IMPLICIT LARGE EDDY SIMULATION

The numerical simulation of turbulent flows is a subject of great practical importance to scientists and engineers. The difficulty in achieving predictive simulations is perhaps best illustrated by the wide range of approaches that have been developed and are still being used by the turbulence modeling community. In this book the authors describe one of these approaches: implicit large eddy simulation (ILES). ILES is a relatively new approach that combines generality and computational efficiency with documented success in many areas of complex fluid flow. This book synthesizes the current understanding of the theoretical basis of the ILES methodology and reviews its accomplishments. Here ILES pioneers and lead researchers combine their experience to present the first comprehensive description of the methodology. This book should be of fundamental interest to graduate students, basic research scientists, and professionals involved in the design and analysis of complex turbulent flows.

Fernando F. Grinstein and Len G. Margolin are theoretical and computational physicists in the Applied Physics Division of Los Alamos National Laboratory.

William J. Rider is theoretical and computational physicist in the Computational Physics Research and Development Department of Sandia National Laboratories.

To our parents,
our wives, Julia, Holly, and Felicia,
our children, Frederic, Rachel, and Jackson,
and the many contributors to this volume.

Implicit Large Eddy Simulation

COMPUTING TURBULENT FLUID DYNAMICS

Edited by

FERNANDO F. GRINSTEIN
Los Alamos National Laboratory

LEN G. MARGOLIN
Los Alamos National Laboratory

WILLIAM J. RIDER
Sandia National Laboratories

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore,
São Paulo, Delhi, Dubai, Tokyo, Mexico City

Cambridge University Press
32 Avenue of the Americas, New York, NY 10013-2473, USA

www.cambridge.org
Information on this title: www.cambridge.org/9780521869829

First published 2007

A catalog record for this publication is available from the British Library

Library of Congress Cataloging in Publication data

Implicit Large Eddy Simulation : computing turbulent fluid dynamics /
edited by Fenando F. Grinstein, Len G. Margolin, William J. Rider.
p. cm.
Includes bibliographical references and index.
ISBN 0-521-86982-x (hardcover)
1. Turbulence – Mathematical models. 2. Eddies – Mathematical models.
I. Grinstein, Fenando F. II. Margolin, Len G. III. Rider, William. IV. Title.
TA357.5.T87I47 2006
532′.0527 – dc22 2006031149

ISBN 978-0-521-86982-9 Hardback
ISBN 978-0-521-17272-1 Paperback

Additional resources for this publication at www.cambridge.org/9780521869829

Contents

Preface

This book represents the combined efforts of many sponsors. Most of the basic planning and organization was carried out while one of us (F. F. Grinstein) was the 2003–2004 Orson Anderson Distinguished Visiting Scholar at the Institute for Geophysics and Planetary Physics (IGPP) at Los Alamos National Laboratory (LANL). It is very important that we acknowledge the critical role played by the implicit large eddy simulation (ILES) workshops at LANL in January and November of 2004. These workshops took place under the auspices of IGPP and with partial support from the Center for Nonlinear Studies at LANL. They provided us with an ideal forum to meet and exchange ILES views and experiences, and to extensively discuss their integration within the book project. At the personal level, special thanks go to IGPP's Gary Geernaert and to the U.S. Naval Research Laboratory's (NRL's) Jay Boris and Elaine Oran for their continued encouragement and support. Last but not least, continued support of F. F. Grinstein's research on ILES during his tenure at NRL from the U.S. Office of Naval Research through NRL and from the U.S. Department of Defense High-Performance Computing Modernization Program is also greatly appreciated.

This book has evolved far beyond the early plan of merely putting together a collection of review papers on ILES authored by the lead researchers in the area. Several very useful collaborations have quite spontaneously occurred in the process of integrating the material, and we now have an active ILES working group that is focusing on a variety of timely research projects.

Much of the work on ILES reported here was accomplished despite the lack of acceptance and support of the turbulence modeling community. We hope that our readers will recognize the quality of these results and will be encouraged to do their own experiments and evaluations.

Fernando F. Grinstein, Len G. Margolin, and William J. Rider

List of Acronyms

ALE	Arbitrary Lagrangian Eulerian
AMR	Adaptive Mesh Refinement
BBC	code name
CFD	Computational Fluid Dynamics
CV	Control Volume
DES	Detached Eddy Simulation
DNS	Direct Numerical Simulation
ENO	Essentially Non-Oscillatory
ENZO	code name
EULAG	code name
EV	Eddy Viscosity
FCT	Flux-Corrected Transport
FLASH	code name
FLIC	Fluid in Cell
FV	Finite Volume
ILES	Implicit LES
KH	Kelvin-Helmholtz
KRAKEN	code name
LES	Large-Eddy Simulation
MEA	Modified Equation Analysis
MILES	Monotone (or Monotonically) Integrated LES
MM	Mixed Model
MPDATA	Multidimensional Positive Definite Advection Transport Algorithm
MUSCL	Monotonic Upstream-Centered Scheme for Conservation Laws
NFV	Non-Oscillatory Finite Volume
NSE	Navier-Stokes Equations
ODE	Ordinary Differential Equation
OEEVM	One-Equation EV Model
PDE	Partial Differential Equation
PIC	Particle in Cell
PPM	Piecewise Parabolic Method
RANS	Reynolds-Averaged Navier-Stokes
Re	Reynolds Number

RM	Ritchmyer-Meshkov
RT	Rayleigh–Taylor
SGS	Sub-Grid Scale
SHASTA	code name
SMAG	Smagorinsky
TGV	Taylor Green Vortex
TURMOIL3D	code name
TVD	Total Variation Diminishing
VC	Vorticity Confinement
VH-1	code name
WENO	Weighted ENO

List of Contributors

Prof. Dr. Nikolaus A. Adams
Lehrstuhl für Aerodynamik
Technische Universität München
Boltzmannstrasse 15
85748 Garching, Germany

Dr. Niklas Alin
The Swedish Defence Research Agency (FOI)
SE-172 90 Stockholm, Sweden

Dr. Magnus Berglund
The Swedish Defence Research Agency (FOI)
SE-172 90 Stockholm, Sweden

Dr. Jay P. Boris
Laboratory for Computational Physics & Fluid Dynamics
Naval Research Laboratory
Washington, DC 20375

Dr. Carl R. DeVore
Laboratory for Computational Physics & Fluid Dynamics
Naval Research Laboratory
Washington, DC 20375

Bill Dietz
University of Tennessee Space Institute
Tullahoma, TN 37388

Professor J. A. Domaradzki
Department of Aerospace and Mechanical Engineering
University of Southern California
Los Angeles, CA 90089

Professor Dimitris Drikakis
Cranfield University
School of Engineering
Befordshire MK43 0AL
United Kingdom

Meng Fan
University of Tennessee Space Institute
Tullahoma, TN 37388

Dr. Christer Fureby
Department of Weapons and Protection
The Swedish Defence Research Agency (FOI)
SE-172 90 Stockholm, Sweden

Dr. Fernando F. Grinstein
Applied Physics Division, MS B259
Los Alamos National Laboratory
Los Alamos, NM 87545

Marco Hahn
Cranfield University
School of Engineering
Befordshire MK43 0AL
United Kingdom

Dr. S. Hickel
Institute of Aerodynamics
Technische Universitaet Muenchen
85747 Garching, Germany

Prof. Doyle D. Knight
Department of Mechanical and Aerospace Engineering
Rutgers University – The State University of New Jersey
Piscataway, NJ 08854

Dr. Marco Kupiainen
Department of Numerical Analysis and Computer Science
Royal Institute of Technology
S-144 00 Stockholm, Sweden

Dr. Mattias Liefvendahl
The Swedish Defence Research Agency (FOI)
SE-172 90 Stockholm, Sweden

Dr. Eric Lillberg
The Swedish Defence Research Agency (FOI)
SE-172 90 Stockholm, Sweden

Dr. Nicholas Lynn
University of Tennessee Space Institute
Tullahoma, TN 37388

Dr. Len G. Margolin
Applied Physics Division, MS F644
Los Alamos National Laboratory
Los Alamos, NM 87545

Dr. Oskar Parmhed
The Swedish Defence Research Agency (FOI)
SE-172 90 Stockholm, Sweden

Dr. Gopal Patnaik
Laboratory for Computational Physics & Fluid Dynamics
Naval Research Laboratory
Washington, DC, 20375

Dr. Leif Persson
The Swedish Defence Research Agency (FOI)
Department of NBC Protection
SE 901 82 Umeä, Sweden

Dr. Tobias Persson
Chalmers University of Technology
Department of Shipping and Marine Technology
SE 412 96 Göteborg, Sweden

Prof. David H. Porter
Department of Astronomy
University of Minnesota
Minneapolis, MN 55455

Dr. William J. Rider
Computational Physics Research and Development Department
Sandia National Laboratories
PO Box 5800, Albuquerque, NM 87185-0183

Prof. Pierre Sagaut
Laboratoire de Modélisation en Mécanique
Université Pierre et Marie Curie
Centre National de la Recherche Scientifique
75252 Paris, Cedex 05, France

Dr. Piotr K. Smolarkiewicz
Mesoscale and Microscale Meteorology Division
National Center for Atmospheric Research
PO Box 3000, Boulder, CO 80307

Prof. John Steinhoff
University of Tennessee Space Institute
Tullahoma, TN 37388

Dr. Urban Svennberg
The Swedish Defence Research Agency (FOI)
SE-172 90 Stockholm, Sweden

Dr. Lesong Wang
University of Tennessee Space Institute
Tullahoma, TN 37388

Prof. Paul R. Woodward
Department of Astronomy
University of Minnesota
Minneapolis, MN 55455

Wenren Yonghu
University of Tennessee Space Institute
Tullahoma, TN 37388

Ted R. Young
Laboratory for Computational
Physics & Fluid Dynamics
Naval Research Laboratory
Washington, DC, 20375

Dr. David L. Youngs
Atomic Weapons Establishment
Building E3 Aldermaston
Reading Berkshire RG7 4PR
United Kingdom