chosen. Different forces can be taken into account in Lagrangian equation: drag, buoyancy, EM, lift, flow acceleration, added mass and Basset historical forces. All these forces except the last one (due to computational complexity) are analyzed for particles with different sizes and densities in the turbulent flow of induction crucible furnace that is the typical object for metal melting and mixing. Some of the forces have coefficients that depend on the particle Reynolds number and other dimensionless parameters, the approximations for these coefficients were chosen on the base of computational results. The model that simulates the flow using Large Eddy Simulation method and particles in the Lagrangian approach was created and programmed within free code Open FOAM software. The results of simulation shows that turbulent pulsations of the flow significantly influence on the particle motion and small shift can make the trajectory of particles totally different. Thus it is necessary to analyze the motion of numerous particles to obtain the representative results, so macroscopic dynamics of the particle cloud during the process of homogenization was analyzed and also will be presented in this paper.

Phase relaxation of a cloud water droplet ensemble undergoing turbulent mixing

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Abstract: The understanding of the entrainment and mixing of clear (subsaturated) with cloudy air at the boundary of a cloud is still far from being complete. Mixing is determined by the ratio of two time scales: the mixing time and the phase relaxation time, which can be combined as a Damkoehler number. The phase relaxation time is connected with the water phase change and thus changes in the cloud water droplet size distribution and their number density. The mixing time of the advecting turbulent flow is determined by the size and velocity of the turbulent eddies. Here, we will outline a direct numerical simulation model that couples the Eulerian description of the velocity and water vapor fields with a Lagrangian ensemble of cloud water droplets. The simulations resolve a small cubic fraction of the cloud and simulate a homogeneous isotropic turbulent flow in which a vapor field is advected. Turbulence properties at larger scal es are taken from field measurements of the helicopter-based measurement platform ACTOS. Cloud water droplets can grow and shrink, as determined by the advected vapor concentration field that sets the local supersaturation at the droplet position. We discuss the phase relaxation for different initial distributions of the cloud water droplets and different liquid water content.

Particles and droplets in turbulent pipe flow: Kinetic modelling and added mass effects

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Abstract: A major challenge is to predict the distribution and transport rates of the dispersed phase (particles/droplets/bubbles) in inhomogeneous, wall bounded turbulence. We have implemented a Reynolds stress-type model for the dispersion in fully developed turbulence. The model accounts for the virtual mass effect and hydrodynamic interactions between the particles, and it is based on the kinetic theory of Reeks and Swailes. The model has been tested for water and polystyrene particles of diameter 950μm up to a Reynolds number of 115000 in a 5cm diameter horizontal pipe. We have also applied the theory successfully for droplets in high Reynolds number, high density gas flow, in a 10 cm pipe. We discuss a case where the particles are largely controlled by the fluid acceleration via the added mass mass term in the equation of motion. Hydrodynamic interaction between the particles are important for kinetic stress redistribution. We will also discuss inertial effects on the diffusion properties of droplets in gas flow. A remaining challenge for applications is a-priori prediction of the associated correlation times of the fluid acceleration seen by the particles. We have applied PIV/PTV experiments to measure these correlation times.

Particle deposition and re-entrainment in turbulent channel flow with wall roughness

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Abstract: Wall roughness is known to influence strongly deposition and re-entrainment fluxes to a surface in turbulent flow (Sommerfled, 1992; Squires and Simonin, 2006), in turn controlling the distribution of suspended sediments. In this work, we examine how modeling surface roughness affects deposition and re-entrainment by looking at the local microscale interactions between particles and turbulent structures. To this aim, we use pseudo-spectral DNS to compute the flow field, while a Lagrangian approach is adopted for particle tracking. The statistical behavior of colliding spherical particles is investigated by assuming that particles rebound onto a smooth "virtual wall" generated from a Gaussian distribution of wall roughness angles. The distribution of wall roughness angles experienced by the incident particles at the first rebound matches the effective probability distribution function (PDF) given by Sommerfeld and Huber (1999). Two different methods are considered to relocate particles upon rebound: the single-rebound "Shadow Effect" model proposed by Sommerfeld and Huber (199) and the "Multi-Wall Collision Model" (MWCM) proposed by Konan et al. (2009) to account for multiple rebounds. Results obtained with both methods will be presented for shear Reynolds number Re=150 and for particle Stokes numbers St=25, 100 and 400. Values of St are obtained changing particle density while keeping particle diameter constant (and equal to one wall unit). Preliminary results confirm previous observations that the tendency of particles to accumulate at the wall appears reduced when particle-rough wall collisions are accounted for. This is related to roughness-induced modifications in particle segregation and preferential concentration in the near-wall region, which will be discussed in detail. It is also observed that considering either single or multiple rebounds changes significantly the global behavior of the particles moving away from the near-wall region, especially for "grazing" particles, namely particles hitting the wall with primary collision angles close to zero. The MWCM leads to a zero probability for these particles to rebound with a grazing angle after the final collision onto the rough wall, contrary to the results obtained with the "Shadow Effect" model.
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Bubbly drag reduction and local bubble distribution in bubbly turbulent Taylor-Couette flow

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Abstract: In turbulent Taylor-Couette flow, the injection of bubbles reduces the global drag on the cylinder surfaces. The torque measurements of bubbly flow in the T3C (Twente Turbulent Taylor-Couette) system show surprisingly large drag reduction (more than 50% at a gas concentration of 4%) at very high Reynolds numbers (~ 2x10^6). The investigation of the global drag reduction is combined with local mea surements on the bubble distribution and liquid velocity profile. The local gas concentration measurements show that the bubbles tend to accumulate on the inner cylinder wall and form a lubrication layer. The injection of the bubbles results in the reduction of the liquid velocity in the boundary layer and the bulk.

The Fully-Mixed (Zero-Drift) Limit in PDF Models for Disperse Particle Flows

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Abstract: In the first version of his kinetic equation for the phase-space distribution of disperse particulates in turbulent flows Reeks used the formalism of Lagrangian History Direct Interaction (LHDI) (Physics of Fluids 1991, 3, 446-456). Despite the apparent rigour of the method Reeks noted that the resulting model exhibited a crucial anomaly, namely the presence of a spurious-drift effect such that, in the zero Stokes number limit, the fully-mixed condition for fluid-points was not respected. Other workers have derived what is essentially the same kinetic equation using an alternative formalism (Furutsu-Novikov) but, to date, no resolution of this spurious-drift paradox has been put forward. In this work we identify the source of this model failure, and show how a more correct interpretation of the dispersion tensors within the model resolves the anomaly. The analysis also throws light on the relationship between this type of kinetic equation and those later developed by Reeks and others, making use of the notion of particle velocity fields. In particular, the application of both approaches is considered in the analysis of radial distribution functions (RDFs) for particle-pair separation: The balance between the contributions of drift and diffusion present in the particle mass flux governs the form of the RDF, and these contributions are examined for the different models, both theoretically and computationally. The works serves to emphasis (and quantify) the critical role played by the drift contributions generated by gradients in the kinetic stresses of both fluid and particle phases.

Three-dimensional Voronoi analysis for inertial particle clustering in turbulence

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Abstract: The clustering behavior of inertial particles in homogeneous isotropic turbulence is studied with 3D Voronoi analysis. We use data of particles with different density ratios and Stokes numbers in numerics [1] and experiments. It is found that the PDFs of the Voronoi cell volumes of light and heavy particles show a different behavior from that of randomly distributed particles (fluid tracers) implying that clustering is present. The standard deviation of the Voronoi cell volumes is used to quantify the clustering. The maximum clustering for both light and heavy particles is found to be in the range of 1<2. The results from experimental dataset show a good agreement with numerics, and we also compare them other approaches for studying particle clustering. [1] iCFDdatabase (http://cfd.cineca.it)

Droplets dynamics and breakup in turbulent flows

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Abstract: Turbulent emulsions are relevant to many Natural and industrial flows. In order to study the statistical properties of droplets deformation and breakup in turbulence we perform high resolution numerical simulations of a multicomponent flow composed by two fluid with equal density. Our goal is to investigate the interplay between turbulent fluctuations and surface tension. The flow is solved in a cubic periodic box with a stirring at the largest scales in order to realize an homogeneous and isotropic turbulent flow field. The numerical simulations are performed by means of a fully-parallel Lattice Boltzmann code where the two fluid components are described by means of a Shan-Chen model without need for explicit interface tracking. Our nume rical investigation allow to measure e.g. the probability distribution function of droplet radii and the physics of the exchange of energy between surface and fluid fluctuations. We present results for a selected number of problem parameters.

Investigating turbulence-particle interaction mechanisms with near-field resolved simulations

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Abstract: In the present contribution we report on our work towards a full numerical investigation of turbulent flow involving a substantial number of finite-size spherical particles. In our approach the flow field around each particle is resolved, allowing us to study wake effects which arise when there is an appreciable average relative velocity as e.g. induced by gravity. Recent progress in algorithms and computing power makes it now possible to simulate 10^5 particles in the dilute regime. The present contribution will describe the analysis of two flow configurations: homogeneous turbulence and horizontal channel flow. In the former case, the main question we are addressing is the influence of 'background' turbulence upon the settling rate of finite-size heav y particles. In the latter case, we are focusing upon the mechanism for the appearance of a lag between the average velocities of both phases. Voronoi tesselation and cluster analysis are applied in order to determine the spatial structure of the dispersed phase.

Analysis of turbulent air-solid flow in a multichannel cyclone

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Abstract: This paper analyses the problem of aerodynamics of gas-solid particles in a multichannel (three-ring) centrifugal cyclone-filter (four-channel dust collector - FDC) with tangential inlet flow. A review of experimental and theoretical papers is conducted introducing cyclones with a particularly complicated flow. An experimental investigation and numerical air flow modelling in a FDC cyclone the height of which is 0.73 m, diameter – 0.48 m, the height of a cylindrical part – 0.29 m, a conical part – 0,43 m and an inlet area is 0,29 x 0,034 m2 is presented. Three-dimensional differential equations for transfer processes to estimate an incompressible turbulent flow inside a cyclone are numerically solved using the finite volume method usi ng standard k–ε and RNG k–ε model of turbulence. As a source of experimental particles the following materials were used: quartz sand (physical density 3200 kg/m3, particle size 400–50 mm), quartz sand dust (crystalline silicon dioxide) (physical density 2450 kg/m3, particle diameter 50-0 mm) and calcium carbonate (CaCO3) (physical density 2700 kg/m3, particle diameter 50-0 mm). To conduct the experimental investigation Test 452 multifunctional meter to measure air flow velocity in the inlet and outlet of a multichannel cyclone was used. An optimal inlet velocity of a FDC cyclone is 9,5-10,0 m/s with the highest cyclone efficiency of 90,3±0,15 %. Mathematical model of the air flow inside a cyclone consisted of the system of Navier–Stokes (Reynolds) three-dimensional differential equations. A reasonable agreement between the presented modelling results, when inlet velocity was 6,27 – 10,78 m/s and fluid flow rate – 0,111– 0,190 m3/s, and data, experimentally obtained by other authors, was found with the mean relative error of ±4,6 %. Keywords: cyclone-filter, solid particles, numerical modelling, turbulence, one-phase flow, two-phase flow.

An efficient, second order method for the approximation of the Basset history force.

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Abstract: The hydrodynamic force exerted by a fluid on small isolated rigid spherical particles are usually well described by the Maxey-Riley (MR) equations. In order to be able to simulate a large number of particles the methods for solving the MR equations need to be fast and accurate. The most time-consuming contribution in the MR equations is the Basset history force which is a well-known problem for many-particle simulations in turbulence. In this study a novel numerical approach is proposed for the computation of the Basset history force based on the use of exponential functions to approximate the tail of the Basset force kernel. Typically, this approach not only decreases the cpu time and memory requirements for the Basset force computation by more than one order of magnitude, but also increases the accuracy by an order of magnitude. The method has a temporal accuracy of $O(\Delta t^2)$ which is a substantial improvement compared to methods available in the literature. Furthermore, the method is partially implicit in order to increase stability of the computation.
Another time consuming aspect in numerical simulations of particle laden turbulent flows is the interpolation of the flow field. This will become the new bottleneck when using the proposed approach for the Basset history force. This topic will be discussed only briefly. For the interpolation many different approaches are used. Where some studies use low order linear interpolation others use high order spline methods. This study focuses on estimating the error made by the interpolation method and compares it with the error made in the discretisation of the flow field. In this way one can balance the errors in order to achieve an optimal result.

TR-PIV measurements of polystyrene beads entrained in a turbulent water channel flow

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Abstract: Time-Resolved Particle Image Velocimetry (TR-PIV) measurements were carried out in a dilute particle-laden flow to track both the movement of polystyrene beads (nominal diameter of 0.583 mm) as well as resolve the instantaneous velocity field of the turbulent water flow transporting the spheres. TR-PIV data were captured at a sampling rate of 1 kHz, corresponding to a time scale 5 times smaller than the flow's viscous time scale. Measurements were performed in a closed loop, transparent, square water channel facility with cross section of 50 x50 mm2 and a length of 2 m. PIV data were taken in a vertical plane (29.3x29.3 mm2) oriented along the channel's centerline at a bulk water velocity of 0.3 m/s. The polystyrene beads were imaged together with the flow tracers (hollow glass spheres, ~10mm) and were discriminated based on their size difference. Particle Reynolds numbers based on the relative velocity between the particle and the fluid were below 40, indicating a closed wake without flow separation. Instantaneous sequences of polystyrene spheres plotted on the spatial velocity, vorticity and swirling strength distributions clearly show the effect of turbulent flow structures and resulting particle movement; Ejections pushing particles upwards and sweeps directing particles downwards in agreement with DNS studies. Using the TR-PIV data both fluid and particle accelerations were calculated in a Lagrangian frame of reference. Using the particle's equation of motion different terms of the instantaneous in-p lane forces on the particle can be calculated, such as particle and fluid inertial terms, added mass and buoyancy terms as well as the drag forces. The remaining residual term comprising the lift and Basset history force are discussed. Examples are provided for particles deposited and lifted up from the bottom of the channel.

Experimental investigation of particle movement in turbulent flow through rectangular elbow

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Abstract: The analysis of the turbulent fluid flow in a rectangular elbow is important for many engineering applications like heat exchanger, fluid transport piping system, air cleaning and conditioning devices etc. Present study investigates the solid particles movement in turbulent fluid flow through a rectangular elbow. The working fluid is air and flow taken to be is incompressible, turbulent and non-reacting. The air flow measurements was taken by means of Testo 400 – to determine air flow rate and temperature. The particles measurements was taken by Casella analyser MicroDust pro – to determine the solid particles concentrations. The experimental result shows the influence of the turbulence on the solid particles movement through rectangular elbow. It was also found that the solid particles concentrations variation is very complicated and as a consequence the flow in the downstream side is chaotic and unpredictable. Key words: rectangular elbow, solid particles, turbulent flow, re-circulation zone.

Particles in Turbulence

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Abstract: The first part of this talk will deal with turbulence, and in particular wind tunnel experiments in London, Nagoya and Oldenburg which show that there is more than one class of small-scale turbulence and which are now beginning to examine how qualitatively different classes of small-scale turbulence may be generated. This raises the issue of knowing which class of small-scale turbulence is present in which natural or industrial context (e.g. in forests, clouds, rivers, industrial mixers, etc) and whether mixtures of classes are possible, and if so in what sense. The second part of the talk will deal with particles in turbulence and will naturally follow from the first part. It will present a discussion of mechanisms of particle clustering and droplet size growth.

Technology for Finding Optimum Fairways for Environmental Management in the Baltic Sea

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Abstract: The Baltic Sea is the sea with the most intense ship traffic in the world. A major part of its shipping activities consist of oil transportation, which poses a large threat to many vulnerable coastal areas. The drift of oil spills is influenced by wind stress, waves, and currents. The properties of transport by wind and waves are relatively well known, but the prediction of current-induced transport is more challenging. During a few recent years it has been found that there exist quasi-persistent patterns of currents in various parts of the Baltic Sea and rapid pathways of the current-driven transport are also present – this opens a new way towards a technology that uses the marine dynamics for the reduction of environmental risks stemming from shipping and offshore and coastal engineering activities. The key benefit of this particular technology is an increase in the time during which an adverse impact (for example an oil spill) reaches the coastal zone. The idea is to identify areas (of reduced risk), which are statistically safer to travel to in terms of the probability of the transport of accidental pollution to the vulnerable areas. The coastal areas usually have the largest ecological value, thus in this study we consider the nearshore as a generic example of a valuable area. While the probability of coastal pollution for most of the open ocean coasts can be reduced by shifting ship routes to a larger distance from the coast, the problem for narrow bays, like the Gulf of Finland, is how to minimize the probability of hitting either of the opposite coasts. The first order solution to this problem is the equiprobability line, the probability of propagation of pollution from which to either of the coasts is equal. The safe fairway would either follow the equiprobability line or cross an area of reduced risk. Owing to extreme complexity and high variability of the instantaneous patterns of current fields, we use a large number of single simulations in order to estimate the pathways of current-induced drift patterns. The propagation of pollution is calculated with the use of the Lagrangian trajectory model TRACMASS (Döös, 1995; de Vries and Döös, 2001) that uses pre-computed Eulerian velocities calculated by the Rossby Centre global circulation model (Regional Ocean model, RCO, Meier, 2001) with a horizontal resolution of 2×2 nautical miles and 41 vertical levels. The trajectories of pollution (particle) propagation are calculated based on a linear interpolation of the velocity field in each point of grid cells. The position of the trajectories is updated every six hours. Trajectories of particles are simulated for a few weeks and saved for further analysis. Simulations with the same initial positions of particles are restarted from another time instant and the process is repeated over a chosen time period 1987-1991. Two methods are used for numerical estimation of the spatial distribution of the probability of hitting the opposite coasts. Firstly, four particles ($N_i = 4$, $1 \le i \le N$) are placed in each grid cell. If three or all four particles reach the nearshore of a particular coast, the cell is assumed the value of $c = \pm 1$ depending on which coast was hit. If no more than two tracers reached a coast within the time period, the cell is assumed the value $c = 0$. Secondly, we used another method, involving a certain local smoothing, by dividing the sea area into clusters of 3×3 cells and placing one particle in each cell.

By tracing nine trajectories in each cluster it is established whether or not the majority of the trajectories end up at one of the coasts. The basic idea is the same as above; only the values of ($N_i = 9$, $1 \leq i \leq N$) and the initial positions of the tracer with respect to the centres of the grid cells are different. The third approach was to calculate the average probability of pollution released into a grid cell of reaching the nearshore, and the average time (particle age) it takes under the assumption that hitting any section of the coast (called coastal hit below) is equally dangerous. All three approaches lead to qualitatively similar results that show substantial seasonal and also certain inter-annual variability. A highly interesting feature of the resulting distributions is that some open sea regions contain a clear probability gradient while some other regions of basically the same size exhibit extensive areas with very low (and essentially constant) probability of hitting either of the coasts. In the former areas it is possible to clearly define the equiprobability line whereas the latter areas can be identified as areas of reduced risk. The distance between different estimates for the location of the equiprobability line serves as an implicit measure of uncertainty related with this sort of solution. All three approaches are also extended to the northern Baltic Proper area and an analysis of most frequently hit coastal areas for both sea areas are included. The presented results confirm that it is possible to considerably reduce the probability of coastal pollution by adverse impacts released from ships by means of optimising the fairways. The relatively small difference in the location of the optimum fairways obtained by different methods indicates a reasonable level of uncertainty connected with this type of solution. A highly interesting side result is the discovery of substantially different regions in the underlying spatial distributions of the probability of coastal hits. This feature probably reflects certain intrinsic difference in the dynamics of sea currents and the corresponding pollution transport between different sea areas.

Solid particle acceleration in a high Reynolds number channel flow : DNS versus LES with stochastic modelling of subgrid acceleration

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Abstract: Understanding and modelling the transport of inertial particles, such as sediments, is of practical interest for both industrial engineering or environmental problems. Inertial particles exhibit dynamics that are more complicated than those of the fluid. Particles are ejected from vortical regions of the turbulent flow and tend to cluster in regions of the fluid experiencing relatively low fluid accelerations (Bec et al. 2006), (Ayyalasomayajula et al. 2008). Inertial particle acceleration has been measured (Ayyalasomayajula et al. 2006) or obtained by numerical simulations (Bec et al. 2006) in the case of homogeneous isotropic turbulence. Here we focus on inertial particle accel eration statistics in a high Reynolds turbulent channel flow. First, direct numerical simulation (DNS) coupled with Lagrangian tracking of particles is used to analyze fluid and particle acceleration statistics. These statistics are highly intermittent. Then, in the context of large-eddy simulation (LES), this intermittency is introduced through a stochastic model for the subgrid acceleration. The capability of the proposed model in the case of high Reynolds turbulent channel flow is then assessed.

Investigation of the bounds on the transport of heat and momentum in two turbulent fluid flows

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Abstract: The optimum theory of turbulence is one of the few tools for obtaining analytical results for the characteristic quantities of the turbulent flows and turbulent thermal convection. This is achieved on the basis of asymptotic theory which is valid for large values of characteristic dimensionless numbers of the corresponding fluid system. For small and intermediate values of the dimensionless numbers of the flow one has to solve numerically the Euler - Lagrange equations of the corresponding variational problems. In such a way the profiles of the optimum fields connected to the fluid velocity and temperature can be obtained. The discussion in this presentation is devoted to the evolution of the thickness of the boundary layers of the optimum fields for problems connected to the maximum heat transport through a fluid layer by means of turbulent thermal convection. The influence of rotation on the profiles of the optimum fields and on the heat transport is investigated. In addition several results from the numerical investigation of the lower bounds on the transport of momentum in pipe flow are discussed.

Rain in the test tube?

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Abstract: In clouds the adiabatic cooling drives uprising air across the cloud point and hence causes nucleation of cloud droplets which subsequently coarsen and eventually lead to rain. In clouds nucleation is due to seeds (mostly small salt particles) such that droplets have to grow from a submicrometer to millimeter scale. Surprisingly similar scenarios lead to precipitation in binary liquid mixtures subjected to a shallow temperature ramp. In that case, however, critical nuclei are two orders of magnitude smaller, and gravity becomes noticeable when droplets have grown to a size of tens of microns. Consequently, the resulting "clouds" fit into test tubes with lateral dimensions of a few centimeters such that one can follow the evolution of the phase-separating mixtures for very long times under carefully controlled conditions. Upon slow cooling the mixtures repeatedly go through cycles of nucleation, coarsening and sedimentation. We suggest a set of PDEs describing the evolution of the mixtures, and discuss its instability towards nucleation and convection. This approach also provides a minimal model explaining the arising of the repeated rain formation, and it allows us to discuss physical mechanisms leading to precipitation. The results are compared to detailed measurements. Similarities and differences to rain formation in clouds are discussed.

Measurements of accelerations of large spheres and rotation rates of rods

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Abstract: Experimental measurements of the motion of large or elongated particles can be related to small scale properties of the flow. The accelerations of spheres that are large compared with the Kolmogorov scale can be described by averaging the fluid acceleration across the size of the particle, allowing single particle acceleration measurements to provide information about the small scale spatial distribution of acceleration. When using rod shaped particles, rotation can be measured in addition to translation. Since the rotation rate of small rods is determined by both the vorticity and the strain rate, single particle measurements of rod rotation rate allows access to statistics of the velocity gradients. Further, the orientation distribution of rods can be related to the Lagrangian history of strain along the particle trajectory.

Particle concentrations in turbulent flows in the low-τ_P limit

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Abstract: The motivation for our work is to explain the particle transport induced by rising bubbles in dispersions of a liquid with solid particles, which is generally referenced in literature as bubbly flotation. The generalised problem is to determine the concentration (the probability density function) of dispersed particles in dependence on the flow. Starting from a simplified Maxey&Riley-equation, we derive a Poisson equation for the time-averaged particle concentration in statistically stationary flows, provided that the particle concentration is sufficiently low to assume one-way coupling. We introduce a modified particle response time as the only relevant scaling parameter for the material properties of the dispersed phase. An integral version of the model for the wake of a spherical cap shows good agreement with our measurement data on this two-phase wake flow.

Turbulence of dilute polymer solution: the Weissenberg Number effect

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Abstract: It is known for a long time that even a minute amount of long chain polymer added to turbulent flow changes the flow dramatically. However the mechanism of the interaction between the polymer and turbulent flow is still poorly understood. We investigate experimentally the effect of minute high-molecular-weight polymers on bulk turbulence, i.e., turbulence away from boundaries. The experiments are carried out in a fully developed turbulent von Karman flow between two counter-rotating baffled disks. Using a three-dimensional Lagrangian Particle Tracking technique, we follow simultaneously many tracer particles seeded in the flow, from which we extract both Eulerian and Lagrangian statistics of the turbulence. We report the results from measurements fo r varying Weissenberg number but constant Reynolds number and polymer concentration. We found a sharp transition of acceleration variance at Wi around one, as we usually expected. Further studies reveal that the transition Wi is different for small and larger scales.

Solid particle acceleration in a high Reynolds number channel flow : DNS versus LES with stochastic modelling of subgrid acceleration

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Abstract: Understanding and modelling the transport of inertial particles, such as sediments, is of practical interest for both industrial engineering or environmental problems. Inertial particles exhibit dynamics that are more complicated than those of the fluid. Particles are ejected from vortical regions of the turbulent flow and tend to cluster in regions of the fluid experiencing relatively low fluid accelerations (Bec et al. 2006), (Ayyalasomayajula et al. 2008). Inertial particle acceleration has been measured (Ayyalasomayajula et al. 2006) or obtained by numerical simulations (Bec et al. 2006) in the case of homogeneous isotropic turbulence. Here we focus on inertial particle acceleration statistics i n a high Reynolds turbulent channel flow. First, direct numerical simulation (DNS) coupled with Lagrangian tracking of particles is used to analyze fluid and particle acceleration statistics. These statistics are highly intermittent. Then, in the context of large-eddy simulation (LES), this intermittency is introduced through a stochastic model for the subgrid acceleration. The capability of the proposed model in the case of high Reynolds turbulent channel flow is then assessed.

Two-way coupled simulations of particle-laden wall turbulence

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Abstract: The present work aims to explore the modulations of the turbulence due to the presence of inertial solid spherical particles in plane turbulent channel flow. The turbulence field is fully resolved by means of Direct Numerical Simulations (DNS) at a frictional Reynolds number 360 (based on the wall separation h). The translational motion of the particles is handled by a Lagrangian point-particle approach. The size of the particles is assumed to be smaller than the smallest eddies and the particle Reynolds number is below unity. Since the feedback effect of the particles on the local fluid field is of primary concern, a two-way force-coupling method using a volume-force concept is implemented in accordance with Newton's third law. Only Stokes drag is considered in present work, while other forces, such as gravity, lift and virtual-mass forces are neglected. Particle-particle collisions are also negligible since the flow is assumed to be sufficiently dilute. We focus on the influence of the particle mass loading and the particle response time on the turbulence modulations. Comparisons between the particle-laden flow and an unladen channel flow are made. The results indicate that the presence of the particles leads to a remarkable increase of the mean bulk velocity if the loading is sufficiently high, i.e. drag reduction. At lower loading rates the bulk velocity is reduced. Moreover, the streamwise turbulence intensity is augmented in the high loading case whereas the spanwise turbulent intensity and, in particular, the Reynolds shear stress are attenuated compared with the unladen flow. Additionally, the overall turbulence is suppressed, i.e. the small-scale eddies are been damped, and the flow comprises larger eddies than a flow without particles. Iso-contours of the instantaneous Stokes drag-force reveal that the particles are driven by the larger eddies in the core region of the channel whereas the particles are driving the flow in the near-wall region. To explore in detail the interaction between the particles and fluid, the kinetic energy conversion will be examined by means of conditional averaging. The present results also show that the turbulence becomes more anisotropic and less energetic with higher mass loading or larger particle response time.

Rotational intermittency and turbulence induced lift experienced by large particles in a turbulent flow

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Abstract: The translation and rotation of a large, neutrally buoyant, particle, freely advected by a turbulent flow is determined experimentally. We demonstrate that both the translational and angular accelerations exhibit very wide probability distributions, a manifestation of intermittency. The orientation of the angular velocity with respect to the trajectory, as well as the translational acceleration conditioned on the spinning velocity provides evidence of a lift force acting on the particle.