EUROPEAN
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Newsletter 37

July 2010

President's Address

It is a great pleasure to announce that the 4th EUROMECH Fluid Mechanics Prize was awarded to John Hinch (University of Cambridge).

Two Fellows have been elected for their seminal contributions to Fluid Mechanics: Luca Biferale (University of Rome; Tor Vergata) and Elisabeth Guazzelli (Polytech', Marseille). These awards will be conferred on the occasion of the 8th European Fluid Mechanics Conference in September 2010 in Bad Reichenhall, Germany. We are very grateful to colleagues for taking the time to prepare the nomination packages and to the Fluid Mechanics Prize and Fellowship committee led by Alfred Kluwick for their rigorous evaluation procedure.

I am also very pleased to inform all EUROMECH members of the outcome of the recent Council elections, as reported in detail elsewhere in this issue of the Newsletter.

The following distinguished colleagues have been elected: Professor Pedro Camanho (University of Porto, Solids, Professor Viggo Tvergaard (Technical University of Denmark, Solids) and Professor GertJan van Heijst (Eindhoven University of Technology, Fluids). They will serve on the Council for six years from 1 January 2010 and we will benefit greatly from their close involvement in EUROMECH activities.

Professor Bernhard Schrefler (University of Padua, Solids) and Professor Wolfgang Schroeder (RWTH-Aachen, Fluids) expressed their willingness to continue serving EUROMECH as Secretary General and Treasurer respectively. Their re-election to the Council effectively ensures that the society will benefit from their leadership and vision for the coming years.

I would like to thank the candidates who stood for election and did not get elected. They received strong support from EUROMECH members and I very much hope that they will remain actively involved in EUROMECH.

On behalf of the Council, let me express our gratitude to the three colleagues who ended their term on the Council at the end of 2009: Professor Jorge Ambrosio (Technical University of Lisbon, Solids), Professor Detlef Lohse (University of Twente, Fluids) and Professor Henrik Myhre Jensen (Aalborg University, Solids). Their initiative and their contributions to the well-being of EUROMECH are very much appreciated.

Patrick Huerre
President, EUROMECH

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EUROMECH Council Elections

At the end of 2009, five seats on the EUROMECH Council became vacant. After consultation with the advisory board, the affiliated organisations and suggestions made by EUROMECH members, the following members stood for election to the Council for a six-year term starting 1 January 2010.

SLOT 1	B. Schrefler (S)	
SLOT 2	W. Schroeder (F)	
SLOT 3	Pedro Camanho (S)	Javier Cuadrado (S)
SLOT 4	Bruno Eckhardt (F)	GertJan van Heijst (F)
SLOT 5	Ole Sigmund (S)	Vigo Tvergaard (S)

Generally, two candidates stand for one seat and this was the case in slots 3 to 5. This rule is not an obligation imposed by the statutes: when there are good reasons, this unwritten rule needs not to be applied. This was the case in slot 1 because B. Schrefler and W. Schroeder have accepted to continue serving in 2010 as secretary-General and Treasurer respectively.

An electronic voting procedure was set-up by the Secretary General and Sara Guttilla, Scientific Officer in Udine, and voting instructions were emailed to the regular EUROMECH members.

A total of 256 votes was expressed, which is less than 1/3 of the total number of EUROMECH members required for the election to be valid. In agreement with the statutes, a second round of votes was organized, this time without restriction on the number of valid votes.

The result is as follows:

SLOT 1	139	B. Schrefler (S)		
SLOT 2	141	W. Schroeder (F)		
SLOT 3	69	Pedro Camanho (S)	60	Javier Cuadrado (S)
SLOT 4	64	Bruno Eckhardt (F)	79	GertJan van Heijst (F)
SLOT 5	44	Ole Sigmund (S)	87	Vigo Tvergaard (S)

B. Schrefler (University of Padua), W. Schroeder (RWTH-Aachen), P. Camanho (University of Porto), V. Tvergaard (Technical University of Denmark) and G. Van Heijst (Eindhoven University of Technology) are therefore elected to the EUROMECH Council. The composition of the new Council is given in this Newsletter.

Udine, May 2010

S. Guttilla, Scientific Officer B. Schrefler, Secretary General

EUROMECH Solid Mechanics Fellow 2008 Paper

“Shallow-layer flows: 2D or not 2D?”

GertJan van Heijst [1],

G.J. van Heijst was named Fellow of EUROMECH at the 7th
EUROMECH FLUID Mechanics Conference held in Manchester, September 2008

Introduction

Flows in shallow layers of fluid are encountered in a number of situations, ranging from industrial configurations to environmental or geophysical flow systems. An example of such an approximately planar flow is seen in the Landsat-7 satellite picture of Fig. 1, with the cloud distribution showing the atmospheric wake structure of the Aleutian Islands. When considering large-scale motion in a horizontal shallow layer with a free surface, it is commonly assumed that the motion is quasi-two-dimensional (quasi-2D), i.e. the principal flow field is horizontal and planar, but with a vertical gradient that is associated with the no-slip condition at the solid bottom. This effect is often parameterized by adding a linear friction term to the 2D Navier-Stokes equation, which is usually referred to as the ‘Rayleigh friction’ term. In this way the motion in the shallow fluid layer can be treated as being 2D, with an additional damping term whose origin lies in the vertical gradients of the flow.

It is well-established that 2D turbulence is characterized by an inverse energy cascade, i.e. a spectral flux of kinetic energy towards the larger length scales. Phenomenologically, the action of this inverse cascade is observed in the emergence of coherent vortices, which are particularly visible in slowly decaying 2D turbulent flows [1]. The vortices thus emerging spontaneously from an initially random vorticity distribution may take the form of monopolar or dipolar structures, and even tripolar vortices have been observed to emerge. This fascinating self-organization property of (mildly forced or decaying) 2D turbulence forms a remarkable contrast with the commonly observed behaviour of 3D turbulent flows. During the last few decades the dynamics and spectral characteristics of 2D turbulence – both forced and decaying – have received a lot of attention, and have been studied both theoretically and by numerical simulation. For a recent review of work on this topic, see Clercx & van Heijst [2].

In addition to the theoretical and numerical studies, the (quasi-) 2D turbulence dynamics has also been studied experimentally in carefully designed laboratory experiments. In order to create conditions in which the flow component in one direction is suppressed, such experiments utilized density stratification, background rotation, or the geometrical confinement as a means of creating quasi-2D flows. In the latter category, experiments were conducted in soap films and in shallow fluid layers. Recent work on shallow flows – based on table-top experiments – has revealed some unexpected, fascinating features.

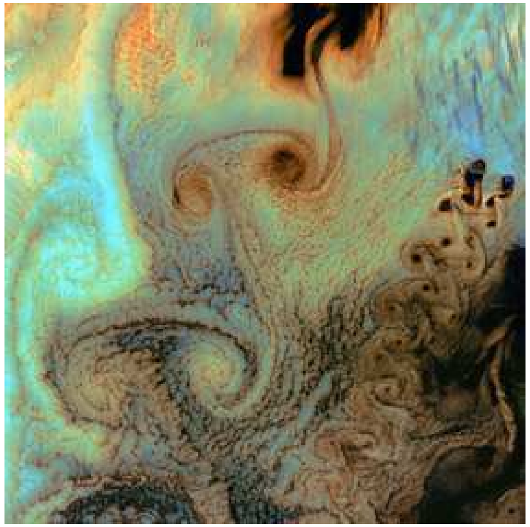

Figure 1: Satellite (Landsat-7) picture showing multiple atmospheric vortex structures in the wake behind the Aleutian Islands in Alaska, USA. (image courtesy of USGS National Center for EROS and NASA).

Laboratory experiments on vortices

Flows in a shallow-layer configuration can be conveniently generated by applying the non-intrusive technique of electromagnetic forcing: by placing a magnet underneath a layer of electrolyte through which an electrical current is flowing, the Lorentz force induced by the combined magnetic and electrical fields sets the fluid in motion locally. When using a flat, disk-shaped magnet underneath the thin tank bottom, one thus creates a dipolar vorticity structure that moves away from the forcing area. By applying a large array of magnets, with alternating polarity, one may thus generate a large collection of vortices that soon start to interact, giving the flow an irregular, turbulent appearance. This array configuration has been used in quite a few studies [3, 4, 5].

In order to ‘shield’ the fluid motion somewhat from the no-slip bottom, in some studies a two-layer stratification was used in which the motion was generated in the upper fluid layer. Flow measurements in the upper layer have been used to derive spectral and other characteristics of the supposedly 2D turbulent flow (see e.g. [3, 6, 7]).

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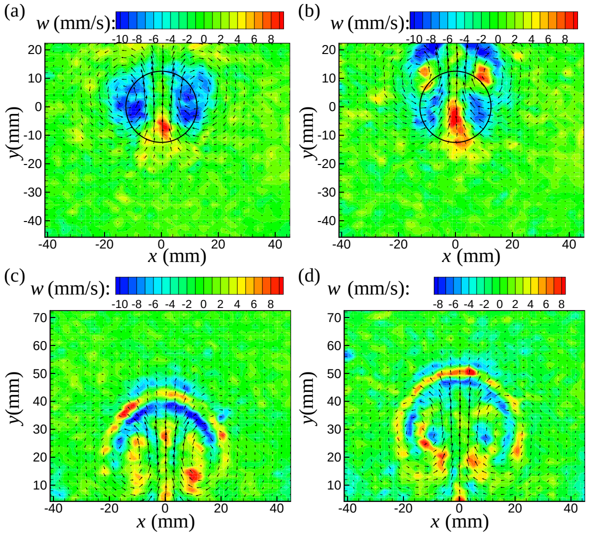

Figure 2: Sequence of graphs showing the evolution of the dipolar flow field at half-depth in a shallow-layer dipolar vortex after the electromagnetic forcing was switched off. The grey shading indicates regions of vertical velocities. Velocity measurements were carried out by using Stereo-PIV. The pictures were taken at t = 0.96 s (a), 1.5 s (b), 2.0 s (c) and 2.6 s (d), while the forcing (duration 1 s) was stopped at t = 1.0 s. (from [8])

In recent studies on a single dipolar vortex, electromagnetically forced by applying a single disk-shaped magnet underneath the electrolytic fluid layer, it was found that this generic flow structure may contain and further develop significant 3D components [8, 9]. This is clearly illustrated by Fig. 2, which shows the measured evolution of the horizontal flow field as well as the vertical velocity in the horizontal cross-sectional plane at mid depth in the fluid layer. The measurements were obtained with Stereo-PIV. The horizontal flow field is visualized by the velocity vectors, while the colour coding (grey shading) indicates the vertical velocity component. Apart from some noisy patches, it is clearly seen that two regions of downward motion develop during and directly after the forcing stage (Fig. 2a,b). The downward motion in the dipole cores is not driven by the vertical component of the Lorentz force, but is caused by a vertical pressure gradient in the horizontal swirling flow in each core. During the forcing in each swirl a cyclostrophic balance is established between the centripetal horizontal pressure gradient and the centrifugal force. Because the forcing is strongest close to the magnet, the swirling motion is less intense higher up in the fluid layer, implying a vertical pressure gradient in each swirl region, with the lowest pressure near the bottom. As a result, a secondary motion arises, downward in each dipole core, as long as the flow is forced. Once the forcing has been switched off, no swirl is maintained in the lower part of the fluid layer and the pressure builds up. Very soon after the forcing is stopped, this downward motion in the dipole cores changes into upward flow, see Fig. 2b,c.

In addition to the vertical flow in the dipole cores, a region of pronounced upward motion is observed in the tail of the dipole structure, which gradually extends forward along the dipole axis (Fig. 2a,b). Rather intense vertical motions are also seen to be present in an arc-shaped band at the front of the dipole. The double structure of upward and downward motion in this curved band suggests a ‘frontal circulation’ taking place in the form of a curved roll in front of the dipole, very similar to what has been observed by Sous et al. [9].

Akkermans et al. [7, 8] have also carried out numerical simulations with stress-free conditions at both the bottom and the free surface. It was found that the flow evolution is very similar to that for the no-slip bottom. Evidently, the initial z-dependence of the flow as induced by the electromagnetic forcing is the cause of the further development of the 3D structure of the flow, and not the no-slip bottom per se. Since the vortex dipole can be considered as a prototype flow structure, it is to be expected that more complicated flows in shallow fluid layers will also show 3D features to some extent.

Recent laboratory experiments on shallow two-layer flows, with a non-conducting bottom layer, have revealed a flow evolution similar to that shown in Fig. 2, i.e. with substantial vertical velocities both during the forcing and the post-forcing stages. These observations are confirmed by recent numerical simulations of such two-layer fluid configurations.

Laboratory experiments on an array of vortices

Shallow-layer configurations with electromagnetic forcing by a regular n x n array of magnets have been used in a number of studies [3, 5, 6, 10], aiming at experimental verification of (spectral) characteristics and vortex statistics of two-dimensional turbulence. Under the assumption of two-dimensionality, the vortices induced by the magnets would interact and gradually give rise to larger coherent vortex structures, as illustrated for example by the numerical simulations by McWilliams [1]. Recent experiments by Cieślik et al. [11, 12] on shallow flows driven electromagnetically by a regular array of 10 x 10 magnets have revealed a different flow evolution, however: in the post-forcing stage the flow shows large-scale meandering structures rather than vortices. This is clearly observed in the streak photographs presented in Fig. 3: during the forcing (Fig. 3a) the flow is organized in a regular array of 10 x 10 counter-rotating cells, but some time after the forcing has stopped large meandering currents are visible throughout the flow domain (Fig. 3b).

The flow evolution is also well observed in the dye visualization photographs shown in Fig. 4. Prior to the forcing of the flow, dye was introduced in a number of bands across the whole domain. During and after the forcing the emerging dipoles and their subsequent interactions are clearly visible, and in particular the larger meandering structures in the later stages are obvious. Stereo-PIV measurements in horizontal cross-sectional planes in the fluid layer have revealed the rather complex three-dimensional structure of the flow, both during and after the forcing. Significant vertical motion has been measured in the initial stages, when the flow consists of interacting dipolar vortices, but also in the later stages, when the large-scale meanders are present. The measurements have revealed that the strongest vertical motion is associated with downward rather than upward flow. Besides, regions of downward flow seem to be correlated with the meandering flow structures, while the weaker upward motion occurs in regions dominated by vorticity.

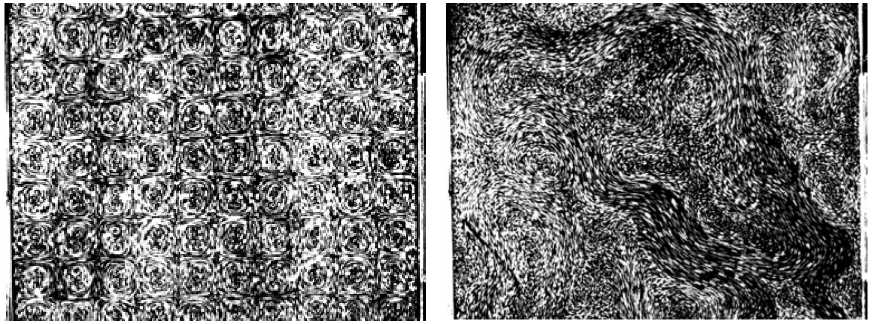

Figure 3: Streakline pictures showing how the unforced flow evolves from (a) a regular cellular pattern to (b) one with larger vortices and meandering structures. (from [11])

An important feature concerns the dispersion characteristics of shallow flows. In a numerical study, the dispersion properties were studied by releasing large quantities of passive tracers at the free surface of the fluid layer. In purely 2D simulations, they were advected without showing any clear concentration regions. In the fully 3D simulations, however, they showed a very clear tendency to accumulate in elongated patches, coinciding with areas of negative horizontal divergence, i.e. where the vertical velocity $w < 0$ below the surface.

Apparently, shallow flows generated under the conditions of the experiments reported in [7, 8, 11, 12] do not behave in a quasi-2D fashion, as is commonly assumed in experimental shallow-flow studies related to 2D turbulence. Of course, by applying a two-layer fluid configuration (as in the latter studies) the upper layer is somewhat shielded from the no-slip bottom, by which the vertical gradients are reduced to some extent. Recent high-resolution Stereo-PIV measurements in such two-layer configurations by Akkermans et al. [13], however, have revealed that significant vertical motions do still occur in the upper layer, so that the shielding by the lower layer appears to have a limited effect.

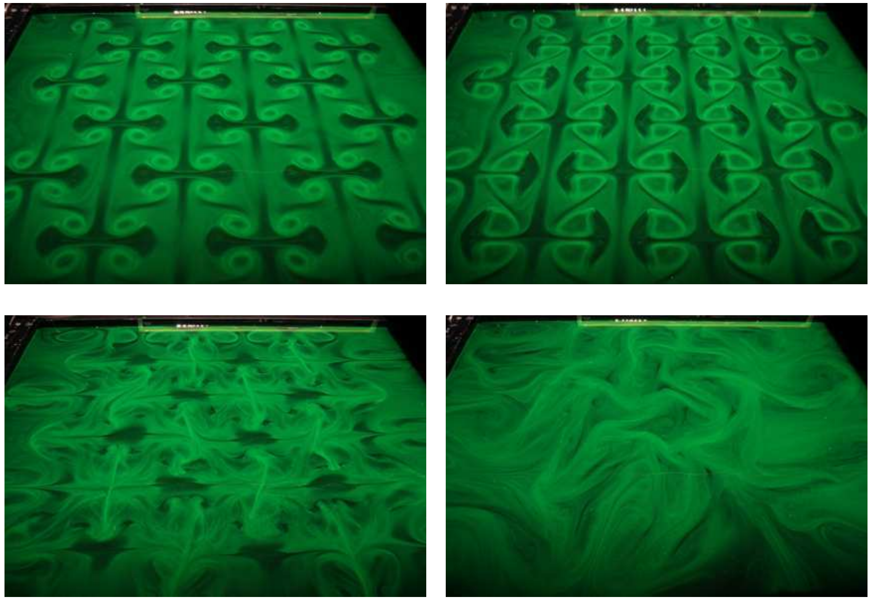

Figure 4: Sequence of dye-visualization photographs showing the evolution of the shallow flow during and after the forcing with a 10 x 10 array of magnets with alternating polarity. (photographs taken by Andrzej Cieślik)

Concluding remarks

Recent laboratory experiments and numerical simulations have clearly demonstrated that electromagnetically forced shallow-layer flows are not 2D, not even quasi-2D: vertical velocities and vertical shear may locally be substantial. In the case of single dipoles these 3D effects are seen in oscillating upwelling / downwelling flows in the vortex cores, upwelling in the tail of the dipole, and a frontal circulation roll ahead of the translating dipole. Forcing with a large array of magnets – often applied when attempting to generate a turbulent flow field – is under certain conditions found to lead to large meandering flow structures rather than to the emergence of larger coherent vortices, as predicted by the theory of 2D turbulence. Again, this behaviour is due to the 3D structures present in the shallow-layer flow, whose origin lies in the presence of the horizontal boundaries.

Although substantial progress has been made in understanding the development of the 3D structure of shallow flows, the properties of tracer transport in shallow one- or two-layer configurations are still not well understood.

in direct collaboration with my colleagues Herman Clercx, Leon Kamp and Ruben Trieling, whom I acknowledge for the many pleasant and stimulating discussions on shallow flows and other topics.

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EUROMECH Young Scientist Prize paper: “Repellers and the decay of localized pipe flow turbulence”

Marc Avila*

June 28, 2010

Marc Avila won the EUROMECH Young Scientist Prize, awarded at the 12th EUROMECH European Turbulence Conference in Marburg, September 7 - 10, 2009

Abstract

The spatio-temporal coexistence of laminar and turbulent dynamics is one of the most prominent features of shear flow turbulence. At low Reynolds number localized turbulent spots suddenly collapse and the flow returns to laminar, which gives rise to the question of whether localized turbulence remains transient or becomes persistent as the Reynolds number is increased. Efforts to elucidate this relaminarization process have led to contradictory results, either suggesting a critical point for the onset of self-sustained turbulence, or different scalings indicating transience. Extensive numerical simulations are presented here that support a super-exponential increase in turbulent lifetimes with Reynolds number and provide strong evidence that the appropriate model for localized turbulence is that of a strange repeller. The results are in excellent quantitative agreement with recent experiments.

1 Introduction

The complexity of fluid motion is fully described by the Navier–Stokes equations, which have been successfully used for more than a century to understand laminar flows. The advent of high performance computing has made it possible to simulate turbulent flows and makes accessible fully resolved information of the flow fields in space and time. In addition, numerical simulations allow one to compute unstable solutions and to modify terms in the governing equations, revealing their role in detail. These techniques have been used to obtain the first exact coherent solutions of pipe flow [1, 2], traveling waves, and have revolutionized the approach to understanding the onset of shear flow turbulence.

The problem of transition to turbulence in pipe flow has a long-standing tradition that was initiated with the seminal work of Reynolds [3]. In other canonical flows, such as convection between two differentially heated plates or swirling flow between two concentric cylinders, a wealth of patterns with increasing complexity is observed as a prelude to fully developed turbulence. In contrast, turbulence emerges in pipes in the absence of a linear instability, i.e. at a given Reynolds number (Re) the perturbations to the laminar flow have to surpass a threshold in order to trigger transition [4]. Indeed, laminar Poiseuille flow has been reported up to $Re = 100,000$ in very carefully conducted experiments [5]. Here, the Reynolds number is defined as $Re = UD/\nu$, where U is the mean speed of the flow, D the pipe diameter and ν the kinematic viscosity of the fluid.

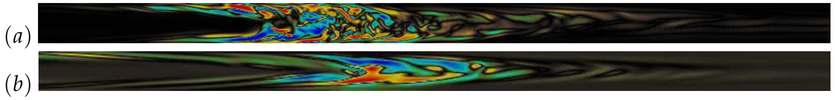

Figure 1: Localized turbulence in pipe flow at low Reynolds number (flow from left to right). The visualizations correspond to stream-wise vorticity distributions in a (r, z)-plane of (a) a turbulent puff at $Re = 2000$ and (b) a decaying puff at $Re = 1860$. In the axial direction 20 diameters are shown from a periodic domain of 50. The colormaps are scaled independently.

In practical pipes at about $Re \sim 2000$ the flows show already a strong intermittent behavior, characterized by adjacent regions of turbulent and laminar dynamics. In carefully conducted experiments the introduction of an isolated disturbance results in a so-called *puff* [6], a localized turbulent spot that propagates down the pipe at approximately the flow mean-speed while remaining constant in size (see figure 1(a)). A major feature of puffs is that they may suddenly decay, even after very long times since being generated [7]. Figure 1(b) shows a decaying puff at $Re = 1860$. This transient behavior of turbulence was already recognized in simulations of a short pipe [8], and has been identified with the presence of a strange repeller (also referred to as a chaotic saddle) in the phase space of the Navier–Stokes equations [9, 10, 11]. A key feature of the chaotic saddle is an exponential distribution of lifetimes, i.e. the probabilities of relaminarization are independent of the time that turbulence has been active [9]. The skeleton of the saddle is constructed from exact coherent solutions of the Navier–Stokes equations and their connections, and the simplest of such solutions correspond to nonlinear traveling waves [1, 2]. Indeed, close visits to such traveling waves in turbulent flows were reported in experiments [12].

The question of whether with increasing Reynolds number a bifurcation occurs that turns the repelling chaotic saddle into an attractor, is an important theoretical issue and thus has attracted much attention. The results in the literature are contradictory, with some studies reporting a crisis to sustained puff turbulence [7, 13] and others supporting a very fast, but non-diverging, increase of lifetimes [14, 15, 16]. In this paper, results obtained from numerical simulations in fully resolved long pipes are presented and compared to the existing data. Very good quantitative agreement with recent experiments [15, 16] is found, providing evidence that localized turbulence is of a transient nature.

2 Methods

The Navier–Stokes equations are solved in cylindrical coordinates using the hybrid spectral finite-difference method developed by A. P. Willis [17]. In the results presented, ±384 axial and ±24 azimuthal Fourier modes were used, whereas in the radial direction the explicit finite-difference method was used on 9-point stencils in a grid of $N = 40$ points. Time-evolution was performed with a second order accurate predictor-corrector method.

The dashed line in figure 2 shows the time-evolution of the kinetic energy of a turbulent puff at $Re = 2200$ over a $1000D/U$ time units. The full velocity field of the puff was saved at a rate of about $10D/U$, and these velocity fields were used as initial conditions for new independent simulations at lower Re, which were run until the flow relaminarized. This is illustrated by the solid lines in figure 2, corresponding to sample kinetic energy time-series of puffs after a reduction of the flow rate to $Re = 1860$.

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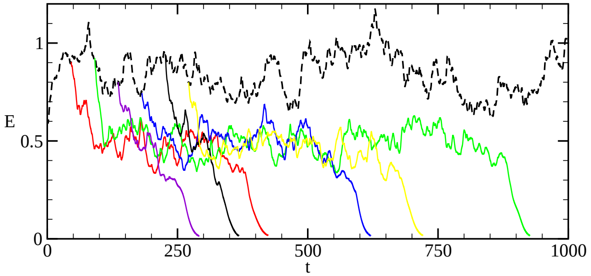
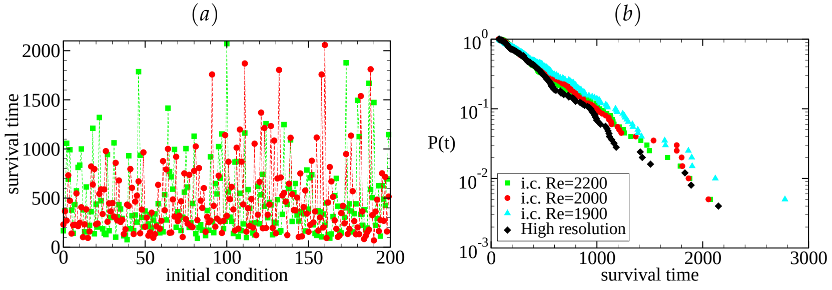


Figure 2: Time-series of the turbulent kinetic energy of a puff (figure 1(a)) at $Re = 2200$ over $1000D/U$ time units (black dashed line). The solid colored lines are the time-series obtained when the Reynolds number is reduced to $Re = 1860$. Subsequently, the puffs are active until sudden decay to laminar flow (figure 1(b)).


(a)

(b)

Figure 3: (a) Survival times for reduction simulations from $Re = 2200$ (squares) and $Re = 2000$ (circles) to $Re = 1860$ as a function of initial condition. (b) Probability of survival at $Re = 1860$ from initial conditions at $Re = 2200$ (squares), $Re = 2000$ (circles), $Re = 1900$ (triangles) and high numerical resolution (diamonds).

Repeating this procedure with 200 initial conditions, puff survival times were collected and are shown in figure 3(a) as squares. From these data, the probability of survival up to time t was obtained and is shown as squares in a logarithmic scale in figure 3(b). Here the approximately constant slope of $P(t)$ indicates the memoryless nature of the relaminarization process.

The dependence of the relaminarization probabilities on the initial conditions has been controversial as a possible source of discrepancies present in the lifetime literature. Here four data sets of initial conditions at $Re = \{2200, 2000, 1925, 1900\}$, each comprising 200 velocity fields, have been used in order to test the robustness of the lifetime distribution at $Re = 1860$. The circles (triangles) in figure 3(b) show the probability of survival from initial conditions at $Re = 2000$ (1900). In all tested cases, the results are contained in the 95% confidence interval about the prediction from $Re = 2200$. This confirms the independence of the lifetime statistics from initial conditions and hence highlights the uniqueness of the chaotic saddle associated to the puff. It is worth mentioning that further evidence has been recently provided from experiments that used four different protocols to induce the turbulent puffs [18].

The numerical resolution was checked by simultaneously increasing the number of modes in the azimuthal and axial directions by 33% and the number of finite-difference points by 25%. The results are plotted as diamonds in figure 3(b) and are within statistical certainty of the default case, indicating that turbulent puffs are accurately resolved.

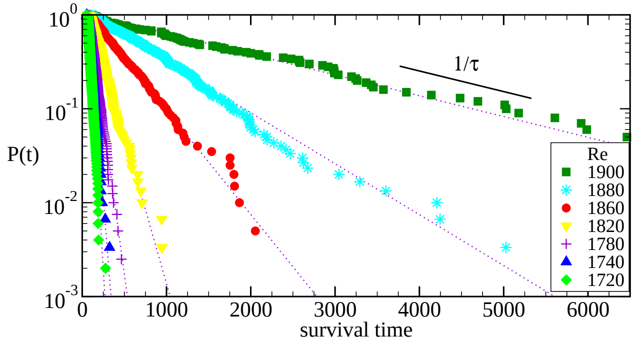


Figure 4: Probabilities of survival of turbulent puffs at several Reynolds numbers. The relaminarization is a memoryless process whose average lifetimes (τ) become longer as Re is increased.

3 Lifetime scaling with Reynolds number

In order to investigate the characteristic lifetime scaling with Re, simulations were run to obtain the probabilities of survival of a puff at several Reynolds number. The results are shown in figure 4. Here, between 200 and 500 simulations were run for each $Re \in [1720, 1880]$, whereas at the highest $Re = 1900$ investigated, only 100 cases were simulated due to the long time-evolutions required. The large sample sizes allowed to probe the underlying assumption of an exponential distribution of lifetimes. Indeed, the simulations revealed that for $Re \lesssim 1700$ the relaminarization process is no longer memoryless, in particular, the distributions decay faster than exponential. This hints at a global bifurcation that gives rise to the chaotic saddle and highlights that lifetime data with $Re \lesssim 1700$ cannot be used to infer its fate.

The scaling with Re is elucidated in figure 5, showing characteristic inverse lifetimes ($1/\tau$) as a function of Reynolds number. Here τ is the mean puff survival time and has been extracted from figure 4. With increasing Re, $1/\tau$ decreases extremely fast, although it approaches zero only asymptotically, indicating that no critical points exists in the regime investigated. In particular, the inset in the figure, which shows the same data on a logarithmic scale, reveals that the lifetimes scale super-exponentially with Reynolds number. Overall, the results are in excellent quantitative agreement with recent experiments [15], shown as $\triangle$.

The interested reader is referred to Ref. [19] for details on the statistical techniques and a detailed discussion of the discrepancies in the literature. Here it suffices to say that the experiments of Hof *et al.* (2006) [14] and Peixinho & Mullin (2006) [7], appear to be shifted by 2.5% and 7% in Reynolds number with respect to the present simulations and to the later experiments of Hof *et al.* (2008) [15] and Kuik *et al.* (2010) [16]. The agreement with the simulations of Willis & Kerswell [13] is good for $Re > 1700$, with significant differences only at $Re = 1860$. The extended sample sizes and Reynolds number range (up to $Re = 1900$) in the present simulations indicate that the lifetimes increase very fast, but without diverging.

4 Conclusions

The numerical simulations presented here support the dynamical model of a repeller for localized pipe flow turbulence. In particular, the characteristic turbulent lifetimes increase super-exponentially with Reynolds number, in excellent quantitative agree-

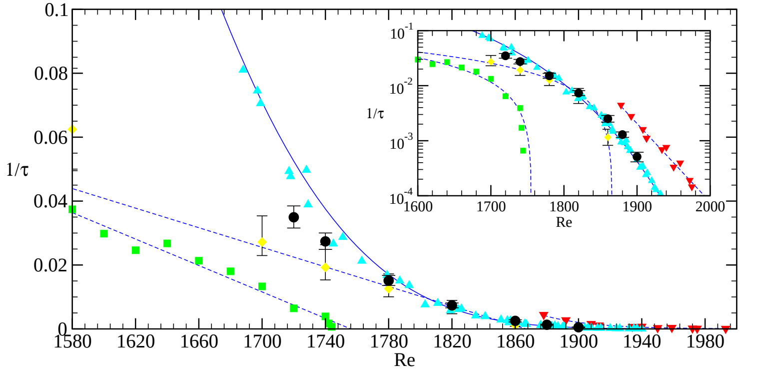


Figure 5: Inverse mean lifetime scaling with *Re* as obtained from the probabilities of survival in figure 4 (black circles). The inset with a logarithmic vertical axis shows that the lifetimes of turbulent puffs do not diverge but increase superexponentially with *Re*. The other symbols correspond to experiments by Hof *et al.* [15] (△), Hof *et al.* [14] (▽), Peixinho & Mullin [7] (□) and numerical simulations of Willis & Kerswell [13] (⋄).

ment with experiments [15, 16]. This is an uncommon achievement in transition studies, where often only statistical properties of the velocity fields or qualitative features can be compared between experiment and numerics. A similar super-exponential scaling of lifetimes has been reported for Taylor–Couette flow [20], suggesting that the dynamical model for localized turbulence might be universal in shear flows. It is worth mentioning that at higher Reynolds number, when turbulence delocalizes to fill the domain, this dynamical model may no longer be appropriate. This transition to expanding turbulence constitutes a major challenge and is the subject of current investigations.

I would like to acknowledge Ashley P. Willis and Björn Hof, with whom the work that led to the award was jointly done. A full account of the collaborative results summarized here has been published in Journal of Fluid Mechanics [19]. Support from the Max Planck Society is gratefully acknowledged.

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EUROMECH Young Scientist Prize paper: "Lagrangian statistics of inertial particles in turbulent flow"

Mickaël Bourgoin[*]

July 1, 2010

Mickaël Bourgoin won the EUROMECH Young Scientist Prize, awarded at the 12th EUROMECH European Tubulence Conference held in Marburg, September 7 - 10 2009.

Abstract

Turbulent transport of material inclusions plays an important role in many natural and industrial situations. In the present study, we report an exhaustive experimental investigation of material particles Lagrangian dynamics in a turbulent air flow, over a wide range of sizes and densities. For fixed carrier flow conditions, we find that (i) velocity statistics are not affected by particles inertia ; (ii) acceleration statistics have a very robust signature, where only acceleration variance is affected by inertia ; (iii) inertial particles always have an intermittent dynamics ; (iv) intermittency signature depends on particles inertia ; (v) particles actual response time to turbulent forcing remains essentially of the order of the carrier flow dissipation time rather than any particles dependent time (as the Stokes time for instance).

1 Introduction

Predicting the dynamics of material particles dispersed and transported in a turbulent flow remains a challenge with important applications in industrial and natural systems: dust and pollutants dispersion, industrial mixers, sediments in rivers, dispersion of gametes of marine animals, water droplets in clouds, atmospheric balloons, etc. One of the main difficulties lies in the intrinsic multi-scale nature of turbulence: depending on their size and density, particles will interact with structures of the carrier flow at different time and spatial scales. For instance neutrally buoyant particles much smaller than the dissipation scale η of the turbulent field are expected to behave as tracers, with the same dynamics as fluid particles. On the contrary particles with mismatch density and/or with size comparable to turbulent eddies, will not follow the flow exactly. We refer to these particles as inertial. How the coupling between particle dynamics and fluid dynamics is influenced by size and density effects remains an open question and a very active field of research. Several inertial effects have been known for a long time and can be interpreted qualitatively in terms of particle interaction with turbulent eddies. For instance the well known preferential concentration effect leading to the formation of clusters of inertial particles separated by depleted regions can be understood as the centrifugal expulsion of denser particles from the turbulent eddies. However an accurate quantitative description of such effects is still lacking. One of the reasons is our inability to write a proper equation of motion for inertial particles in a turbulent environment. A relatively rigorous analytical approach only exists for the limit case of point particles, for which the BBOT (Basset-Boussinesq-Oseen-Tchen) equation - revisited in 1983 by Maxey & Riley [10] and Gatignol [7] - offers a suitable model. In a more general case (finite size particles with arbitrary density), apart from some first order corrections to the BBOT equation (as Faxèn corrections for instance [4]), a valid equation of motion remains to be found. For these reason recent experimental and numerical investigations have shown much interest in studying particle acceleration, which is a direct image of the turbulent forcing experienced by the particles, a key ingredient in any dynamical model for particles motion.

The goal of the present work is to investigate experimentally how size and density affect the turbulent dynamics of particles. Comparison with predictions in the point particle limit is particularly enlightening in order to catch the range of validity of this limit case, which is by far the most documented from theoretical studies and numerical simulations. In the first section we briefly summarize main previous results concerning particle acceleration. In the second section we describe our experimental setup (acoustical Lagrangian tracking of particles transported in a grid generated wind tunnel turbulent flow). In the third section we present the results on particle dynamics. To finish, a brief discussion and comparison of experimental results with existing models is proposed.

2 Inertial particle acceleration : a brief review

As already mentioned, much effort has been put recently in characterizing the acceleration of inertial particles. In experiments, particles are characterized by their diameter D and density ρ_p. In the following we will consider the dimensionless size and density parameters: $\Phi = D/\eta$ and $\Gamma = \rho_p/\rho_f$, where η is the carrier flow dissipation scale and ρ_f is the carrier fluid density. In the point particle limit, particle inertia is generally parametrized by the so-called particle response time τ_p, which for a real particle in a smooth flow is given by the Stokes time $\tau_p = D^2(\rho_f + 2\rho_p)/(36\nu\rho_f)$ (the dimensionless Stokes number $St = \tau_p/\tau_\eta$ is commonly used). In this limit, particle response time therefore combines in a single parameter the role of size and density. It is sometimes associated with the added mass parameter $\beta = 3\rho_f/(\rho_f + 2\rho_p)$ [4]. During the past decade, high resolution Lagrangian particle tracking techniques have emerged [16, 12] which have allowed a detailed characterization of particle acceleration statistics. Figure 1a presents particle classes, in the (Φ, Γ) parameter space, which have been recently investigated experimentally. Most existing studies have considered either tracer particles ($\Phi << 1, \Gamma = 1$) or particles much denser than the carrier fluid ($\Gamma >> 1$) but small ($\Phi << 1$), or particles over a wider range of size (including $\Phi > 1$) but weakly inertial ($\Phi > 1, \Gamma < 4$).

In the case of tracers, highly intermittent Lagrangian dynamics and highly non-Gaussian acceleration statistics (with high acceleration events occuring with a probability orders of magnitude higher than a Gaussian distribution with the same variance) have been reported [9, 11]. For inertial particles, numerical simulations in the point particle limit predicted a reduction of these non-Gaussian statistical tails and a trend of acceleration probability density function (PDF) to a Gaussian shape as particles Stokes number is increased [3, 15]. This trend seems to be confirmed by recent experiments [1, 2]. Beyond the point particle limit, experiments had mainly considered so far only the case of weakly inertial particles ($\Phi > 1, \Gamma < 4$). In this situation, no clear evidence of gaussianization of acceleration PDF with increasing Stokes number has been observed. In all cases however, a trend of acceleration variance to decrease with increasing Stokes number has been reported.

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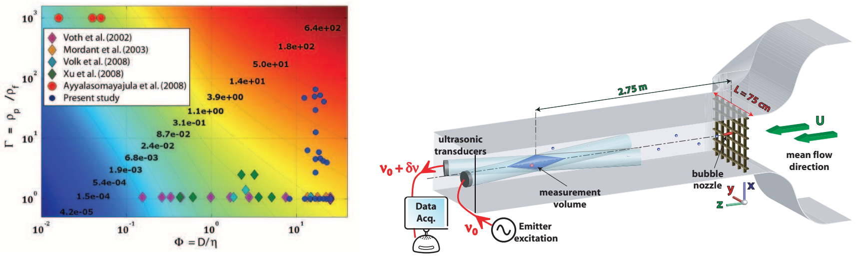


(a) (b)

Figure 1: *(a) Particle size and density parameter space explored in previous investigations of acceleration statistics. Present studies (blue circles) concern particles which are both large and dense. Background countours indicate corresponding particle Stokes number (b) Sketch of our acoustical Lagrangian tracking facility in grid generated turbulence.*

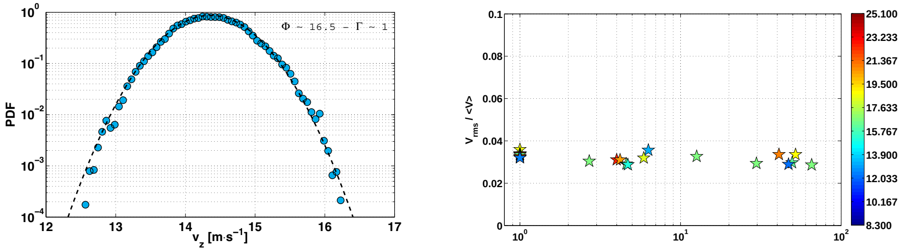
In this work we present the first measurements of particles which are both much larger than the dissipation scale of the carrier flow and significantly denser than the carrier flow (we cover the range $10 < \Phi < 30$ and $1 < \Gamma < 70$).

3 Experimental setup

Our experiment runs in a large wind tunnel with a measurement section of 75x75 cm downstream of a grid (with a 7.5 cm mesh size) which reproduces almost ideal isotropic turbulence (figure 1b). The mean velocity of the fluid is $U = 15$ ms^{-1} and the turbulence level is $u_{rms}/U \sim 3\%$. The corresponding Reynolds number, based on Taylor microscale, is of the order of $R_\lambda = 175$. The Kolmogorov dissipation scale (giving the typical size of the smallest turbulent eddies) is $\eta = (\nu^3/\epsilon)^{1/4} \sim 240\ \mu$m (where $\nu = 1.5$ m^{2}s^{-1} is the air viscosity at working temperature and $\epsilon \sim 1.0$ m^{2}s^{-3} is the turbulent energy dissipation rate per unit mass) and the energy injection scale (giving the typical size of the largest eddies) is $L \sim 6$ cm. Particles are individually tracked by 1D Lagrangian acoustic Doppler velocimetry [12, 14, 13]. We measure the streamwise velocity component v_z of the particles as they are tracked along their trajectory. Acceleration component a_z is obtained by differentiation of the velocity. As particles we use soap bubbles which we can inflate with different gases (we use helium to produce neutrally buoyant bubbles and air for denser ones) and for which we can tune the thickness of soap film to adjust the density from neutrally buoyant to about 70 times heavier than air. Bubble diameter can be adjusted independently.

4 Particle dynamics

In this section we present results on the Lagrangian dynamics of particles. The first subsection deals with single time velocity and acceleration statistics while the second one presents some results on two time statistics, with a main focus on Lagrangian intermittency and acceleration Lagrangian correlation.



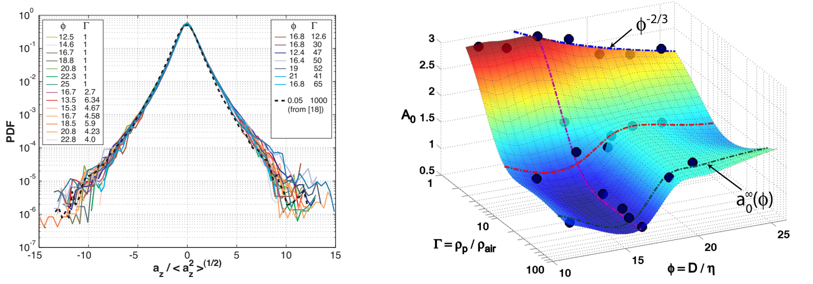
(a) (b)

Figure 2: *(a). Typical particle velocity probability distribution function. (b) Velocity flucutation rate as a function of particle density (color code indicates particle size).*

4.1 Single time statistics

Velocity statistics are found to have Gaussian fluctuations, as shown in figure 2a. We define the particle fluctuation rate as the ratio of the root mean square velocity v_{rms} and the average velocity $< V >$ (which is identical to the mean streamwise velocity U of the carrier flow). This fluctuation level is found to be independent of particle properties and does not present any trend either with particle size or with particle density (figure 2b). Moreover the corresponding fluctuation level, of the order of 3%, is identical to the turbulence level of the carrier flow itself measured from classical hotwire Eulerian anemometry. While Eulerian and Lagrangian velocity fluctuations are indeed expected to coincide for tracer particles, this result is in contrast with predictions from inertial point particle models, as the Tchen-Hinze approach [6], where a monotonic decrease of velocity fluctuation as particle inertia increases is predicted (as the result of a low-pass filtering effect from the particle response time scale). Such a filtering effect is not observed experimentally. A possible interpretation of the observed invariance could be that v_{rms} mainly reflects large scale fluctuations and should not therefore be significantly affected by a small scale filtering related to a simple Stokes number effect.

This suggest that if there is any significant change in particles dynamics, it should better be looked for in the small scales than in the large scales. A typical small scale quantity is particle acceleration. Figure 3a shows acceleration probability density functions for all the particle classes we have investigated. Note that in this plot PDFs have been normalized to unity variance. It is striking to observe that all such normalized PDFs collapse onto almost a single curve, indicating a very robust statistical signature of acceleration fluctuations that is independent of particle size and density. This observation is again in contrast with predictions based on point particle models where the filtering Stokes number effect has been shown to induce a Gaussianization of acceleration PDF with increasing particle inertia. A clear influence of particle size and density can however be observed when PDFs are not normalized to unity variance. PDFs tend then to narrow and to peak as particle density increases. The evolution of acceleration PDFs is therefore entirely coded by acceleration variance only, while the global PDF shape remains unchanged when normalized to unity variance. Size and density effects on particles acceleration statistics can therefore be entirely characterized by the single investigation of acceleration variance $< a^2 >$. Figure 3b represents the evolution of $< a^2 >$ as a function of particle size and density. Several important features need to be stressed. For neutrally buoyant particles, a monotonic decrease of $< a^2 > \sim \Phi^{-2/3}$ is observed for particles larger than $\Phi \sim 10$ (smaller particles reach the fluid tracer limit). This trend has already been reported by Voth et al. [16] and we have recently shown



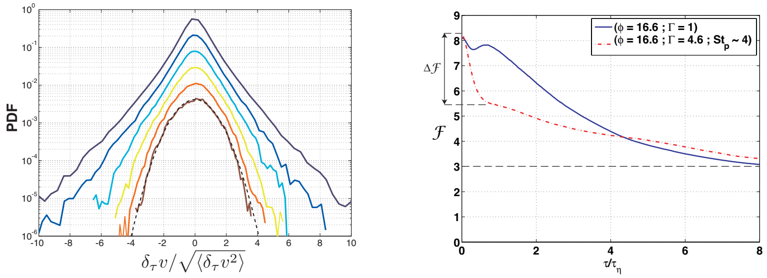
(a) (b)

Figure 3: *(a) Particle acceleration probability density function.* (b) Acceleration variance as a function of particle size and density ($< a^2 >$ is presented in the dimensionless form $A_0 =< a^2 > \epsilon^{-3/2}\nu^{1/2}$ - Heisenberg-Yaglom scaling).

that it can be interpreted as the leading role of pressure forces at the particle scale [14]. For a fixed particle size Φ, $< a^2 >$ is found to decrease monotically when particle density is increased and to reach a finite limit a_0^∞ for large density values. An interesting finding is the non trivial size dependence of a_0^∞ which is found to increase abruptly for increasing particle size around $\Phi \sim 18$. This counter-intuitive observation (it shows an increase of fluctuations with increasing particle size and therefore with increasing paricle Stokes number) needs to be understood and will be discussed later.

4.2 Two time statistics

Previous single time statistics analysis has shown that large scales (as represented by velocity fluctuations) and small scales (as represented by acceleration fluctuations) are affected differently by particle inertia. A classical way to investigate scale by scale turbulent dynamics is to consider velocity increments. Figure 4a presents PDFs of Lagrangian velocity increments ($\delta_\tau v(t) = v(t+\tau) - v(t)$) for one class of particle ($\Phi = 16.6, \Gamma = 1$). We observe a continuous deformation from highly non-Gaussian fluctuations at small scale increments (which reflect acceleration) to Gaussian fluctuations at large scale increments (which reflect velocity itself). This evolution of increments statistics with the inertial scales is representative of the intermittent nature of particle Lagrangian dynamics. An interesting finding of the present work is that intermittency is observed for all the particles which have been investigated. However, the fine signature of this intermittent dynamics is found to depend on particle inertia. To illustrate this point, figure 4b presents the evolution of increment flatness $\mathcal{F}$ (which measures the extent of PDF tails) as a function of time scale τ for two different classes of particles with fixed size and increasing density. Within error bars, flatness is comparable for both at small sub-Kolmogorov scales (this only reflects the robustness of acceleration PDF shape, already discussed above) and at large scales (flatness tend to a value of 3, which corresponds to large scale Gaussian fluctuations). However the evolution between small and large scales is strongly particle class dependent, in particular for time scales near the dissipation time scale τ_η of the carrier flow. At such scales, a clear drop $\Delta\mathcal{F}$ of the flatness (corresponding to a sudden reduction of increments PDF tails) can be observed, with an increasing amplitude as particle density is increased. Subsequently to this drop flatness smoothly tend to its large scale Gaussian limit as larger time scales are considered. This indicates that the main effects associated to particle inertia occur for time scales near τ_η. Such effects are usually expected



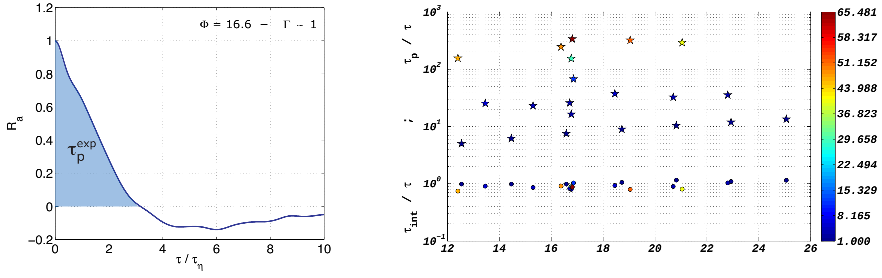
(a) (b)

Figure 4: *(a) Typical evolution of velocity Lagrangian increments. (b) Increment flatness coefficient as a function of time lag.*

to occur at a time scale related to the particle response time τ_p. Therefore, a natural question at this point is : what is the actual response time of the particle? As already mentioned, usual estimations of τ_p are based on particle Stokes time. In the limit of vanishing particles Reynolds number it is given by $\tau_p = D^2(\rho_f + 2\rho_p)/(36\nu\rho_f)$. For finite particle Reynolds number, empirical corrections to this relation can be found in the litterature [5] (these corrections have been used to estimate the Stokes time in figure 1a for instance). Inaddition to this a priori estimation of τ_p, an experimental measurement of actual particle response time to the turbulent solicitations τ_p^{exp} can be obtained from the analysis of the particle acceleration Lagrangian correlation function R_a. Such a typical correlation function is shown in figure 5a. We define the experimental particle response time as $\tau_p^{exp} = \int_0^{t_0} R_a(t)dt$, where t_0 is the first zero crossing of R_a. Figure 5b shows the evolution of a priori estimated Stokes time τ_p (stars) and experimentally measured response time τ_p^{exp} (circles) as a function of particle size and density. It is striking to observe that, while the estimated τ_p is expected to vary over more than one order of magnitude among the different particles we have investigated, the actual measured response time does not exhibit any significant change with particle size and density and remains of the order of τ_η. Not only is the actual response time different to the estimated one, but also it appears to be determined mainly by the carrier flow itself and not to change significantly with particle properties. This observation gives a crude argument for the failure of point particle models (where particles are characterized by their estimated response time as main parameter) to correctly describe the dynamics of real finite sized particles. As most filtering effects predicted in existing models are related to an increasing particle response time with increasing inertia, they cannot be present if the actual response time of the particles does not change as expected.

5 Dicussion and Conclusions

Our results for the investigation of finite sized inertial particles indicate that : (i) velocity statistics are not affected by particle inertia ; (ii) acceleration statistics have a very robust signature, where only acceleration variance is affected by inertia ; (iii) inertial particles always have intermittent dynamics ; (iv) intermittency signature depends on particle inertia ; (v) particle actual response time to turbulent forcing remains of the order of the carrier flow dissipation time rather than any particle dependent time (the Stokes time for instance). Most of these observations cannot be interpreted by a simple filtering effect (or Stokes number effect) as suggested by existing models in the limit



(a) (b)

Figure 5: *(a) Typical acceleration correlation function R_a and definition of the experimental particle response time τ_p^{exp}. (b) A priori estimated Stokes time τ_p (stars) and experimentally measured particle time τ_p^{exp} (circles) as a function of particle size (color codes particles density).*

of point particles. A first correction to this limit can be made by including so called Faxèn corrections in the point particle equation of motion. A recent numerical investigation including these corrections [4] has been shown to improve qualitative trends of the model when compared to experiments, in particular regarding the shape of acceleration statistics, but quantitative discrepancies still remain. We believe that our observations can be better understood in terms of a sampling effect, related to the preferential sampling by particles of certain turbulent structures in the carrier flow, rather than a filtering response time effect. Such preferential sampling is expected due to inertial particles clustering in the quietest regions of the flow. It would exhibit several features shared with our observations: (i) numerical simulations of stick-sweep mechanisms [8] show that inertial particles tend to cluster near low acceleration points of the carrier flow and that velocity statistics of such points are identical to overall velocity statistics of the carrier flow as observed in our experiments ; (ii) as a result of clustering, acceleration fluctuations are expected to be reduced when particle density increases; (iii) when particles become larger than the typical size of these quiet regions, an increase of fluctuations is expected as particles experience again the influence of more active surrounding structures (which could explain the increase of $< a_0^\infty >$ we have observed for $\Phi \sim 18$). Several points still need to be investigated further. Important questions remain. What fixes the shape of acceleration PDFs ? (is it somehow related to large scale properties of the carrier flow as (an)isotropy and flow confinement ?) What fixes the limit $< a_0^\infty >$ for acceleration variance at high density ratios ? Why is the particle response time so weakly affected by particle properties ? Finally, what adequate equation of motion is needed to model the dynamics of finite sized particles ?

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EUROMECH Fellows: Nomination Procedure

The EUROMECH Council was pleased to announce the introduction of the category of **EUROMECH Fellow**, starting in 2005. The status of Fellow is awarded to members who have contributed significantly to the advancement of mechanics and related fields. This may be through their original research and publications, or their innovative contributions in the application of mechanics and technological developments, or through distinguished contribution to the discipline in other ways.

Election to the status of Fellow of EUROMECH will take place in the year of the appropriate EUROMECH Conference, EFMC or ESMC respectively. The number of fellows is limited in total (fluids and solids together) to no more than one-half of one percent of the then current membership of the Society.

Nomination conditions:

- The nomination is made by **two sponsors** who must be members of the Society;
- Successful nominees must be members of the Society;
- Each nomination packet must contain a completed Nomination Form, signed by the two sponsors, and no more than four supporting letters (including the two from the sponsors).

Nomination Process:

- The nomination packet (nomination form and supporting letters) must be submitted **before 15 January** in the year of election to Fellow (the year of the respective EFMC or ESMC);
- Nominations will be reviewed before the end of February by the EUROMECH Fellow Committee;
- Final approval will be given by the EUROMECH Council during its meeting in the year of election to Fellow;
- Notification of newly elected Fellows will be made in May following the Council meeting;
- The Fellow award ceremony will take place during the EFMC or ESMC as appropriate.

Required documents and how to submit nominations:
Nomination packets need to be sent before the deadline of **15 January** in the year of the respective EFMC or ESMC to the President of the Society. Information can be obtained from the EUROMECH web page **www.euromech.org** and the Newsletter. Nomination Forms can also be obtained from the web page or can be requested from the Secretary-General.

EUROMECH - European Mechanics Society

NOMINATION FORM FOR FELLOW

NAME OF NOMINEE:…………………………………………………………………………

OFFICE ADDRESS:…………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

EMAIL ADDRESS:…………………………………………………………………………

FIELD OF RESEARCH: ……………………………………………………………………

Fluids: ☐ Solids: ☐

NAME OF SPONSOR 1: ……………………………………………………………………

OFFICE ADDRESS:…………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

EMAIL ADDRESS:…………………………………………………………………………

SIGNATURE & DATE: ……………………………………………………………………

NAME OF SPONSOR 2: ……………………………………………………………………

OFFICE ADDRESS:…………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

EMAIL ADDRESS:…………………………………………………………………………

SIGNATURE & DATE: ……………………………………………………………………

SUPPORTING DATA

- Suggested Citation to appear on the Fellowship Certificate (30 words maximum);
- Supporting Paragraph enlarging on the Citation, indicating the Originality and Significance of the Contributions cited (limit 250 words);
- Nominee’s most Significant Principal Publications (list at most 8);
- NOMINEE’S OTHER CONTRIBUTIONS (invited talks, patents, professional service, teaching etc. List at most 10);
- NOMINEE’S ACADEMIC BACKGROUND (University Degrees, year awarded, major field);
- NOMINEE’S EMPLOYMENT BACKGROUND (position held, employed by, duties, dates).

SPONSORS’ DATA

Each sponsor (there are two sponsors) should sign the nomination form, attach a letter of recommendation and provide the following information:

- Sponsor’s name;
- Professional address;
- Email address;
- Eponsor’s signature/date.

ADDITIONAL INFORMATION

Supporting letters (no more than four including the two of the sponsors).

TRANSMISSION

Send the whole nomination packet to:
Professor Patrick Huerre
President EUROMECH
Laboratoire d’Hydrodynamique, École Polytechnique
91128 Palaiseau Cedex, France
E-mail: huerre@ladhyx.polytechnique.fr

EUROMECH Prizes: Nomination Procedure

Fluid Mechanics Prize
Solid Mechanics prize

Regulations and Call for Nominations

The *Fluid Mechanics Prize* and the *Solid Mechanics Prize* of EUROMECH, the European Mechanics Society, shall be awarded on the occasions of Fluid and Solid conferences for outstanding and fundamental research accomplishments in Mechanics.

Each prize consists of 5000 Euros. The recipient is invited to give a Prize Lecture at one of the European Fluid or Solid Mechanics Conferences.

Nomination Guidelines:

A nomination may be submitted by any member of the Mechanics community. Eligible candidates should have undertaken a significant proportion of their scientific career in Europe. Self-nominations cannot be accepted.

The nomination documents should include the following items:

- A presentation letter summarizing the contributions and achievements of the nominee in support of his/her nomination for the Prize;
- A curriculum vitae of the nominee;
- A list of the nominee's publications;
- At least two letters of recommendation.

Five copies of the complete nomination package should be sent to the Chair of the appropriate Prize Committee, as announced in the EUROMECH Newsletter and on the Society's Web site www.euromech.org Nominations will remain active for two selection campaigns.

Prize committees

For each prize, a Prize Committee, with a Chair and four additional members shall be appointed by the EUROMECH Council for a period of three years. The Chair and the four additional members may be re-appointed once. The committee shall select a recipient from the nominations. The final decision is made by the EUROMECH Council.

Fluid Mechanics Prize

The nomination deadline for the Fluid Mechanics prize is **15 January in the year of the Fluid Mechanics Conference**. The members of the *Fluid Mechanics Prize and Fellowship Committee* are:

- A. Kluwick (Chair)
- O. E. Jensen
- D. Lohse
- P. Monkewitz
- W. Schröder

Chairman's address
Professor A. Kluwick
Institut für Strömungsmechanik und Wärmeübertragung
Technische Universität Wien
Resselgasse 3,
A -1040 Wien, Austria
Tel. : +43 1 58801 32220
Fax : +43 1 58801 32299
Email: akluwick@mail.tuwien.ac.at

Solid Mechanics Prize

The nomination deadline for the Solid Mechanics prize is **15 January in the year of the Solid Mechanics Conference**. The members of the *Solid Mechanics Prize and Fellowship Committee* are:

- W. Schiehlen (Chair)
- H. Myhre Jensen
- N.F. Morozov
- M. Raous
- B. A. Schrefler

Chairman's address
Professor W. Schiehlen
Institut für Technische und Numerische Mechanik
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Pfaffenwaldring 9
D-70550 Stuttgart, Germany
Tel. : +49 711 685-66391
Fax : +49 711 685-66400
Email: schiehlen@itm.uni-stuttgart.de

EUROMECH Conferences in 2010 - 2011

The general purpose of EUROMECH conferences is to provide opportunities for scientists and engineers from all over Europe to meet and to discuss current research. Europe is a very compact region, well provided with conference facilities, and this makes it feasible to hold inexpensive meetings.

The fact that the EUROMECH Conferences are organized by Europeans primarily for the benefit of Europeans should be kept in mind. Qualified scientists from any country are of course welcome as participants, but the need to improve communications within Europe is relevant to the scientific programme and to the choice of leading speakers.

A EUROMECH Conference on a broad subject, such as the ESMC or the EFMC, is not a gathering of specialists all having the same research interests. Much of the communication which takes place is necessarily more in the nature of imparting information than exchange of the latest ideas. A participant should leave a Conference knowing more and understanding more than on arrival, and much of that gain may not be directly related to the scientist's current research. It is very important therefore that the speakers at a Conference should have the ability to explain ideas in a clear and interesting manner, and should select and prepare their material with this expository purpose in mind.

2010

EFMC8
8th European Fluid Mechanics Conference
DATE: 13 – 16 September 2010
LOCATION: Bad Reichenhall, Germany
CONTACT: Prof. Nikolaus A. Adams
E-MAIL: nikolaus.adams@tum.de
WEBSITE : http://efmc8.aer.mw.tum.de/

2011

ENOC7
7th European Nonlinear Oscillations Conference
DATE: 24 - 29 July 2011
LOCATION: Rome, Italy
CONTACT: Prof. Giuseppe Rega
E-MAIL: giuseppe.rega@uniroma1.it

ETC13
13th European Turbulence Conference
DATE: 5 - 8 September 2011
LOCATION: Warsaw, Poland
CONTACT: Prof. Konrad Bajer
E-MAIL: kbajer@fuw.edu.pl

EUROMECH Conferences Reports

7th European Fluid Mechanics Conference

14-18 September 2008, Manchester, UK

Chairperson: Prof. Peter Duck

The 7th EUROMECH Fluid Mechanics Conference took place on September 14-18th 2008 at the University of Manchester. The conference was attended by 439 researchers from around the world, including 179 researchers under the age of 35. The main purpose of the Conference was to bring together researchers with a common interest in fluid mechanics.

The 312 oral presentations in 68 contributed sessions covered the entire range of topics in fluid mechanics including the theoretical, computational and experimental areas of the discipline. Each of the oral presentations (12 minutes) in these sessions was followed by time for questions and further discussion.

In addition, four day-long minisymposia were hosted, focusing on the topics of Subcritical flow instability, Internal bio-fluids, Granular flows and Nature-inspired fluid mechanics. In these minisyposia, as well as contributed papers, a number of invited papers were presented in each session by experienced researchers, with the aim of providing training to early-stage researchers in these particular areas of fluid mechanics research.

Furthermore, eight plenary lectures were presented by internationally-recognized researchers, and F. Busse was awarded the EUROMECH Fluids Prize and gave the EUROMECH Fluids Lecture entitled What can Thermal Convection Teach Us about the Nature of Turbulence?

The two coffee breaks and the lunch that took place each day, as well as the three social events, provided many opportunities for further discussion, interaction and networking. This was the first large-scale meeting to take place in the newly opened University Place conference facility and much positive feedback was received by the organisers regarding the facilities, the organisation of the event and the quality of the papers presented. The conference banquet was held at Manchester United Football Club.

The website www.mims.manchester.ac.uk/events/workshops/EMFC7/index.php remains live, at which abstracts of all presentations, together with the presentations of the plenary lecturers can be found.

7th European Solid Mechanics Conference

7-11 September 2009, Lisbon, Portugal

Chairperson: Prof. Jorge Ambrosio

ESMC2009 was attended by 631 participants from 50 countries. Altogether, 1 general lecture, 6 plenary lectures, 1 lecture by the EUROMECH Solid Mechanics Prize Winner and about 588 presentations were delivered in 7 general sessions and 25 organized mini-symposia.

A website with all information concerning the conference was opened in 2007 and maintained until the end of the Conference (http://www.dem.ist.utl.pt/esmc2009/). In order to ensure participation by the most active researchers in Solid Mechanics in Europe and to make the conference attractive to the rest of the world, a period of applications for the organization of mini-symposia was opened. Ultimately, there were 25 mini-symposia at the conference and several of their organizers decided to publish special issues of scientific journals dedicated to ESMC2009. Contributions to the general sessions and to the mini-symposia were solicited during mid-2008.

About 950 extended abstracts (2 pages) were received, addressing all the topics proposed for ESMC2009. The scientific committee for the Conference, chaired by Prof. Raymond Ogden, reviewed all the abstracts proposed for the general sessions. Abstracts submitted to the mini-symposia were reviewed by the organizers and by at least one member of the scientific committee, so that a high overall standard could be achieved. About 650 abstracts were accepted for presentation at ESMC2009. In order to ensure the full commitment of the participants to presentations, the minimization of the no-shows and the correct representation of all participants, a rule of no more than one presentation per participant was implemented. Furthermore, only presentations by registered and paid-up participants appeared in the scientific programme and in the conference proceedings. With these rules, only 24 participants cancelled their participation during the month prior to the conference or did not show.

Optional full length papers were invited and 239 were published in the conference proceedings on CD-ROM. This allowed two objectives to be met:

- participants could widen their funding opportunities (today, many funding agencies only support applications that include a paper in the proceedings);
- organizers of any mini-symposium that led to a special issue of a scientific journal had the full-length paper for early peer review.

The proceedings were published in two volumes, with a companion CD-ROM. The first volume contains the edited abstracts of the lectures and presentations in the general sessions. The second contains abstracts of the mini-symposia presentations. The CD-ROM contains the abstracts and full-length papers for all oral and poster presentations at ESMC2009.

The scientific programme of ESMC2009 was organized according to the traditional arrangement for this conference. An opening ceremony and the lecture by the EUROMECH Solid Mechanics Prize winner took place on the first day, together with the general lecture. Plenary lectures were the first events of morning and post-lunch sessions. There were ten parallel sessions for oral presentation in general sessions and mini-symposia. A special session for poster presentations was organized for the morning of the third day, posters having been on display in a prime meeting area throughout, to ensure high visibility.

All sessions were chaired by established scientists and were well attended. Timing was organised carefully to ensure that participants could move easily from one session to another. The opening plenary session was attended by more than 500 participants while there were about 400 at the closing session.

The Best Paper and Best Poster awards to scientists under the age of 35 were made during the closing ceremony. Each had a nominal value of 500€. It was decided to give two Best Paper awards and one Best Poster award, in view of the large number of good presentations by young scientists. The winners were:

Best Paper Awards:

- Margarida Machado, University of Minho, Portugal, for: ‘Development and Implementation of a Generic Methodology for Contact Dynamics of the Human Knee Joint’
- Oscar Lopez-Pamies, State Univ. of New York, USA, for: ‘Onset of Cavitation in Hyperelastic Solids under Arbitrary Loading Conditions’

Best Poster Award:

- Yuriy Natanzon, Institute of Nuclear Physics, Poland, for: ‘Quantum Mechanical Calculations of Elastic Properties of Doped Tetragonal Yttria-Stabilized Zirconium Dioxide’.

EUROMECH Colloquia in 2010-2011-2012

EUROMECH Colloquia are informal meetings on specialized research topics. Participation is restricted to a small number of research workers actively engaged in the field of each Colloquium. The organization of each Colloquium, including the selection of participants for invitation, is entrusted to a Chairman. Proceedings are not normally published. Those who are interested in taking part in a Colloquium should write to the appropriate Chairman. Number, Title, Chairperson or Co-chairperson, Dates and Location for each Colloquium in 2010, and preliminary information for some Colloquia in 2011 and 2012, are given below.

EUROMECH Colloquia in 2010

505. Multiscale effects in fatigue metals

Chairperson : Dr. Andrei Constantinescu
CNRS Ecole Polytechnique
Laboratoire de Mécanique des Solides
91128 Palaiseau cedex, France
Phone:+33 1 69 33 57 56
Fax: +33 1 69 33 57 06
E-mail: andrei.constantinescu@lms.polytechnique.fr
Co-Chairperson: Dr. Pedro Donatella Portella
Dates and location: 5-9 July 2010, Palaiseau, France
Website:http://www.lms.polytechnique.fr/users/constantinescu/Euromech/index.html

513. Dynamics of non-spherical particles in fluid turbulence

Chairperson: Prof. Helge I. Andersson
Department of Energy and Process Engineering
Norwegian University of Science and Technology
7491 Trondheim, Norway
Phone: +47 73 59 35 56
Fax: +47 73 59 34 91
Email: helge.i.andersson@ntnu.no
Co-Chairperson: Prof. Alfredo Soldati
Dates and location: 29 September 2010 - 1 October 2010, Trondheim, Norway

515. Advanced applications and perspectives of mutibody system dynamics

Chairperson: Prof. Dr. Evtim Zahariev
Institute of Mechanics
Bulgarian Academy of Sciences

Acad. G. Bonchev St., bl. 4
1113 Sofia, Bulgaria
Phone: +359-2-9547147
E-mail: evtimvz@bas.bg
Co-chairperson: Prof. Marco Ceccarelli
Dates and location: 13-16 July 2010, Blagoevgrad, Bulgaria
Website: http://www.imbm.bas.bg/euromech515

517. Interfaces and inhomogeneous turbulence

Chairperson: Prof. Ian Eames
University College London
Torrington Place
London, WC1E 7JE, UK
Phone: +44 20 7679 3550
Fax: +44 20 7388 0180
E-mail: i_eames@meng.ucl.ac.uk
Co-chairpersons: Prof. Jerry Westerweel, Prof Carlos B. da Silva
Dates and location: 28-30 June 2010, UCL, London, UK.
Website: http://www.lasef.ist.utl.pt/london2010/Home.html

518 Biomechanics of the Eye

Chairperson: Dr. Jennifer Siggers
Department of Bioengineering
Imperial College London
London SW7 2AZ, UK
Phone: +44 (0)20 7594 3663
Fax: +44 (0)20 7594 9817
E-mail: j.siggers@imperial.ac.uk
Co-chairperson: Dr. Rodolfo Repetto
Dates and location: 26-28 July 2010, Imperial College, London, UK.
Website: http://www3.imperial.ac.uk/bioengineering/events/euromech

519. Mixing and dispersion in flows dominated by rotation and buoyancy

Chairperson: Prof. Herman Clercx
Fluid Dynamics Laboratory, CC 2.15
Department of Applied Physics
Eindhoven University of Technology
PO Box 513
NL-5600 MB Eindhoven, The Netherlands
Phone: + 31 40 247 2680 or + 31 40 247 3110
Fax: + 31 40 246 4151
E-mail: h.j.h.clercx@tue.nl
Co-chairperson: Dr. Beat Lüthi

Dates and location: 20-23 June 2010, Conference Centre Rolduc, Limburg, NL.
Website:http://web.phys.tue.nl/nl/de_faculteit/capaciteitsgroepen/transportfysica/fluid_dynamics_lab/euromech_colloquium_519/

520. High Rayleigh number convection

Chairperson: Prof. Francesca Chilla
Ecole Normale Supérieure de Lyon
Laboratoire de Physique
46 allée d'Italie
69007 Lyon, France
Email: francesca.chilla@ens-lyon.fr
Dates and location: 24-29 January 2010, Les Houches, France
Website: http://www.hirac4.cnrs.fr/

EUROMECH Colloquia in 2011

511. Biomechanics of Human Motion. New Frontiers of Multibody Techniques for Clinical Applications

Chairperson : Prof. Jorge A.C. Ambrosio
IDMEC- Instituto Superior Tecnico
Av. Rovisco Pais 1
1049-001 Lisbon, Portugal
Phone: +351 2184 17680
Fax: +351 2184 17915
E-mail: Jorge@dem.ist.utl.pt
Co-Chairpersons: Prof. Frans van der Helm, Prof. Andrés Kecskemethy
Dates and location: March 2011 (postponed from March 2010), Açores, Portugal

516. Nonsmooth contact and impact laws in mechanics

Chairperson: Prof. Bernard Brogliato
INRIA Grenoble Rhone-Alpes
Inovallée
655 avenue de l'Europe
Montbonnot, 38 334 Saint Ismier Cedex France
Email: bernard.brogliato@inrialpes.fr
Co-chairpersons: Prof. Christoph Glocker, Prof. Caishan Liu
Dates and location: 6-8 July 2011, Grenoble, France

521. Biomedical Flows at Low Reynolds Numbers

Chairperson: Prof. Leonhard Kleiser
Institute of Fluid Dynamics
ETH Zurich
Switzerland

Email: kleiser@ifd.mavt.ethz.ch
Co-chairpersons: Prof. Thomas Rösgen Prof. Timothy Pedley
Dates and location: 29 - 31 August 2011, ETH Zurich, Switzerland
Website: http://www.ifd.mavt.ethz.ch/research/EC521

522. Recent Trends in Optimization for computational Solid Mechanics

Chairperson: Prof. Paul Steinmann
University Erlangen/Nuremberg
Erlangen, Germany
Email: paul.steinmann@ltm.uni-erlangen.de
Co-chairpersons: Prof. Kai-Uwe Bletzinger, Prof. Gunther Leugering
Dates and location:October 2011, Erlangen/Nuremberg, Germany
*Website: **http://www.ifd.mavt.ethz.ch/research/EC521***

523. Ecohydraulics: linkages between hydraulics and ecological processes in rivers

Chairperson: Prof. Wim S.J. Uijttewaal
Environmental Fluid Mechanics section
Faculty of Civil Engineering and Geosciences
Postbox 5048, 2600 GA Delft, The Netherlands
Email : w.s.j.uijttewaal@tudelft.nl
Co-chairpersons: Dr. Johannes Steiger
Dates and location:June-July 2011, GEOLAB University Blaise Pascal Clermont-Ferrand, France

525. Instabilities and transition in three-dimensional flows with rotation

Chairperson: Prof. Benoît Pier and Prof. Fabien Godeferd
Laboratoire de mécanique des fluides et d'acoustique
CNRS-Université de Lyon
École centrale de Lyon
36 avenue Guy-de-Collongue
F-69134 Lyon, France
Email: benoit.pier@ec-lyon.fr
Email: fabien.godeferd@ec-lyon.fr
Co-chairpersons: Prof. Nigel Peake
Dates and location: June 2011, École centrale de Lyon, France

526. Patterns in soft magnetic matter

Chairperson: Dr. habil. Adrian Lange
Chair Magnetofluiddynamik
Institute of Fluid Mechanics
TU Dresden
D-01062 Dresden, Germany
Email: adrian.lange@tu-dresden.de

Co-chairpersons: Dr. Sofia Kantorovich
Dates and location: March 2011, Dresden, Germany

527. Shell-like Structures – Nonclassical Theories and Applications
Chairperson: Prof. Dr.-Ing. Holm Altenbach
Lehrstuhl Technische Mechanik
Zentrum für Ingenieurwissenschaften
Martin-Luther-Universität Halle-Wittenberg
Kurt-Mothes-Str. 1
06120 Halle (Saale), Germany
Email: holm.altenbach@iw.uni-halle.de
Co-chairpersons: Prof. Victor A. Eremeyev
Dates and location: August 2011

529. Cardiovascular Fluid Mechanics
Chairperson: Prof. Giorgio Querzoli
Dipartimento di Ingegneria del Territorio,
Università di Cagliari
Via Marengo 3
09123 Cagliari, Italy
Email: querzoli@unica.it
Co-chairpersons: Prof. Gianni Pedrizzetti
Dates and location :27 - 29 June 2011, Cagliari, Italy
Website: http://cvfm.unica.it/

530. Structural Control and Energy Harvesting
Chairperson: Dr. Simon Neild
Department of Mechanical Engineering
University of Bristol
Queen's Building
University Walk
Bristol, BS8 1TR, UK
Email : Simon.Neild@bristol.ac.uk
Co-chairpersons: Prof. Dan Inman
Dates and location: 25 – 27 July 2011, University of Bristol, UK

531. Vortices and waves: identifications and mutual influences
Chairperson: Prof. Yuli D. Chashechkin
Institute for Problems in Mechanics of the Russian Academy of Sciences
101/1 prospect Vernadskogo
Moscow, 119526, Russia
Email: chakin@ipmnet.ru

Co-chairpersons: Prof. Xavier Carton
Dates and location: June 2011, Moscow, Russia

EUROMECH Colloquia in 2012

524. Multibody system modelling, control and simulation for engineering design
Chairperson: Prof. Ben Jonker
University of Twente, Faculty CTW
Mechanical Automation
P.O. Box 217 – Building Horst
7500 AE Enschede, The Netherlands
Email : J.B.Jonker@utwente.nl
Co-chairpersons: Prof. Werner Schiehlen
Dates and location: February/March 2012, Ensched, The Netherlands

528. Wind Energy and the impact of turbulence on the conversion process
Chairperson: Dr. Joachim Peinke
Institute of Physics & ForWind
University of Oldenburg
D 26111 Oldenburg, Germany
Email: peinke@uni-oldenburg.de
Co-chairpersons: -
Dates and location: April 2012, Oldenburg, Germany

514. New trends in Contact Mechanics
Chairperson: Dr. Michel Raous
Directeur de Recherche CNRS
Laboratoire de Mécanique et d'Acoustique
31, Chemin Joseph Aiguier
13402 Marseille Cedex 20, France
Email : raous@lma.cnrs-mrs.fr
Co-chairpersons: Prof. Peter Wriggers
Dates and location: May 2012, Marseille, France

EUROMECH Colloquia Reports

EUROMECH Colloquium 497

"Recent Developments and New Directions in Thin-Film Flow"

6-9 July 2009, Edinburgh; UK

Chairperson: Prof. Stephen K. Wilson

Thin films of fluid are of central importance in numerous industrial, biomedical, geophysical and domestic applications and display a rich and varied range of behaviours, including pattern formation, de-wetting, rupture and finite-time blow up. As well as being of great interest in their own right, thin-film flows provide a "test bed" for research into a huge range of challenging nonlinear problems in physics, chemistry and mathematics. As a consequence research by a wide range of scientists, including physicists, engineers, chemists and mathematicians, using a wide variety of analytical, numerical and experimental techniques on many different aspects of thin-film flow, has grown dramatically in recent years as novel applications have continued to appear and increasingly sophisticated theoretical and experimental techniques have been developed.

The aim of EUROMECH 497 was to bring together the leading international experts in thin-film flow from across several different traditional academic disciplines, including mathematics, engineering, physics and chemistry, to report on their latest discoveries and to foster new inter-disciplinary collaborations. The meeting was a natural continuation of an unofficial series of meetings on thin-film flow that has taken place in recent years, including the famous International Centre for Mathematical Sciences (ICMS) workshop on "The Dynamics of Thin Films" held in Edinburgh in 1999 and the more recent (and also highly successful) EUROMECH 490 meeting on "Dynamics and Stability of Thin Liquid Films and Slender Jets" held in London in 2007.

EUROMECH 497 was organised by Professor Stephen Wilson and Dr Brian Duffy from the Department of Mathematics at the University of Strathclyde in Glasgow together with Professor George "Bud" Homsy from the University of California, Santa Barbara, USA. Following a competitive bidding process, the meeting secured the valuable support of the ICMS in Edinburgh, who organised the meeting on our behalf and recognised the significance of EUROMECH backing. ICMS also unlocked significant external funding from other sources, namely £20,100 from the UK Engineering and Physical Sciences Research Council (ESPRC) and £1,000 from the London Mathematical Society (LMS) via the support given to the entire ICMS program by these two organisations. This support allowed us to provide all participants with accommodation for four nights in local guest houses, a cheese and wine reception, an informal evening meal and a workshop dinner, plus substantial morning and afternoon refreshments on all four days of the workshop.

All of the scientific sessions took place in the historic Royal Society of Edinburgh, with the reception in the nearby ICMS building (the house in which James Clark Maxwell was born in 1831). The mix of participants was international, with 7 from France, 6 from Germany, 4 from the USA, 2 from the Netherlands and 1 from each of Belgium, Ireland, Israel and India, in addition to the 26 from the United Kingdom.

A full list of participants and talks together with some photographs taken during the meeting can be found on the workshop webpages at http://www.icms.org.uk/workshops/thinfilms. Scientifically the meeting was very successful, with 49 participants present for the duration of the workshop and a full programme of 40 scientific presentations. Around ten research papers written by participants in the workshop will be published in a special themed issue of the Journal of Engineering Mathematics on "thin-film flow", guest edited by Wilson and Duffy and scheduled to appear in late 2010 or early 2011. It will begin with an introduction describing EUROMECH 497 and how all of the papers in the volume were either presented at the meeting or are closely related to work described at the meeting.

Feedback from participants confirmed the friendly and lively, but scientifically challenging, nature of the workshop. Areas identified by the participants as key future research areas and/or directions in the field included:

- Thin films in the boundaries of biology, chemistry and physics;
- The dynamics of contact lines;
- Microfluidic applications;
- Thin-films in the presence of complexities (e.g. complex fluids, stochastic effects and particle rheology);
- Flow over textured surfaces/in complex geometries.

Many participants felt that the meeting helped them to develop/sustain contacts likely to result in new research and that the workshop had resulted in new ideas or the acquisition of new techniques or methods. There were many positive comments about the practical arrangements. A workshop booklet, containing full details of all the talks, the participants and the domestic arrangements is available. We are very grateful for the support given by EUROMECH and look forward to another EUROMECH meeting in the general area of thin-film flow in the not too distant future.

EUROMECH Colloquium 520

“High Rayleigh number convection”

25-29 January 2010, Les Houches, France

Chairperson: Professor Francesca Chilla
Co-chairperson: Professor Detlef Lohse

Thermal convection is a very common phenomenon present both in nature and in industrial and laboratory flows. One of the common and apparently simple systems is the Rayleigh-Benard system, where a fluid is heated from below and cooled from above. Some years ago, this problem had been considered to be basically solved. However, improvements in experimental and numerical techniques have led to new insights. These improvements allow high Rayleigh number measurements, large and small Prandtl number measurements, flow visualizations, PIV measurements which give access to the velocity field, measurements on non-Boussinesq effects, and measurements under rotation. Moreover, flows such as channel convective flow give interesting insights into the problem of convection and they require more discussion. The goal of EUROMECH 520 and the associated Les Houches workshop was to allow for an exchange of ideas on recent developments in the field.

There were altogether 52 participants and 32 talks, including 8 by key-note speakers:

- Jeywant Arakeri (Bangalore);
- Enrico Calzavarini (Ens-Lyon);
- Hermann Clerx (Eindhoven);
- Ronald Dupuits (Ilmenau);
- Denis Funfschilling (Nancy);
- Ulrich Hansen (Munster);
- Philippe Roche (Grenoble);
- Shengqi Zhou (Hong Kong).

Three main subjects, on which significant advances have been made recently, were addressed in the talks during the first three days and debated in a round table discussion at the end of the corresponding day:

- Non-Boussinesq effects
- Effects of rotation
- Heat flux at Ra > 1012

On the fourth and fifth days, space was left to address related problems such as Rayleigh-Taylor turbulence and convective channel flow. The special Les Houches formula with lectures in the morning and at the end of the afternoon left time for discussion and collaborative work. The informal atmosphere and the beautiful environment facilitated personal contacts and discussion.

Non-Boussinesq effects

Non-Oberbeck-Boussinesq (i.e. fluids parameter as viscosity or thermal diffusivity depending on temperature) conditions have been largely discussed. Numerical simulations and experimental results have been presented. The most relevant non-Boussinesq effects were identified and in some cases numerical simulations, theory, and experiments nicely agree. In other cases, e.g. when the fluid becomes compressible, the insight is less developed and further investigations are needed.

Effects of rotation

Rotation is an important parameter acting on geophysical convective flows such as in the atmosphere or in the earth's core. The most recent experiments and numerical simulations on Rayleigh-Benard with rotation were presented. Several interesting effects have been shown. The main issue addressed during the round table discussion was the intermediate regime in which the effect of rotation is to enhance the heat transfer. This regime seems to vanish for very large Rayleigh number.

Heat flux at Ra > 1012

The discrepancy between Oregon data and Grenoble data for Nusselt numbers with Ra > 1012 was still an open question. This conference has witnessed the end of a 15 years controversy. The problem is now being addressed from a new point of view: above Ra = 1012, multi-stability of the flow must be taken into account. Some of the parameters influencing the state of the flow can now be defined. The round table discussion focused on the question of how to characterize the most conductive regime. Is it a Kraichnan regime? This is still an open question.

Channel Flows

A new kind of flow seems to be very interesting for study of convection. It is the flow in a vertical channel between two chambers that are at different densities. Two different approach were presented: difference of density induced by either salt concentration or by temperature. Also numerical simulations (infinite channel or periodic flow) were presented.

Character of the kinetic and thermal boundary layer

Though older theories assume a turbulent boundary layer with a scaling of $\lambda_u = L/Re$ for its thickness, it became clear meanwhile that the Reynolds and thus Rayleigh number dependence of λ_u is weaker. The profiles of both boundary layers were controversially discussed at the beginning of the workshop. They could depend on the large-scale flow and eventually also on the aspect ratio. During the workshop Xia and co-workers presented new exciting results from recent PIV measurements in slightly tilted cells: conditional averaging leads to clear Prandtl-Blasius profiles both for the velocity and the temperature fields, at both Pr=4.3 (water) and Pr=0.7 (gas).

Flow visualizations

Flow visualizations turn out to be essential for the comprehension of the physical mechanisms. Many useful visualizations of flows were shown during the workshop, derived from both experiments and numerical simulations. PIV measurement techniques in particular have improved significantly in the last three years.

We thank Ecole de Physique de Les Houches for hospitality and EUROMECH, the ENS Lyon, the Laboratoire de Physique, the COST action MP0806, the Ecole Doctoral PHAST, and the CNRS for financials support.

Objectives of EUROMECH, the European Mechanics Society

The Society is an international, non-governmental, non-profit, scientific organisation, founded in 1993. The objective of the Society is to engage in all activities intended to promote in Europe the development of mechanics as a branch of science and engineering. Mechanics deals with motion, flow and deformation of matter, be it fluid or solid, under the action of applied forces, and with any associated phenomena. The Society is governed by a Council composed of elected and co-opted members.

Activities within the field of mechanics range from fundamental research on the behaviour of fluids and solids to applied research in engineering. The approaches used comprise theoretical, analytical, computational and experimental methods. The Society shall be guided by the tradition of free international scientific co-operation developed in EUROMECH Colloquia.

In particular, the Society will pursue this objective through:

- The organisation of European meetings on subjects within the entire field of mechanics;
- The establishment of links between persons and organisations including industry engaged in scientific work in mechanics and in related sciences;
- The gathering and dissemination of information on all matters related to mechanics;
- The development of standards for education in mechanics and in related sciences throughout Europe.

These activities, which transcend national boundaries, are to complement national activities.

The Society welcomes to membership all those who are interested in the advancement and diffusion of mechanics. It also bestows honorary membership, prizes and awards to recognise scientists who have made exceptionally important and distinguished contributions. Members may take advantage of benefits such as reduced registration fees to our meetings, reduced subscription to the European Journal of Mechanics, information on meetings, job vacancies and other matters in mechanics. Less tangibly but perhaps even more importantly, membership provides an opportunity for professional identification; it also helps to shape the future of our science in Europe and to make mechanics attractive to young people.

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