

Direct and Large-Eddy Simulation IX

ERCOFTAC SERIES

VOLUME 20

Series Editor

Bernard Geurts

*Faculty of Mathematical Sciences, University of Twente, Enschede,
The Netherlands*

Aims and Scope of the Series

ERCOFTAC (European Research Community on Flow, Turbulence and Combustion) was founded as an international association with scientific objectives in 1988. ERCOFTAC strongly promotes joint efforts of European research institutes and industries that are active in the field of flow, turbulence and combustion, in order to enhance the exchange of technical and scientific information on fundamental and applied research and design. Each year, ERCOFTAC organizes several meetings in the form of workshops, conferences and summerschools, where ERCOFTAC members and other researchers meet and exchange information.

The ERCOFTAC Series will publish the proceedings of ERCOFTAC meetings, which cover all aspects of fluid mechanics. The series will comprise proceedings of conferences and workshops, and of textbooks presenting the material taught at summerschools.

The series covers the entire domain of fluid mechanics, which includes physical modelling, computational fluid dynamics including grid generation and turbulence modelling, measuring-techniques, flow visualization as applied to industrial flows, aerodynamics, combustion, geophysical and environmental flows, hydraulics, multiphase flows, non-Newtonian flows, astrophysical flows, laminar, turbulent and transitional flows.

More information about this series at <http://www.springer.com/series/5934>

Jochen Fröhlich · Hans Kuerten
Bernard J. Geurts · Vincenzo Armenio
Editors

Direct and Large-Eddy Simulation IX

 Springer

Editors

Jochen Fröhlich
Institut für Strömungsmechanik
Technische Universität Dresden
Dresden
Germany

Hans Kuerten
Department of Mechanical Engineering
Eindhoven University of Technology
Eindhoven
The Netherlands

Bernard J. Geurts
Faculty EEMCS, Multiscale Modeling
and Simulation
University of Twente
Enschede
The Netherlands

Vincenzo Armenio
Dipartimento di Ingegneria Civile ed
Ambientale
Università di Trieste
Trieste
Italy

ISSN 1382-4309

ERCOFTAC Series

ISBN 978-3-319-14447-4

ISBN 978-3-319-14448-1 (eBook)

DOI 10.1007/978-3-319-14448-1

Library of Congress Control Number: 2014959198

Springer Cham Heidelberg New York Dordrecht London

© Springer International Publishing Switzerland 2015

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Preface

Representing turbulence by a small number of quantities, such as intensity and length scale, for example, is appropriate and efficient in many engineering situations. Resolving most of or even all turbulent motion by means of Large-Eddy Simulation (LES) or Direct Numerical Simulation (DNS), respectively, provides much more information but is computationally very demanding. Recent years have witnessed an ever-increasing availability of computer power so that the approach can now be applied by many researchers. Indeed, a minimum number of operations, determined by the grid size and the required time steps, needs to be executed to obtain sound separation of length and timescales between the smallest and the largest resolved ones.¹ During recent years, the required performance threshold is met by more and more computer systems. Also, discretization methods and solution algorithms have improved as a result of decades of scientific activities in this field. As a consequence, meaningful DNS and LES can now be performed for more and more applications. For the same reason, a central issue of LES, subgrid-scale modelling, has become less critical today as the grid scales are further away from the resolved scales than before. Still, these methods present lots of pitfalls, and a cost-effective simulation requires optimal models. Much work has been done on improving discretization schemes, subgrid-scale models and other model contributions such as generation of inflow turbulence. On this basis, the development and application of these methods and models continues to be a very active field of research. More and more data sets from DNS nowadays provide detailed and accurate reference for improved understanding and development of physical models.

“Direct and Large-Eddy Simulation 9” was organized in Dresden, Germany, with a local team from the Institute of Fluid Mechanics at TU Dresden and the Helmholtz Center Dresden Rossendorf. This ninth edition took place almost two decades after the start of this ERCOFTAC workshop series in 1994. The first event, DLES1, had been organized by Peter Voke at the University of Surrey and seen 25

¹ S.B. Pope, *New J. Phys.* 6:35, 2004.

papers, almost equally partitioned into four sessions, turbulent structures and round jets, subgrid-scale modelling, stratified and atmospheric flows and transition. The papers mainly came from those European countries in possession of large computers, six from Great Britain, four from France, the Netherlands and Germany, each, two from Italy and Sweden, one from Switzerland and Norway and two from overseas, USA and Japan, all attributed according to the first author.

During the 20 years since then, the workshop has substantially increased in size and has been tracing the development of the subject from an exclusive one to a broadly applied and fast developing area of research. DLES9 in 2013 so far was the biggest event of the series with 86 contributed talks and 23 poster presentations, selected after a careful reviewing process. Naturally, the range of session topics has become much broader compared to DLES1. Beyond the traditional core subjects of DLES, LES modelling, numerics, turbulent structures, transition and environmental flows, they have been spreading to further applications, among which reactive flows and combustion together with multiphase flows being the largest ones, in terms of the number of papers. Certain methodological topics which have come up over recent years were also featured at DLES9, such as quality of LES and extension to hybrid LES/RANS methods, while other sessions dealt with developments and results in further application areas. A special session on MHD turbulence was put together by HZDR. In addition to the regular contributions, nine keynote presentations provided overviews of recent developments and state of the art for transition (Dan Henningson), cavitation (Stefan Hickel), marine boundary layers (Peter Sullivan), combustion (Heinz Pitsch), LES modelling (Roel Verstappen), MHD turbulence (Annick Pouquet), multiphase flow (Alfredo Soldati), jet noise (Tim Colonius) and applications to industrial flows (Florian Menter).

Most of the invited and contributed papers have been submitted for inclusion in the Proceedings of DLES9 and after a careful review procedure most of these can be found in this volume. The papers are grouped into themes, mostly along the order of the sessions of the workshop. These contributions give a good overview of the most important current issues and application areas in DNS and LES. Fundamental issues related to the usage of LES and the development of the various models required for LES are still an important research topic. The applications to various research questions show that LES and DNS have become important tools for fundamental research able to generate substantial physical insight into numerous phenomena related to various and diverse turbulent flows.

The organization of the ERCOFTAC DLES9 Workshop and the preparation of these proceedings would not have been possible without the support of many. We thank the members of the Scientific Committee for their contribution to the reviewing process and the numerous helpers involved in preparing and managing the event as well as handling the proceedings. We also gratefully acknowledge financial support from the J.M. Burgerscentrum, ANSYS Germany, Innisus GTD, Howden Germany, DFG priority programme MetStröm, Gesellschaft der Freunde

und Förderer der TU Dresden and Helmholtz-Zentrum Dresden Rossendorf. The European Research Community on Flow, Turbulence and Combustion, ERCOFTAC, supported the attendance and contribution of young scientists to DLES9 by making available scholarships to Ph.D. students.

Dresden, May 2014

Jochen Fröhlich
Hans Kuerten
Bernard J. Geurts
Vincenzo Armenio

Committees

Local Organizing Committee

Jochen Fröhlich, TU Dresden, Germany
Andre Giesecke, HRZD Dresden, Germany
Frank Rüdiger, TU Dresden, Germany
Jörg Stiller, TU Dresden, Germany
Uta Stempel, TU Dresden, Germany

Scientific Committee

B.J. Boersma, TU Delft, The Netherlands
D. Borello, University of Rome, Italy
M. Breuer, Helmut-Schmidt-University, Hamburg, Germany
L. Davidson, Chalmers University of Technology, Sweden
S. Elghobashi, University of California, Irvine, USA
R. Friedrich, TU Munich, Germany
K. Fukagata, Keio University, Japan
M. García-Villalba, Universidad Carlos III de Madrid, Spain
W.P. Jones, Imperial College, London, Great Britain
T. Kempe, TU Dresden, Germany
L. Kleiser, ETH Zurich, Switzerland
E. Lamballais, PPRIME Poitiers, France
C. Meneveau, Johns Hopkins University, USA
J. Meyers, University Leuven, Belgium
U. Piomelli, Queens University, Kingston, Canada
S.B. Pope, Cornell University, USA
M.-V. Salvetti, University of Pisa, Italy
S. Sarkar, University of California, San Diego, USA

W. Schröder, RWTH Aachen, Germany
J. Sesterhenn, TU Berlin, Germany
S. Sherwin, Imperial College London, Great Britain
F. Stefani, HZDR, Dresden, Germany
D. Thévenin, Universität Magdeburg, Germany
A. Tomboulides, Aristotle University of Thessaloniki, Greece
F. Toschi, TU Eindhoven, The Netherlands
M. Uhlmann, Karlsruhe Institute of Technology, Germany
L. Vervisch, Coria, Rouen, France

Contents

Part I LES Modelling

On Scale Separation in Large Eddy Simulations	3
Roel Verstappen	
Numerical Experiments with a New Dynamic Mixed Subgrid-Scale Model	15
P. Lampitella, F. Inzoli and E. Colombo	
Implicit Large-Eddy Simulation of Isotropic Turbulent Mixing	23
F.F. Grinstein, A.J. Wachtor, J.R. Ristorcelli and C.R. DeVore	
New Differential Operators for Large-Eddy Simulation and Regularization Modeling	29
F.X. Trias, A. Gorobets, A. Oliva and R.W.C.P. Verstappen	
Assessment of Implicit Subgrid-Scale Modeling for Turbulent Supercritical Mixing	37
C.A. Niedermeier, S. Hickel and N.A. Adams	
Validation of an Entropy-Viscosity Model for Large Eddy Simulation.	43
J.-L. Guermond, A. Larios and T. Thompson	
A Stochastic Closure Approach for LES with Application to Turbulent Channel Flow	49
P. Metzner, M. Waidmann, D. Igdalov, T. von Larcher, I. Horenko, R. Klein, A. Beck, G. Gassner and C.D. Munz	

Comparison of URANS, PANS, LES and DNS of Flows Around Simplified Ground Vehicles with Passive Flow Manipulation. 57
 X. Han, S. Krajnović, C.-H. Bruneau and I. Mortazavi

Variational Multiscale LES Investigation of Drag and Near-Wake Flow of an Axisymmetric Blunt-Based Body. 65
 A. Mariotti, M.V. Salvetti and G. Buresti

SVV-LES and Active Control of Flow Around the Square Back Ahmed Body. 73
 Noele Peres and Richard Pasquetti

Design of High-Order Implicit Filters on Unstructured Grids for the Identification of Large-Scale Features in Large-Eddy Simulations 81
 L. Guedot, G. Lartigue and V. Moureau

Part II Numerical Methods

DNS of Canonical Turbulent Flows Using the Modal Discontinuous Galerkin Method 91
 J.-B. Chapelier, M. De La Llave Plata, F. Renac and E. Lamballais

LES Using a Discontinuous Galerkin Method: Isotropic Turbulence, Channel Flow and Periodic Hill Flow 97
 C. Carton de Wiart, K. Hillewaert, L. Briceux and G. Winckelmans

Underresolved Turbulence Simulations with Stabilized High Order Discontinuous Galerkin Methods 103
 Andrea D. Beck, Gregor J. Gassner, Thomas Bolemann, Hannes Frank, Florian Hindenlang and Claus-Dieter Munz

A Characteristic-Based Volume Penalization Method for Arbitrary Mach Flows Around Solid Obstacles 109
 Eric Brown-Dymkoski, Nurlybek Kasimov and Oleg V. Vasilyev

DNS of Square-Cylinder Flow Using Hybrid Wavelet-Collocation/Volume-Penalization Method 117
 G. De Stefano and O.V. Vasilyev

Generation of Intermittent Turbulent Inflow and Initial Conditions Based on Wavelet Construction Method 125
 L. Zhou, J. Grilliat and A. Delgado

A New High-Order Method for the Accurate Simulation of Incompressible Wall-Bounded Flows 133
 Peter Lenaers, Phillip Schlatter, Geert Brethouwer and Arne V. Johansson

Part III Quality of LES Modelling

Investigations on the Effect of Different Subgrid Models on the Quality of LES Results 141
 F. Proch, M.W.A. Pettit, T. Ma, M. Rieth and A.M. Kempf

Computational Complexity of Adaptive LES with Variable Fidelity Model Refinement 149
 Alireza Nejadmalayeri, Oleg V. Vasilyev and Alexei Vezolainen

Elimination of Curvature-Induced Grid Motion for *r*-Adaptation. 155
 C. Hertel, M. Joppa, B. Krull and J. Fröhlich

Reliability of LES Simulations in the Context of a Benchmark on the Aerodynamics of a Rectangular 5:1 Cylinder 161
 M.V. Salvetti and L. Bruno

Quantifying the Impact of Subgrid Scale Models in Actuator-Line Based LES of Wind Turbine Wakes in Laminar and Turbulent Inflow 169
 H. Sarlak, C. Meneveau, J.N. Sørensen and R. Mikkelsen

Part IV Hybrid Models

Elements and Applications of Scale-Resolving Simulation Methods in Industrial CFD 179
 F. Menter

Hybrid LES–URANS Methodology for Wall–Bounded Flows 197
 S. Schmidt and M. Breuer

Part V Stability and Transition

Investigations of Stability and Transition of a Jet in Crossflow Using DNS	207
A. Peplinski, P. Schlatter and D.S. Henningson	
DNS of a Double Diffusive Instability	219
J.G. Wissink, H. Herlina, S.I. Voropayev and H.J.S. Fernando	
Flow Past a NACA0012 Airfoil: From Laminar Separation Bubbles to Fully Stalled Regime	225
I. Rodríguez, O. Lehmkuhl, R. Borrell and A. Oliva	
Large-Eddy Simulation of a Shallow Turbulent Jet	233
R. Mullyadzhyanov, B. Ilyushin, M. Hadžiabdić and K. Hanjalić	

Part VI Turbulence

Large Scale Motions in the Direct Numerical Simulation of Turbulent Pipe Flow	243
B.J. Boersma	
Turbulent Kinetic Energy Transport in Oscillatory Pipe Flow	251
Claus Wagner and Daniel Feldmann	
Large-Eddy Simulation of the Interaction of Wall Jets with External Stream	259
I.Z. Naqavi and P.G. Tucker	
Turbulent Boundary Layers in Long Computational Domains	267
G. Eitel-Amor, R. Örlü and P. Schlatter	
Investigation of Dual-Source Plume Interaction in a Turbulent Wall-Bounded Shear Layer	275
Shahin N. Oskouie, Bing-Chen Wang and Eugene Yee	
LES of the Flow in a Rotating Rib-Roughened Duct	283
D. Borello, A. Salvagni, F. Rispoli and K. Hanjalić	
On the Large-Eddy Simulations of the Flow Past a Cylinder at Critical Reynolds Numbers	289
O. Lehmkuhl, I. Rodríguez, J. Chiva and R. Borrell	

Large Eddy Simulation of Fluidic Injection into a Supersonic Convergent-Divergent Duct 297
 B. Semlitsch, M. Mihăescu and L. Fuchs

Part VII Compressible Flows

Simulation and Modeling of Turbulent Jet Noise. 305
 T. Colonius, A. Sinha, D. Rodríguez, A. Towne, J. Liu, G.A. Brès,
 D. Appelö and T. Hagstrom

Mach Number Influence on Vortex Breakdown in Compressible, Subsonic Swirling Nozzle-Jet Flows 311
 Tobias Luginsland and Leonhard Kleiser

A Symmetry-Preserving Discretization and Regularization Subgrid Model for Compressible Turbulent Flow 319
 W. Rozema, R.W.C.P. Verstappen, J.C. Kok and A.E.P. Veldman

Implicit LES of Noise Reduction for a Compressible Deep Cavity Using Pulsed Nanosecond Plasma Actuator. 327
 Z.L. Chen, B.Q. Zhang, S. Hickel and N.A. Adams

Part VIII Heat Transfer and Natural Convection

DNS of Thermal Convection in Rectangular Domains with Different Depth 337
 S. Wagner and O. Shishkina

Direct Numerical Simulation of Low-Mach Turbulent Natural Convection Flow in an Open Cavity of Aspect Ratio 4 345
 J. Chiva, O. Lehmkuhl, J. Ventosa and A. Oliva

Rotating Rayleigh–Bénard Convection of SF₆ in a Slender Cylinder 353
 S. Horn and C. Wagner

Large-Eddy Simulation of Flow and Heat Transfer Around a Low-Mach Number Turbine Blade 361
 N. Maheu, V. Moureau and P. Domingo

Part IX Aerodynamics and Fluid-Structure Interaction

Large-Eddy Simulations for Wind Turbine Blade: Dynamic Stall and Rotational Augmentation 369
 Y. Kim, I.P. Castro and Z.T. Xie

Unsteady Characteristic of Stall Around an Airfoil by Means of High Fidelity LES 377
 N. Alferez, I. Mary and E. Lamballais

Compressible DNS of a Low Pressure Turbine Subjected to Inlet Disturbances 383
 L.W. Chen, R. Pichler and R.D. Sandberg

Large Eddy Simulation of a NACA-0012 Airfoil Near Stall 389
 J. AlMutairi, I. AlQadi and E. ElJack

Large-Eddy Simulation of a FSI-Induced Oscillation Test Case in Turbulent Flow 397
 M. Münsch, A. Delgado and M. Breuer

Shape Optimization and Active Flow Control of Truck-Trailers for Improved Aerodynamics Using Large-Eddy Simulation and Response Surfaces 405
 M. El-Alti, P. Kjellgren and L. Davidson

Part X Environmental Flows

Numerical Simulation of Breaking Gravity Waves 413
 S. Remmler, M.D. Fruman, U. Achatz and S. Hickel

DNS of a Radiatively Driven Cloud-Top Mixing Layer as a Model for Stratocumulus Clouds 419
 A. de Lózar and J.P. Mellado

Effect of Ekman Layer on Windfarm Roughness and Displacement Height 423
 J.P. Goit and J. Meyers

Pollutant Dispersion in the Urban Boundary Layer 435
 J.M. Tomas, M.J.B.M. Pourquie, H.E. Eisma, G.E. Elsinga, H.J.J. Jonker and J. Westerweel

Large-Eddy Simulation Model for Urban Areas with Thermal and Humid Stratification Effects. 443
 A. Petronio, F. Roman, V. Armenio, F. Stel and D. Giaiotti

Large-Eddy Simulation of Turbulent Flow Over an Array of Wall-Mounted Cubic Obstacles 451
 Mohammad Saeedi and Bing-Chen Wang

Direct Numerical Simulation of the 3D Stratified Separated Viscous Fluid Flows. 459
 P.V. Matyushin and V.A. Gushchin

Part XI Rotating Turbulence

Effects of Rotation on the Oscillatory Flow Over Ripples. 467
 D.G.E. Grigoriadis and V. Armenio

Numerical Simulations of a Middle Gap Turbulent Taylor-Couette-Poiseuille Flow 473
 R. Oguic, S. Viazzo and S. Poncet

Effect of Span-Wise Resolution for LES of Flow Over a Rotating Cylinder at High Reynolds Number 479
 S. Rolfo and A. Revell

Part XII Reactive Flows and Combustion

LES of Turbulence-Radiation Interaction in Plane Reacting and Inert Mixing Layers 489
 Somnath Ghosh, Rainer Friedrich and Christian Stemmer

A Priori Analysis of Dynamic Models for Large Eddy Simulations of Turbulent Premixed Combustion 497
 D. Veynante, V. Moureau, M. Boileau and T. Schmitt

Lagrangian Analysis of Mixing and Soot Transport in a Turbulent Jet Flame 503
 A. Attili, F. Bisetti, M.E. Mueller and H. Pitsch

The Influence of Differential Diffusion in Turbulent Oxygen Enhanced Methane Flames 511
 F. Dietzsch, C. Hasse, G. Fru and D. Thévenin

Application of Flamelet Generated Manifolds Approach with Heat Loss Inclusion to a Turbulent High-Pressure Premixed Confined Jet Flame	519
A. Donini, S.M. Martin, R.J.M. Bastiaans, J.A. van Oijen and L.P.H. de Goey	
Direct Numerical Simulations of Turbulent H₂-Air Pre-mixtures and Analysis Towards Safety-Relevant Ignition Prediction.	525
Gordon Fru, Dominique Thévenin and Detlev Markus	
Large-Eddy-Simulation of High-Frequency Flame Dynamics in Perfect Premix Combustors with Elevated Inlet Temperatures.	533
Mathieu Zellhuber and Wolfgang Polifke	
Direct Numerical Simulation of Hydrogen-Carbon Monoxide Turbulent Premixed Flame	541
F. Battista, F. Picano, G. Troiani and C.M. Casciola	
 Part XIII Magnetohydrodynamics	
Helical Turbulence in Fluids and MHD	549
R. Marino, J. Baerenzung, P.D. Mininni, A. Pouquet, C. Rorai, D. Rosenberg and J. Stawarz	
Linear Instability Analysis of 3D Magnetohydrodynamic Flow by Direct Numerical Simulation	561
I. Grants and G. Gerbeth	
Numerical Study of Turbulent Pipe Flow with Transverse Magnetic Field Using a Spectral/Finite Element Solver	569
X. Dechamps, M. Rasquin, K.E. Jansen and G. Degrez	
On Turbulence Generation and Mixing in the Wake of Magnetic Obstacles: A DNS Study	577
Saša Kenjereš	
Simulation of Instabilities in Liquid Metal Batteries	585
N. Weber, V. Galindo, T. Weier, F. Stefani and T. Wondrak	

Part XIV Multiphase Flows

DNS and LES of Two-Phase Flows with Cavitation 595
 S. Hickel

**Four-Way Coupled LES Predictions of Dense Particle-Laden
 Flows in Horizontal Smooth and Rough Pipes** 605
 M. Alletto and M. Breuer

Biomass Pyrolysis in DNS of Turbulent Particle-Laden Flow 613
 E. Russo, J.G.M. Kuerten and B.J. Geurts

**Modulation of Isotropic Turbulence by Resolved
 and Non-resolved Spherical Particles** 621
 A.H. Abdelsamie and D. Thévenin

**A Hybrid Stochastic-Deconvolution Model for LES
 of Particle-Laden Flow** 631
 W.R. Michałek, J.G.M. Kuerten, J.C.H. Zeegers, R. Liew,
 J. Pozorski and B.J. Geurts

**Direct Numerical Simulation of a Compressible Multiphase
 Flow Through the Eulerian Approach** 639
 M. Cerminara, L.C. Berselli, T. Esposti Ongaro and M.V. Salvetti

**DNS of Turbulent Bubbly Downflow with a Coupled
 Level-Set/Volume-of-Fluid Method** 647
 M. Kwakkel, W.-P. Breugem and B.J. Boersma

Particle-Laden Turbulent Channel Flow with Wall-Roughness 655
 B. Milici, M. De Marchis, G. Sardina and E. Napoli

**Direct Numerical Simulation of Bed-Load Transport
 of Finite-Size Spherical Particles in a Turbulent Channel Flow** 663
 B. Vowinckel, T. Kempe, J. Fröhlich and V. Nikora

**An Inhomogeneous Stochastic Model for Subgrid-Scale
 Particle Dispersion in LES** 671
 M. Knorps and J. Pozorski

LES of the Ranque-Hilsch Vortex Tube 679
 W.R. Michałek, J.G.M. Kuerten, J.C.H. Zeegers and R. Liew

Direct Numerical Simulation of Heat Transfer in Colliding Droplets by a Coupled Level Set and Volume of Fluid Method 687
N. Talebanfard and B.J. Boersma

On the Numerical Modeling of Active Flow Control for Aerodynamics Applications and Its Impact on the Pressure Field 695
M. El-Alti, P. Kjellgren and L. Davidson