Advances in Turbulence XIII

Proceedings of the

13th European Turbulence Conference

12-15 September 2011
University of Warsaw
Poland

Edited by

K. Bajer
J. Kopeć
M. Kursa
K. Kwiatkowski
P. Podziemski

www.etc13.fuw.edu.pl
Organisers

European Turbulence Conference Committee

K. Bajer (Poland)
E. Bodenschatz (Germany)
C. Casciola (Italy)
P.A. Davidson (UK)
B. Eckhardt (Germany)
Y. Kachanov (Russia)
E. Lindborg (Sweden)
D. Lohse (The Netherlands) – Chairman
J.-F. Pinton (France)
N. Sandham (UK)

Local Organising Committee

K. Bajer (Chairman)
J. Kopeć
M. Kursa
K. Kwiatkowski
M. Lisicki
P. Podziemski
K. Wędołowski

Voluntary helpers: S. Arabas, M. Grądzki, M. Grzędzieski, D. Jasiński, K. Nurowska, M. Sosnowska, M. Tomaszewski, K. Wesołek, P. Żuk

We gratefully acknowledge the Sponsors

With special thanks to the Faculty of Physics and to the University of Warsaw Foundation for sponsoring the publication of the Proceedings of the 13th European Turbulence Conference. European Community on Flow Turbulence and Combustion (ERCOFTAC) and European Mechanics Society (EUROMECH) provided much appreciated financial support to several young participants.

Logistic Organiser of ETC13
WWW.GLOBALWINGS.PL
University of Warsaw (UW), established in 1816, is Poland's largest and finest university. It is recognized throughout the world as a leading academic centre in this part of Europe. In 2010 and 2011 UW has been declared number 1 in the ranking published by the national daily Rzeczpospolita and the education monthly Perspektywy.

Today UW employs over 6,200 people, including 3,240 academic teachers and educates almost 53,700 undergraduate and graduate students. Each year over 20,000 young people enrol as students at the University of Warsaw. Their interest in studying at UW results above all from the University's prestige, something UW has earned through the high educational level it offers and the research work.

EUROPEAN MECHANICS SOCIETY

www.euromech.org

EUROMECH is an international non-governmental non-profit scientific organization. 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 EUROMECH Council has overall responsibility for Euromech Colloquia and Euromech Conferences. The latter presently comprise the EUROMECH Solid Mechanics Conference (held every three years), the EUROMECH Fluid Mechanics Conference (held every two years), the EUROMECH Turbulence Conference (held every two years), the EUROMECH Nonlinear Oscillations Conference (held every three years) and the EUROMECH Mechanics of Materials Conference (held every year).
The ETC13 and other events comprising Warsaw Turbulence Week were organised by the faculty members and students of the Faculty of Physics. Together with the team from the Interdisciplinary Centre for Mathematical and Computer Modelling (ICM), the organisers are currently involved in several turbulence-related projects including:

- **Modelling of gasification and combustion of the produced gas**
  
  [website](http://www.syngasburner.eu)

- **Support Platform for Operational Decisions Depending on the State of the Atmosphere**
  
  [website](http://www.projekt-proza.pl)

- **DEmonstration of LIdar based Clear Air Turbulence Detection**
  
  [website](http://www.delicat-fp7.org)

- **European High-Performance Infrastructures in Turbulence**
  
  [website](http://www.euhi.eu)

- **Elaboration of Integrated Technologies for the Production of Fuels and Energy from Biomass as well as from Agricultural and other Waste Materials**
  
  [website](http://www.strateg-z4.imp.gda.pl)

- **Particles in Turbulence**
  
  COST Action MP0806

  [website](http://http://mp0806.cineca.it)

- **INTERNATIONAL COLLABORATION FOR TURBULENCE RESEARCH**
  
  [website](http://www.ictr.eu)
Preface

Turbulence is an area of challenging intellectual pursuit where many disciplines overlap, from pure mathematics to practical engineering. Turbulence is an old concept, whose origins are traced back to Leonardo da Vinci, established in modern science in the first half of the 19th century. The subject is developing at an increasing pace as the experimental techniques are perfected and the power of numerical simulations is multiplied. Yet, many important problems are still unsolved and pose great challenge. On the one hand basic questions remain unanswered at a fundamental mathematical level. On the other hand there is growing demand for accurate and fully realistic numerical simulations validated against the state-of-the-art laboratory experiments.

Making progress requires concerted efforts on the global scale. European Turbulence Conference much contributes to these efforts by providing a unique platform where young as well as established scientists can meet, interact and share their experience thus keeping abreast the most recent developments in the subject.

The ETC is a biennial conference organised under the auspices of the European Mechanics Society EUROMECH (www.euromech.org). Twenty five years have passed since the ETC1 held in 1986 in Lyon, France. This year the University of Warsaw hosted the ETC13 giving us an opportunity to celebrate the silver jubilee of this conference series which is now a well-established landmark and much appreciated forum for the vibrant community of turbulence research. The venue was the Old University Library close to the Warsaw Old Town. The quiet surroundings of the historic academic campus, particularly beautiful in the perfect weather of early autumn, gave the conference, in spite of the large number of participants, an almost familial atmosphere of an interactive, topical meeting.

ETC13 attracted 441 scientists, including 153 students (numbers in parentheses), from 35 countries:

| Country       | Participants | Contributors | Posters |
|---------------|--------------|--------------|---------|
| Algeria       | 1 (1)        |              |         |
| Argentina     | 1 (1)        | 3            |         |
| Australia     | 6 (2)        | 69 (21)      |         |
| Austria       | 1 (1)        | 65 (30)      |         |
| Brazil        | 4 (1)        | 1            |         |
| China         | 5 (2)        | 5 (3)        |         |
| Czech Republic| 9 (3)        | 1 (1)        |         |
| Denmark       | 1 (1)        | 5 (2)        |         |

Participants also included 9 representatives of sponsors presenting their exhibitions and 8 students working as voluntary helpers. We had 417 presentations including 8 invited lectures (45 mins.) listed below, 309 contributed papers (15 mins.) and 99 posters. Programme and abstracts are available on the ETC13 web site www.etc13.fuw.edu.pl.

The ETC13 was immediately followed by the Symposium on Turbulence – the Historical Perspective. For one day and a half the 180 participants enjoyed eleven lectures on the historical development of the fundamental ideas in turbulence research and on the sometimes turbulent
lives of the past luminaries of the subject. The lectures were based on the historical essays published this year by Cambridge University Press in the volume entitled *A Voyage Through Turbulence* edited by P.A. Davidson, Y. Kaneda, H.K. Moffatt and K.R. Sreenivasan. The lectures of the Symposium, delivered in the appropriate historical Auditorium of the Faculty of Physics, were filmed and the video footage is now available on www.etc13.fuw.edu.pl/historical-turbulence. The additional attraction of the Symposium was the lunch-time show of the original films made in 1913 by Henri Bénard on his convection experiments. Bénard was a visionary who already a century ago recognised the power of motion pictures in physical experiment and teaching. The show was narrated by G. Lemoult drawing on the Bénard’s exhaustive scientific biography by J. E. Wesfreid\(^1\).

The popularity of the Symposium showed that the historical perspective is a much appreciated complement to the ETC offering a current account of the most recent progress. We think that this need for historical continuity and link between past and modern developments is prominent, if not specific, to the field of fluid mechanics in general and turbulence research in particular, where the same fundamental, intrinsic difficulties, both physical and mathematical, are faced by subsequent generations. We are glad that the historical companion of ETC13 showed to such a large number of young scientists that the challenges of today’s research were recognised as hard problems by the father figures of the past.

The ETC13 and the Historical Symposium were the two main events of what, in effect, became Warsaw Turbulence Week. In the evening between the two conferences we had an open public lecture on *The Importance and Fascination of Turbulence* by Professor Lord Julian Hunt who outlined the birds-eye view of the status of our discipline from the perspective of an eminent scientist involved for many years in both theoretical and applied research in this field. The lively discussion that followed focused on the interesting and mutually enriching interplay between the scientific and political activities. Last but not least Warsaw Turbulence Week was a good place and time for various European working groups to arrange their business meetings. The COST Action MP0806 *Particles in Turbulence* organised a mini-symposium on *Fragmentation Processes in Turbulent Flows* while the EuHIT Consortium ceased the opportunity to have a discussion session.

Over the years the ETC Proceedings, published in the series *Advances in Turbulence*, have become a recognised and valued source of knowledge about current developments in turbulence research. *Advances in Turbulence XII* (Proceedins of the ETC12 held in 2009 in Marburg, Germany), was the first volume published on line. Expecting this tendency to prevail we continue with on-line publication which is likely to be in demand more than print. In order to increase the impact we decided to adopt the rules of open access making this volume publicly available on the Internet free of charge.

The participants were asked to contribute papers to the Proceedings and here we present the 337 papers that have been submitted and reviewed. The volume opens with five papers by the invited speakers. The contributed papers are collected in the following eight thematic groups

---

\(^1\) Wesfreid, J. (2006) Scientific Biography of Henri Bénard (1874–1939). In *Dynamics of Spatio-Temporal Cellular Structures*. Henri Bénard Centenary Review by I. Mutabazi, J. Wesfreid & E. Guyon (Eds.), Springer, pp. 9--37.
which we identified as the overall general directions of turbulence research represented at the ETC13:

- Wall-bounded flows and control of turbulence;
- Instability, transition, grid turbulence and jets;
- Statistical aspects, modelling and simulations of turbulence;
- Particles in turbulence, transport processes and mixing;
- Vorticity dynamics;
- Geophysical and magnetohydrodynamic turbulence;
- Convection, rotation, stratification and buoyancy effects;
- Reacting, compressible, multi-phase and cryogenic flows.

There are, clearly, no sharp boundaries and we often had to choose between different topics to which some papers equally belonged.

We believe that this collection is a faithful reflection of the current state of turbulence research and, hopefully, it will make a useful record within easy reach.

Konrad Bajer  
Jacek Kopeć  
Miron Kursa  
Kamil Kwiatkowski  
Piotr Podziemski

14 December 2011
Invited Speakers

MICKAËL BOURGOIN

Laboratoire des Ecoulements Géophysiques et Industriels (LEGI), CNRS, Grenoble, France,

Mickaël Bourgoin is a CNRS researcher at LEGI in Grenoble (France) since 2004. He also teaches fluid mechanics at Grenoble Institute of Technology. He graduated in Physics in 2000 and received his PhD in 2003 from Ecole Normale Superieure de Lyon. From 2003 to 2004 he worked as a post-doctoral associate at Cornell University. His research interests include Lagrangian turbulence, turbulent transport of particles and magnetohydrodynamics. In 2009 he received the Euromech young scientist prize at ETC12 in Marburg.

SAID ELGHOBASHI

University of California, Irvine, United States

Said Elghobashi is a professor of Mechanical and Aerospace Engineering at the University of California, Irvine. He received his PhD from Imperial College, University of London in 1974 and DSc in 1999 from Imperial College. He is a Fellow of the American Physical Society, the American Association for the Advancement of Science, and the American Society of Mechanical Engineers.

GREGORY FALKOVICH

Weizmann Institute of Science, Rehovot, Israel

Gregory Falkovich got PhD from Nuclear Physics Inst. Novosibirsk in 1984, worked in Russian Academy of Sciences. Since 1991 at the Weizmann Institute Science, from postdoc to professor and department head. Section Editor of J. Phys. A, Editorial boards of J. Stat. Mechanics, J. Stat. Physics. Got 4 awards of the Russian Academy of Sciences, one in Israel, elected Fellow of the Institute of Physics, London. Authored a textbook on Fluid Mechanics and a monograph on Turbulence.

BERNARD GEURTS

Applied Mathematics, University of Twente, The Netherlands

Currently, Bernard Geurts holds the Chair for Multiscale Modeling and Simulation at the University of Twente and the Chair for Anisotropic Turbulence at Eindhoven University of Technology. He is scientific director of the Applied Mathematics Institute of the Universities of Technology in the Netherlands (3TU.AMI). He chairs the Scientific Program Committee of ERCOF/FTAC (European Research Community On Flow, Turbulence and Combustion), and leads the European COST-Action LESAID, which involves over 50 academic and industrial research groups. A leading theme in his work is the modelling and analysis of interacting dynamical phenomena that are characterized by a wide range of simultaneously occurring length- and time-scales. Specific application areas include process engineering, with emphasis on energy and resources, environmental dynamics, with emphasis on transport processes and aerosol dynamics, and biophysical systems, with emphasis on bio-fluid mechanics and tissue engineering.
Ivan Marusic is a Professor and Federation Fellow at the University of Melbourne. He has a PhD from the University of Melbourne and prior to returning to Australia in 2007 was a faculty member at the University of Minnesota, where he was a recipient of an NSF Career Award and a Packard Fellowship in Science and Engineering. He is a Fellow of the American Physical Society, President of Australasian Fluid Mechanics Society, and is an Associate Editor of the Journal of Fluid Mechanics, and Editor of Experimental Thermal and Fluid Sciences.

Jörg Schumacher is the Heisenberg Professor of Theoretical Fluid Mechanics at Technical University of Ilmenau. In 1994 he graduated in physics from the University of Marburg and in 1997 obtained his Ph.D. in Astrophysics from the Astrophysical Institute, Potsdam. Later he held post-doctoral positions in Marburg and at Yale University. In 2005 he obtained habilitation in theoretical physics. Professor Schumacher’s main research interests include the investigation of small-scale structure of turbulence, scalar mixing and turbulent convection mostly based on the direct numerical simulations of turbulent flows.

Raymond Shaw is Professor of Physics at Michigan Technological University. He is also Director of the Atmospheric Sciences PhD program at Michigan Tech, and an adjunct research scientist at the Leibniz Institute for Tropospheric Research in Leipzig, Germany. He received his PhD in 1998 from Pennsylvania State University and was a postdoc in the Advanced Study Program at the National Center for Atmospheric Research.

Ladislav Skrbek is a Professor of Physics at the Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic, currently acting as a Head of the Department of Low Temperature Physics. He received his Ph.D. from Moscow State University in 1983 and DSc from Charles University in 1997. His research interests include various topics of low temperature physics, such as superfluidity and cryogenic and quantum turbulence – in particular, cryogenic thermal convection, second sound investigation of various superflows and visualization of quantum turbulence using tracking of frozen hydrogen-deuterium micron-size particles. He authored a textbook on Low Temperature Physics and acts as Editorial Board Member of Journal of Low Temperature Physics.
CONFERENCE DINNER AT THE PALACE OF CULTURE AND SCIENCE
POLISH FOLK DANCE
TURBULENCE – THE HISTORICAL PERSPECTIVE

(Library of the Institute of Experimental Physics)
FACULTY OF PHYSICS MAIN LECTURE HALL
WELCOME PARTY AT THE COPERNICUS SCIENCE CENTRE

Foucault pendulum in the foreground
DISCUSSION AFTER THE EVENING LECTURE BY PROFESSOR LORD JULIAN HUNT