DY 57: Focus Session: Turbulence - From Pattern Formation to Stochastic Disorder

Turbulence is the natural state of motion for a fluid flow driven far from equilibrium. Beyond the laminar state, flows can show regular patterns superposed with mild turbulent fluctuations, like convection not too far from onset, or they can be vigorously turbulent in the fully developed turbulent regime. In some settings, regular large-scale patterns even coexist with strong turbulent fluctuations. This variety of states makes turbulence a paradigm of a complex system with a large number of strongly interacting degrees of freedom. With coherent structures on many scales interacting in a complex manner, fully developed turbulence falls in between purely random and pattern-forming systems. This unique combination makes it a challenging research field with connections to non-equilibrium statistical mechanics, pattern formation and stochastic processes. This focus session comprises contributions investigating the spectrum of flow states summarized above and shall review our current understanding of turbulence, its origin as well as its interplay with coherent large-scale patterns. (Organizers: Ronald du Puits, Joachim Peinke, Michael Wilczek)

Time: Thursday 15:00–18:45 Location: H46

Invited Talk DY 57.1 Thu 15:00 H46

The Transition to the Ultimate State in Turbulent Thermal Convection — •Eberhard Bodenschatz — Max Planck Institut für Dynamik und Selbstorganisation, Göttingen, Deutschland

We report measurements of turbulent Rayleigh-Bénard convection in three cylindrical samples with the aspect ratios (diameter/height) $\Gamma = 1.00, 0.50$ and 0.33. All samples had the same diameter $D = 1.1$m, but different heights L. Compressed sulfur hexafluoride gas (SF_6) at pressures up to 19 bars was used as the fluid at the Göttingen Turbulence Facility (see www.EuHIT.org) The measurements were conducted over the Rayleigh-number range $10^{12} \lesssim Ra \lesssim 4 \times 10^{15}$ and for Prandtl numbers Pr near 0.8. In three independent measurements, namely global heat transport, local turbulent Reynolds number, and large scale circulation dynamics, we observed as a function of Rayleigh number a transition over a range of Ra from the classical regime to a regime that can be considered ultimate. Consequences thereof will be discussed and so will be the influence of rotation.

The work was conducted with Guenter Ahlers, Denis Funfschilling, Dennis van Gills, Xiaozhou He, Holger Nobach, and Stephan Weiss.

DY 57.2 Thu 15:30 H46

Percolation model for laminar-turbulent transition of a boundary layer: experimental insight by Particle Image Velocimetry — •Tom Wester, Dominik Traphahn, Pedro G. Lind, Gerd Gülker, and Joachim Peinke — Carl von Ossietzky University, Oldenburg, Germany

The boundary layer's transition from laminar to turbulent is a very complex process, which at present is not fully understood. In order to fully capture this complexity with a very limited number of characteristic stochastic properties, this experimental study aims at describing the phase transition by means of the directed percolation model.

In contrast to the majority of previous studies, the underlying data base is acquired experimentally by high-speed Particle Image Velocimetry. Thus, a boundary layer evolving on a flat plate can be captured in a highly resolved spatio-temporal manner. In this way, sufficient data is provided to determine critical probabilities and critical exponents which describe the transient area between laminar and turbulent boundary layer within the scope of directed percolation. First results from this approach will be presented and compared to theoretical expectations.

DY 57.3 Thu 15:45 H46

Boundary layers in turbulent Rayleigh-Bénard convection — •Ronald du Puits[1] and Christian E. Willert[2] — [1]Institute of Thermodynamics and Fluid Mechanics, Technische Universitaet Ilmenau, POB 100 565, 98684 Ilmenau, Germany — [2]Institute of Propulsion Technology, German Aerospace Center, 51170 Koeln, Germany

The heat transport throughout a fluid layer heated from below and cooled from above is mainly determined by two very thin flow regions adjacent to the hot bottom and the cold top wall. They are referred to as boundary layers. Following a hypothesis of Kraichnan [R. H. Kraichnan. Turbulent Thermal Convection at Arbitrary Prandtl Number. Phys. Fluids 5, 1374-1389 (1962)] it is widely believed nowadays that these boundary layers are of laminar type below a critical threshold in Rayleigh number and that they become turbulent above this limit. We show the results of highly resolved PIV measurements of the near-wall flow field in the large-scale convection facility Barrel of Ilmenau, an experiment which is seven meters in diameter and eight meters in height. Our measurements show that the dynamics of those boundary layers and the formation of coherent structures inside go far beyond a laminar shear layer of Prandtl-Blasius type although the Rayleigh number is considerably below the threshold predicted by Kraichnan.

DY 57.4 Thu 16:00 H46

Multi-PIV Measurements of an Adverse Pressure Gradient Turbulent Boundary Layer — •Christian Willert[1], Christian Kähler[2], Andreas Schröder[3], Julio Soria[4], Michel Stanislas[5], and Jean-Marc Foucaut[5] — [1]Institut für Antriebstechnik, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Köln, Germany — [2]Institut für Strömungsmechanik und Aerodynamik, Universität der Bundeswehr München — [3]Institut für Aerodynamik und Strömungstechnik, DLR, Göttingen, Germany — [4]Monash University, Melbourne, Australia — [5]Laboratoire de Mécanique de Lille, CNRS, Villeneuve d'Ascq, France

We report on a multi-national measurement campaign aimed at providing highly resolved flow field data of a turbulent boundary layer subjected to an adverse pressure gradient (APG). In the case of APGs the structure and dynamics of large scale turbulent flow structures along with their significance on the statistical properties of the flow is not well understood. Hence the fundamental aim was to resolve and characterise the large-scale coherent structures in an APG boundary layer flow. In addition to large-field-of-view PIV measurements using 16 sCMOS cameras along a 3.5m length, stereoscopic PIV measurements were performed at specific locations in order to also resolve the span-wise velocity statistics. Long-distance, high-speed micro-PIV measurements provided near wall statistics at selected locations including the time-resolved wall shear stress. The measurements were performed in the boundary layer wind tunnel of the Laboratoire de Mécanique de Lille (LML) and funded by EuHIT (www.euhit.org).

DY 57.5 Thu 16:15 H46

Microrheology of sphere-shaped and anisometric rod-shaped objects in 2D fluids — Christoph Klopp, •Alexey Eremin, and Ralf Stannarius — Institute of Experimental Physics, Otto von Guericke University Magdeburg, Universitätsplatz 2, 39016 Magdeburg, Germany

Flow phenomena in restricted geometries have been intensively studied in the last years with implications to different physical, chemical and biological systems. Those studies usually employ indirect measurements of the inclusion mobilities for the lack of a convenient 2D model system. On the other hand, smectic liquid crystals form freely-suspended fluid films of highly uniform structure and thickness, making them ideal systems for studies of hydrodynamics in two dimensions. We study the mobility of sphere-shaped and rod-shaped inclusions in freely-suspended liquid crystal films. We demonstrate that in thin films, the mobility is primary determined by the coupling of the fluid to the surrounding air, as predicted by the Saffman-Delbrück theory. The effect of particle anisometry appears when the size of the particle is comparable to or larger than the hydrodynamic size of the system (Saffman length).

The authors acknowledge the support by DFG (STA 425-28)

15 min. break

DY 57.6 Thu 16:45 H46

Characterizing multi-scale interaction in turbulence — •Cristian C Lalescu and Michael Wilczek — Max Planck Institute for Dynamics and Self-Organization

Turbulence is a true multi-scale phenomenon with a broad range of interacting spatial and temporal scales. It is well known that in a linear system, unique length scales are associated to well-defined time scales, through a dispersion relation. A naive application of the 1941 Kolmogorov theory also yields a simple characteristic time scale for each given length scale. In the case of real turbulence, however, interactions take place between structures with different characteristic sizes and life times, leading to a continuous spectrum of length scales associated to a time scale and vice versa.

In this work, we aim to characterize these turbulent multi-scale interactions quantitatively. To this end, we identify the time scales relevant for structures of a given size, both from an Eulerian and a Lagrangian perspective. By employing filtering techniques in space and time, we compare turbulent velocity fields containing length scales above a given cutoff-scale with time-filtered fields. Varying the filter widths and times yields a precise picture of the various interactions. In a second step, we generalize the analysis to the Lagrangian frame to study the impact of large- and small-scale fluctuations on turbulent particle transport.

DY 57.7 Thu 17:00 H46

Reproducibility of turbulent flows in wind tunnel experiments using different active grids — •Lars Kröger, Joachim Peinke, and Gerd Gülker — ForWind, Center for Wind Energy Research, University of Oldenburg, 26129 Oldenburg, Germany

As wind turbines are mainly working inside the turbulent atmospheric boundary layer, the performance of the turbine and resulting structural loads are strongly influenced by the dominating highly intermittent wind fields. Regarding the chaotic nature of turbulence, reproducible measurements in situ are quite difficult and wind tunnel experiments with reproducible and controllable turbulent inflow conditions are of increasing importance. Here we present an active grid with which customized turbulence can be generated in wind tunnel applications. Experiments have shown that it is already possible to replicate atmospheric like turbulence regarding specific statistical properties as intermittency, turbulence intensity or integral length. In this contribution results from hotwire measurements behind two active grids in two wind tunnels of different dimensions are presented. The aim is to determine which requirements are necessary to reproduce the same downstream turbulence behind the different grids as accurately as possible.

DY 57.8 Thu 17:15 H46

Lagrangian intermittency in an ensemble of Gaussian velocity time series with fluctuating time scales — •Laura Lukassen and Michael Wilczek — Max Planck Institute for Dynamics and Self-Organization, Goettingen

Turbulent velocity fluctuations exhibit intermittency in both, the Lagrangian and Eulerian frame. Here, we focus on the Lagrangian velocity increments whose probability density function shows a transition from a nearly Gaussian shape to highly non-Gaussian shapes for decreasing time lags. This inherent non-Gaussianity poses a challenge for statistical approaches suffering from the closure problem.

Our aim is to derive an analytically tractable model of turbulence which captures the characteristics of turbulence such as intermittency. We discuss the properties of an ensemble of Gaussian velocity time series in which the characteristic time scales of the ensemble members are drawn from an underlying distribution of those scales. Such an ensemble naturally exhibits non-Gaussian statistics as has been demonstrated, e.g., in the context of multifractal modeling. In order to provide a more general approach, our model is based on the characteristic functional which captures the complete statistical information of the ensemble. As a result, non-trivial statistical information such as joint statistics of increments at various scales or joint statistics of acceleration and increments can be obtained. Based on that, we will discuss the potential of formulating novel closures in the framework of our approach.

DY 57.9 Thu 17:30 H46

Intermittent Inflow Generation in CFD — •Sebastian Ehrich[1], Bernhard Stoevesandt[2], and Joachim Peinke[1,2] — [1]University of Oldenburg, Institute of Physics, ForWind, Germany — [2]Fraunhofer IWES, Oldenburg, Germany

Complex and unsteady interactions between highly turbulent atmospheric inflow and the flow over wind energy converting systems (WECS) are of crucial importance with respect to the loads on the rotor blades. The disturbed inflow leads to a strong variation of the effective inflow angle over the entire rotor blade radius. Unsteady aerodynamic effects are the reason for phase shifts between excitation and resulting loads, but those effects have not been well described by models yet.

The content of this work is the implementation of a stochastic model based on continuous time random walks (CTRW) for wind fields in the CFD Opensource Code OpenFOAM as an inflow condition. The purpose of this project is the correct description and simulation of short scale fluctuations and extreme events described by longitudinal velocity increments. Those are interesting for load and fatigue calculations on wind turbines. Further, different simulation test cases are shown for proper analysis of turbulence characteristics of the model and the effect of filtering in LES compared to DNS simulations. Especially the decay of turbulence and the evolution of the increment probability density functions in space and time are considered.

DY 57.10 Thu 17:45 H46

Quantifying non-locality in fully developed incompressible turbulence — •Dimitar Vlaykov and Michael Wilczek — MPI for Dynamics and Self-Organisation, Goettingen, Germany

The complexity of turbulence flows is deeply rooted in the non-locality of the governing Navier-Stokes equations. The latter can be understood as the formal dependence of even the short-term evolution of a fluid element on the state of the entire system. In incompressible hydrodynamics, the Navier-Stokes equations encode this through the kinematic pressure gradient. The pressure is determined by a Poisson relation sourced by the difference between the squared rate-of-strain and the enstrophy. This links the non-local pressure to the small-scale topology of the flow.

In this presentation we aim at quantifying the nature and the range of the pressure contributions. In particular, we attempt to characterize the neighbourhood, which contains the governing part of the contributions, via a statistical analysis of a sequence of sub-domains of increasing size. Additionally, we consider the link between the small-scale structure topology and the destructive interference between vortices and strain sheets.

DY 57.11 Thu 18:00 H46

Large-scale structures in the temperature field in turbulent Rayleigh-Bénard convection — •Christian Resagk and Christian Kästner — TU Ilmenau, Ilmenau, Deutschland

Large-scale structures in temperature fields in turbulent convection is a less-studied phenomenon in large aspect ratio convection cells. Furthermore, the existence of superstructures in temperature fields is only known from direct numerical simulations and was not experimentally confirmed so far. Against this background we investigated large-scale circulation in water, applied to a Rayleigh-Bénard cell with large aspect ratio Γ=30 and Rayleigh numbers about Ra=10^4-10^6. We introduce temperature field measurements under the given conditions for the first time. Hence the major aim of this work was on the one hand checking the applicability of temperature field measurements and the accessible thermal resolution in turbulent flow by laser induced fluorescence (LIF) and thus the investigation of changing conditions from weak to strong turbulence, may yielding long term stabilization/oscillation of the convective flow. The Rayleigh number was controlled by adjusting the temperature gradient between hot bottom and cold top enclosure of the convection cell about ΔT=0-35 K. The convective flow of heat was monitored by particle imaging velocimetry (PIV) and compared with contact-less temperature field measurements by LIF, based on temperature induced fluorescence intensity variations of Rhodamin B added to the water. Both, PIV and LIF, were measured in 532 nm light sheet irradiation in the horizontal and vertical plane of the convective cell.

DY 57.12 Thu 18:15 H46

Cluster analysis of coherent structures in Rayleigh-Bénard convection — •Oliver Kamps — Center for Nonlinear Science, University of Münster

Turbulence is an ubiquitous physical phenomenon settled somewhere between randomness and order. On the one hand turbulent flows seem to be irregular and chaotic but on the other hand one can observe coherent structures, patterns or superstructures constituting the flow. The identification of these structures and their dynamics is crucial for the understanding of turbulent flows and therefore for applications in science and engineering.

In many cases the coherent structures live only for a certain time span followed by a rapid transition to another state like a different coherent structure. Such a transition can be regarded as an extreme event which is accompanied by strong distortions of observables like heat transport or mixing. In our approach we use clustering based methods [1] in order to identify these non-stationary states, estimate dynamical models for their time evolution and to anticipate extreme events. As example we apply our methods to Rayleigh-Bénard convection showing reversals.

[1] A. Hutt, M. Svensén, F. Kruggel and R. Friedrich, Phys. Rev. E **61** (2000)

DY 57.13 Thu 18:30 H46

Global flow modes in turbulent Rayleigh-Bénard convection

— •Robert Kaiser and Ronald du Puits — Institute of Thermodynamics and Fluid Mechanics, Technische Universität Ilmenau, Postfach 10 05 65, Ilmenau 98694, Germany

The modes of the global flow structure inside a Rayleigh-Bénard convection cell are analysed by time resolved local wall heat flux data. The measurements were performed at the heating plate of the large scale convection facility, called the Barrel of Ilmenau, using infrared thermography. The experimental data reveals a fundamental change of the heat transport processes between an aspect ratio $1<G<3$, where the large scale vortex splits into two smaller vortices. In 2007 du Puits et al. measured profiles of the velocity and temperature in the boundary layer below the cooling plate at various aspect ratios G in the Barrel of Ilmenau. Between $1.47<G<1.89$, the maximum velocity falls down by 20%. Thus, the critical aspect ratio Gc of the change in the modes of the global flow structure was estimated by a linear interpolation at Gc=1.68. We re-evaluated this value by calculating the average life time of the one-vortex-state and the two-vortex-state between $1<G<3$. The new Gc=1.65 states more precisely the change in the global flow structure in turbulent Rayleigh-Bénard convection.