Cambridge University Press
978-0-521-79221-9 - Intermittency in Turbulent Flows
Edited by J. C. Vassilicos
Frontmatter
More information

INTERMITTENCY IN TURBULENT FLOWS

The Isaac Newton Institute of Mathematical Sciences of the University of Cambridge exists to stimulate research in all branches of the mathematical sciences, including pure mathematics, statistics, applied mathematics, theoretical physics, theoretical computer science, mathematical biology and economics. The research programmes it runs each year bring together leading mathematical scientists from all over the world to exchange ideas through seminars, teaching and informal interaction.

INTERMITTENCY IN TURBULENT FLOWS

edited by

J.C. Vassilicos

University of Cambridge

CAMBRIDGE
UNIVERSITY PRESS

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK
40 West 20th Street, New York, NY 10011–4211, USA
10 Stamford Road, Oakleigh, VIC 3166, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain
Dock House, The Waterfront, Cape Town 8001, South Africa

http://www.cambridge.org

First published 2001

Printed in the United Kingdom at the University Press, Cambridge

Typeset in 12pt Computer Modern

A catalogue record for this book is available from the British Library

ISBN 0 521 79221 5 hardback

Cambridge University Press
978-0-521-79221-9 - Intermittency in Turbulent Flows
Edited by J. C. Vassilicos
Frontmatter
More information

CONTENTS

Contributors

Takahiro Adachi, OTEC Laboratory, Faculty of Science and Engineering, Saga University, 1 Honjo-machi, Saga 840–8502, Japan

L. Biferale, Dipartimento di Fisica and INFM, Università di Roma, 'Tor Vergata', Via della Ricerca Scientifica 1, I–00133, Roma, Italy

Peter N. Blossey, Department of Mechanical and Aerospace Engineering, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093–0411, USA

G. Boffetta, Dipartimento di Fisica Generale and INFM, Università di Torino, via Pietro Giuria 1, I–10125, Roma, Italy

O. Brausch, Institute of Physics, University of Bayreuth, D 95440, Bayreuth, Germany

F.H. Busse, Institute of Physics, University of Bayreuth, D 95440, Bayreuth, Germany

Patrizia Castiglione, Laboratoire de Physique Statistique, Ecole Normale Supérieure, 24, rue Lhomond, 75231 Paris, France

A. Celani, Dipartimento di Fisica Generale and INFM, Università di Torino, via Pietro Giuria 1, I–10125, Roma, Italy

M. Cencini, Dipartimento di Fisica and INFM, Università di Roma, 'La Sapienza', Piazzale Aldo Moro 2, I–00185, Roma, Italy

Michael Chertkov, T13 and CNLS, Los Alamos National Laboratory, NM 87545, USA

Sergio Ciliberto, Laboratoire de Physique, CNRS, Ecole Normale Supérieure de Lyon, 46, Allée d'Italie, 69364 Lyon, France

C.R. Doering, Department of Mathematics, University of Michigan, Ann Arbor, MI 48109–1109, USA

Gregory Falkovich, Department of Physics of Complex Systems, Weizmann Institute of Science, PO Box 26, Rehovot 76100, Israel

Krzysztof Gawędzki, IHES, 35, route de Chartres, F–91440, Bures-sur-Yvette, France

J.D. Gibbon, Department of Applied Mathematics, Imperial College of Science and Technology, Huxley Building, 180, Queen's Gate, London SW7 2BX, UK

Marie-Christine Guegan, Physics Department, Eindhoven University of Technology, PO Box 513, 5600 MB, Eindhoven, The Netherlands

M. Jaletzky, Institute of Physics, University of Bayreuth, D 95440, Bayreuth, Germany

Javier Jiménez, School of Aeronautics, Universidad Politécnica, 28040 Madrid, Spain *and* Center for Turbulence Research, Stanford University, Stanford, CA 94305, USA

A. Juel, Center for Non-Linear Dynamics and Department of Physics, University of Texas at Austin, TX 78712, USA

Marie-Caroline Jullien, Laboratoire de Physique Statistique, Ecole Normale Supérieure, 24, rue Lhomond, 75231 Paris, France

Michael Kholmyanksy, Department of Fluid Mechanics and Heat Transfer, The Iby and Aladar Fleischman Faculty of Engineering, Tel Aviv University, Ramat Aviv 69978, Israel

Shigeo Kida, OTEC Laboratory, Faculty of Science and Engineering, Saga University, 1 Honjo-machi, Saga 840–8502, Japan

Emmanuel Lévêque, Laboratoire de Physique, CNRS, Ecole Normale Supérieure de Lyon, 46, Allée d'Italie, 69364, Lyon, France

John L. Lumley, Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca NY 14853–7501, USA

Hideaki Miura, OTEC Laboratory, Faculty of Science and Engineering, Saga University, 1 Honjo-machi, Saga 840–8502, Japan

F. Moisy, Laboratoire de Physique Statistique, Ecole Normale Supérieure, 24, rue Lhomond, 75231 Paris, France

T. Mullin, Department of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK

K. Ohkitani, Research Institute for Mathematical Sciences, Kyoto University, Kyoto 606–8502, Japan

Jérôme Paret, Laboratoire de Physique Statistique, Ecole Normale Supérieure, 24, rue Lhomond, 75231 Paris, France

T. Peacock, Department of Computer Science, University of Colorado at Boulder, Boulder, CO 80309–0430, USA

W. Pesch, Institute of Physics, University of Bayreuth, D 95440, Bayreuth, Germany

Alain Pumir, INLN, CNRS, 1361, route des Lucioles, F–06560, Valbonne, France

D. Queiros-Conde, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge CB3 9EW, UK

Gerardo Ruiz Chavarria, Departamento de Física, Facultad de Ciencias, UNAM, 04510, Mexico DF, Mexico

Boris I. Shraiman, Lucent Technology, 700 Mountain Avenue, Murray Hill, NJ 07974, USA

Adrian Staicu, Physics Department, Eindhoven University of Technology, PO Box 513, 5600 MB, Eindhoven, The Netherlands

Patrick Tabeling, Laboratoire de Physique Statistique, Ecole Normale Supérieure, 24, rue Lhomond, 75231, Paris, France

Arkady Tsinober, Department of Fluid Mechanics and Heat Transfer, The Iby and Aladar Fleischman Faculty of Engineering, Tel Aviv University, Ramat Aviv 69978, Israel

J.C. Vassilicos, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge CB3 9EW, UK

D. Vergni, Dipartimento di Fisica and INFM, Università di Roma, 'La Sapienza', Piazzale Aldo Moro 2, I–00185, Roma, Italy

A. Vulpiani, Dipartimento di Fisica and INFM, Università di Roma, 'La Sapienza', Piazzale Aldo Moro 2, I–00185, Roma, Italy

Willem van de Water, Physics Department, Eindhoven University of Technology, PO Box 513, 5600 MB, Eindhoven, The Netherlands

H. Willaime, Laboratoire de Physique Statistique, Ecole Normale Supérieure, 24, rue Lhomond, 75231 Paris, France

Introduction

The last decade has seen what is perhaps an unprecedented and multifaceted flurry of activity in the search to describe and understand the intermittency of turbulent flows and other dynamical systems. The aim of the Workshop on Intermittency in Turbulent Flows and Other Dynamical Systems held at the Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, from June 21 to 24, 1999, was to capture and summarize these developments, encourage cross-fertilization of ideas and lay out research directions for the future. This volume provides a record of the Workshop and an overview of our current understanding of the subject.

Different turbulence problems, for example Navier–Stokes turbulence, are encountered in different nonlinear systems described mathematically by different partial differential equations (PDE), for example the Navier-Stokes equation, or systems of ordinary differential equations (ODE). Nevertheless, the dynamics of many nonlinear systems gravitate around a few common central themes: intermittency, order/coherence and disorder. These features affect scalings and lead to deviations from Gaussian behaviour. Intermittency may be the universal outcome of a large class of nonlinear systems, however the universality properties of specific nonlinear systems, that is the dependencies of the intermittent structure on initial and boundary conditions, remain open questions. What is the appropriate kinematic description of intermittency, and how different is it for different nonlinear systems, different boundary and different initial conditions? The challenge is that a general kinematic description of intermittency should encompass both order and disorder and mixtures of both. Furthermore, what are the dynamics of intermittency and the mechanisms that create it? To what extent and in what sense is intermittency related to deviations from self-similar dynamics and to dissipative properties of the nonlinear system? What are self-similar dynamics and what are their dissipative properties?

Intermittency in some form or another is a feature of nonlinear ODEs and PDEs. ODEs are effectively the common focus of the chapters by Blossey & Lumley and by Mullin, Juel & Peacock. Blossey & Lumley discuss the intermittent production of turbulence in the turbulent boundary layer's wall region which is dominated by a few large-scale coherent structures that break down intermittently. A Proper Orthogonal Decomposition of the Navier–Stokes equation leads to a system of coupled nonlinear ODEs which can be used to predict breakdown of structures and thereby act to reduce drag on the wall. Mullin, Juel & Peacock are concerned with low-dimensional chaos and temporal intermittency found in Taylor-Couette and variant flows and they claim that it is impossible to completely reduce these dynamics to a low-order set of ODEs. Busse, Brausch, Jaletzky & Pesch focus on convection layers with and without rotation where phase/weak turbulence appears and is related to heteroclinic orbits. The rest of the Workshop was on internal intermittency in PDEs and turbulence experiments.

The main questions were: how can we relate scaling exponents of structure functions to near-singular flow structure (e.g. vortex tubes but also other straining structures)? Is the near-singular flow structure an imprint of finite-time singularities of the Euler equations assuming they exist? In his chapter Ohkitani proves the existence of finite-time singularities in the inviscid Burgers equation without use of the Hopf–Cole solution and applies his method to the Euler equation with a Taylor-Green vortex initial condition to show that if a finite-time singularity exists it cannot be too weak. A condition for the non-existence of finite-time singularities of the Navier-Stokes equation was derived by Doering & Gibbon at the Isaac Newton Institute during the turbulence research programme (January 6 to July 2, 1999) and a detailed account is given in their chapter here. Other PDEs that were discussed for their intermittency properties during the Workshop are the advection-diffusion equation for scalar fields (chapter by Gawędzki) and the advection-stretching-diffusion equation for magnetic fields (chapter by Falkovich).

Results from a variety of new experiments were presented at the workshop, and can be found in the chapters of Ciliberto, Lévêque & Ruiz Chavarria, Queiros-Conde & Vassilicos, Jullien, Castiglione, Paret & Tabeling, and Kholmyansky & Tsinober. In their investigation of velocity structure functions in a turbulent boundary layer flow near a solid plate, Ciliberto *et al.* report that mean shear significantly influences the scalings of structure functions which therefore depend on the distance from the plate. However, the relative scaling exponents remain constant in the turbulent logarithmic sublayer. Queiros-Conde & Vassilicos have measured turbulence fluctuations and velocity profiles at large distances in the wakes of 3D fractal grids where the turbulence has had the time to travel a large number of turnover times. Their main result is that velocity structure functions are more slowly varying functions of two-time separation for larger fractal grid dimensions and that this is not an effect of mean shear. Jullien *et al.* have developed an experimental setup where a 2D turbulent flow is generated in a large aspect ratio container with stable stratification and friction exerted on the fluid by the bottom wall. The flow is forced by an array of magnets placed below this wall, and according to the scale of the forcing, the turbulent flows produced can have either $-5/3$ or -3 energy spectra. Detailed measurements of both velocity and scalar statistics are presented and compared with theory. Kholmyansky & Tsinober have made atmospheric measurements of all velocity derivatives at the top of a 10-metre tall tower. This is the first time that measurements of all velocity derivatives have been made at a Reynolds number as high as $Re_\lambda = 10^4$. Their conclusion is that the properties of enstrophy and strain production, geometrical statistics, the role of concentrated vorticity and strain and depression of nonlinearity are the same, qualitatively, as they are at $Re_\lambda = 10^2$. However, Kholmyansky & Tsinober's measurements of structure functions conditional on high values of turbulent velocity fluctuations reveal a significant correlation between small and large scales, thereby pointing to non-universality of turbulent flows. The analysis of experimental longitudinal velocity data by Jiménez, Moisy, Tabeling & Willaime leads to results that are at odds with the model of a self-similar multiplicative cascade.

It may be that longitudinal structure functions, which have focussed research interest since the seminal works of Kolmogorov, are not the most appropriate tools for studying intermittency and scalings. In particular they are not very instructive as to the spatio-temporal flow structure of the turbulence. It is for this reason that an entire battery of new ideas, concepts and methods were presented and discussed at the Workshop. The oldest of these new approaches are not more than 20 years old, and the most recent date from the second half of the 1990s: wavelets, extended self-similarity, numerical vortex tube visualization techniques, transversal and inverted structure functions, multi-point correlators and geometrical statistics.

The experimental evidence presented in the chapter of van de Water, Staicu & Guegan indicates that power-law scalings are better defined for transverse than they are for longitudinal structure functions, and that transverse scaling exponents are smaller than the Kolmogorov predictions. Vulpiani, Biferale, Boffetta, Celani, Cencini and Vergni introduce the study of statistics of separations across which the velocity difference has a certain value. These statistics are called inverted structure functions and lead to improved results for Richardson's two-point turbulent diffusion law. However, moving from two-point to multi-point Lagrangian statistics may be a good way to probe more of the turbulence spatial flow structure, and Chertkov, Pumir & Shraiman study multi-point correlators and tetrad dynamics. Finally, Kida, Miura & Adachi present an automatic tracking scheme for unambiguous visualization of flow structure in 3D numerical simulations.

One conclusion from the Workshop is that there are now many new ideas and experiments and new ways to interrogate turbulent fields which may be leading to exciting developments. Another conclusion is that we must be prepared to do away with the concept of universal turbulence, or at least qualify it so as to allow for qualitative rather than quantitative universality.

I, and I believe all the speakers at the Workshop, are extremely grateful to my fellow organizers of the Isaac Newton Institute's turbulence research programme, Geoff Hewitt, Peter Monkewitz and Neil Sandham; to Keith Moffatt and the wonderful staff of the Isaac Newton Institute; to ERCOFTAC, the European Commission, the Royal Academy of Engineering and the Industrial Working Group under the chairmanship of Michael Reeks for their support; and to the Isaac Newton Institute for sponsoring and hosting the Workshop.

J.C. Vassilicos