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978-0-521-13133-9 - Large Eddy Simulation of Complex Engineering and Geophysical Flows
Edited by Boris Galperin and Steven A. Orszag
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Large eddy simulation (LES) is one of the most powerful computational tools available today for studying complex turbulent flows.

This book is the first to offer a comprehensive review of LES – the history, state of the art, and promising directions for future research. Among topics covered are fundamentals of LES; LES of incompressible, compressible, and reacting flows; LES of atmospheric, oceanic, and environmental flows; and LES and massively parallel computing.

The book grew out of an international workshop that, for the first time, brought together leading researchers in engineering and geophysics to discuss developments and applications of LES models in their respective fields.

All those whose work involves turbulence modeling will find this book an invaluable source of information.

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Large Eddy Simulation of Complex Engineering and Geophysical Flows

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Contents

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Preface

Large eddy simulation (LES) is one of the most powerful computational tools available today for the calculation of turbulent flows. The name of this method reflects its very essence: whereas large-scale flow structures are calculated explicitly, small-scale processes, taking place below the limits of numerical resolution, are parameterized using models of various degrees of complexity. Usually such parameterizations are done in the form of eddy viscosity, but characteristic of LES has been an extensive use of nonlinear eddy viscosities introduced in the early 1960s. The first to use a nonlinear viscosity in numerical models of global atmospheric circulation was Joseph Smagorinsky, but in Chapter 1 of this volume he traces even earlier utilizations of such viscosities in simulations of compressible flows with shocks. Truly large eddy simulations in a form not much different from those in use today were performed by James Deardorff in the early 1970s on convective and channel flow turbulence. Because, by today's standards, computer resources of 20 years ago were quite primitive, extensive experimentation with nonlinear viscosities in geophysical models was not feasible. Besides, these models seemed to have problems that were much more acute than subtleties in the choice of eddy viscosity, and soon the center of gravity in geophysical research shifted elsewhere.

An opposite tendency was developing in engineering, where efforts were concentrated on direct simulation of the three-dimensional Navier–Stokes equation in simple geometries resolving all scales up to the viscous, or Kolmogorov, scale (the method known as direct numerical simulation, or DNS). Rapid progress in this field was stimulated by growing computer power, the introduction of vector computer architecture, and the intensive development of spectral methods. Of course, DNS could be applied only to low Reynolds number flows with relatively small spatial scales, but those are often sufficient

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in practical engineering problems. At the same time, DNS codes were used in the LES mode, whereas resolved scales were considerably larger and molecular viscosity was replaced by nonlinear eddy viscosity of the Smagorinsky type to account for the unresolved small-scale mixing. This led to a revitalization of interest in LES in the engineering community.

In the early 1980s meteorologists revived their interest in LES, but it was used mostly in relatively small scale calculations of various features of planetary boundary layers. For some ten years the exploration of the potential of LES in engineering and in geophysics has been going on by almost parallel routes, without much interaction. This weak communication between the fields can be attributed to different objectives in respective LES applications: while engineering flows are relatively small scale and neutrally stratified, geophysical flows occupy large domains and are usually subjected to a host of external factors, such as density stratification, rotation, curvature, and differential rotation.

Recently, however, the overlap between LES applications in geophysics and engineering has been rapidly increasing due to the widening variety of problems made tractable by this method. Among problems of equal importance in both fields are flows in the vicinity of solid walls, flows with open surfaces, rotating flows, flows with chemical reactions and stochastic backscatter. Additional common ground may be flows with two-dimensionalization and relaminarization due to external factors (extra strains in Peter Bradshaw's terminology). In such flows, of particular interest to large-scale geophysics, the inherent backscatter of energy from three-dimensional to two-dimensional regions in the wave number space may become an important energy source for large-scale dynamics, due to the inverse energy cascade.

An international workshop entitled "Large Eddy Simulation: Where Do We Stand?", the first of its kind, took place on December 19–21, 1990, at St. Petersburg Beach, Florida. It was intended to bring together engineers and geophysicists actively engaged in the development and application of LES models. Its objectives were the assessment of the state of the art of LES, facilitation of the cross-disciplinary exchange of information and experience, cross-fertilization of the fields that are or may be benefiting from the application of LES, and an outline of the most promising directions for the future research. A total of 25 presentations by international experts were clustered in five sessions, each of which was devoted to a particular area of engineering or geophysical sciences. The information presented and deliberations that followed were summarized in two panel discussions. The third panel discussion was devoted to assessing the state of the art of the rapidly developing application of massively parallel computers in LES.

This book is the result of the workshop and it contains most of the information presented there. However, the chapters have been updated, and since LES is a rapidly developing field, some contributions made after the work-

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shop have been included. The book therefore actually reflects the status of LES and of applications of massively parallel computers as of the beginning of 1993.

The book consists of four major sections, Fundamentals of LES, LES in Engineering, LES in Geophysics, and LES and Massively Parallel Computing. The first section covers major historical highlights as well as important recent contributions, such as applications of two-point closures, renormalization group theory of turbulence, dynamic eddy viscosity, and formulations of the stochastic backscatter. The second section describes applications of LES for simulations of incompressible, compressible, and reacting flows important in engineering. The third section details applications of LES for geophysical sciences, such as meteorology, physical oceanography, and environmental engineering. The sections on LES in Engineering and LES in Geophysics begin with broad overview chapters which should give the reader a global picture of those respective areas and general guidelines about the rest of these sections' presentations. Finally, updated transcripts of the panel discussions should help the reader to summarize and digest the information presented. The fourth section is based on the panel discussion on LES and massively parallel computing, but it has been substantially extended and upgraded to include important recent developments.

We hope that this book will be useful to a wide community of scientists, engineers, researchers, and graduate students working in different areas of fluid mechanics and interested in the computation of turbulent flows. We also hope that it will promote the continued flourishing of large eddy simulation.

In conclusion, we acknowledge sponsorship of the workshop by the University of South Florida, Office of Naval Research, NASA–Langley Research Center, and Army Research Office, and by the computer companies IBM, Intel, and Silicon Graphics. We also acknowledge the great help of Ms. L. Ellenburg and her staff at the Division of Conferences and Institutes, University of South Florida, Ms. M. Kastrenakes from CommuniK Advertising, Inc., Ms. K. Birchett, and Ms. E. Bedell, Ms. L. Niswander, and Ms. L. Kelbaugh from the Department of Marine Science, University of South Florida, in organizing and running the workshop, and Mr. J. Chad Edmisten from the Marine Science Graphics Department, University of South Florida, for his great help in the layout and design of the artwork. We also appreciate the assistance, patience, and understanding of the authors who have helped us to put this book together in camera-ready form.

Steven A. Orszag

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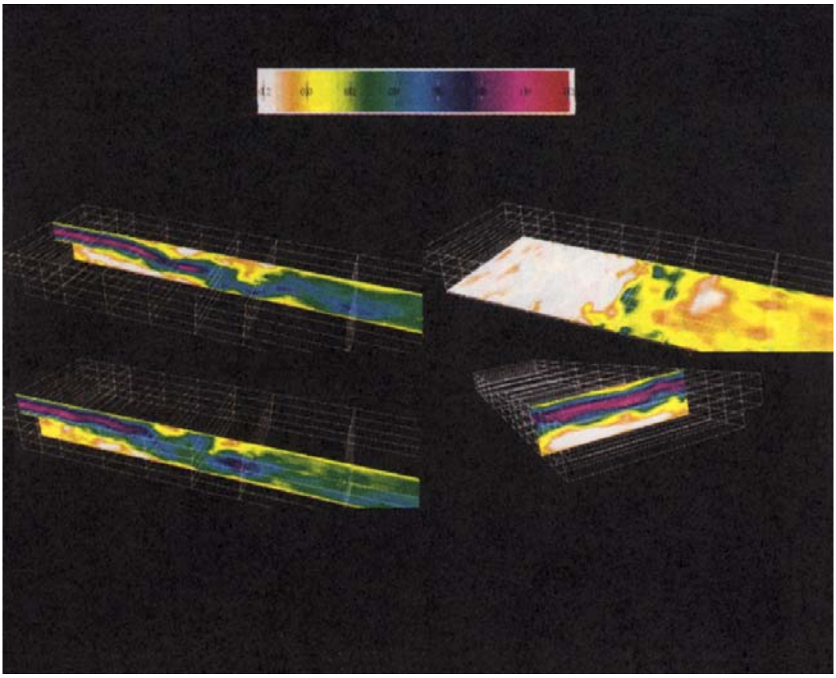

Plate 1 Color contours of instantaneous streamwise velocity along the span, on a horizontal plane, and on a vertical plane downstream of the step [Re = 8,888] (see Chapter 8).

Plate 2 Plot of subgrid product concentration contours for the pseudoincompressible case at $t^* = 0.549$ (see Chapter 15).

Plate 3 Plot of subgrid unmixedness contours for the pseudoincompressible case at $t^* = 0.549$ (see Chapter 15).

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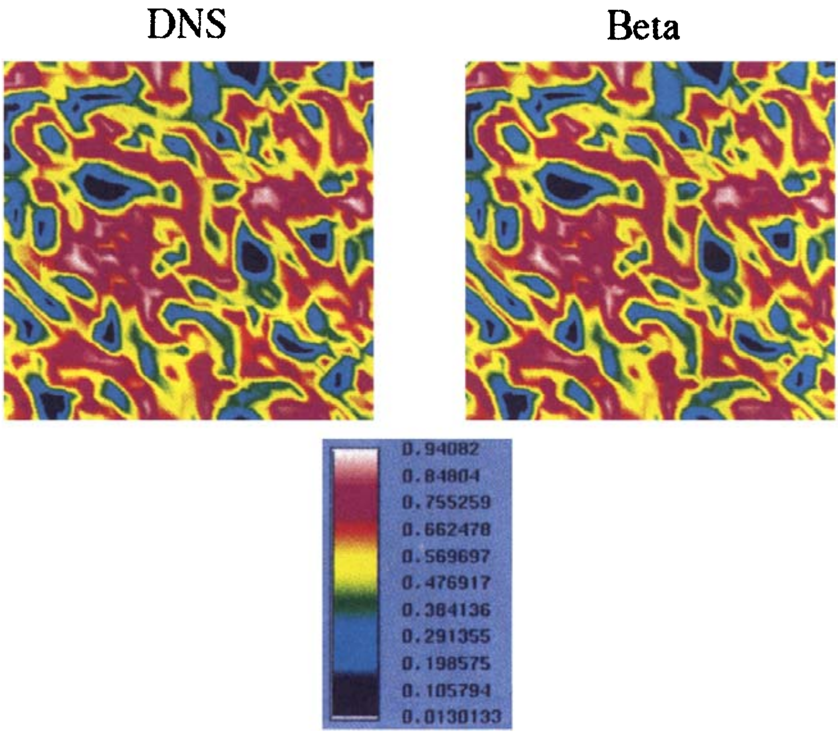

Plate 2

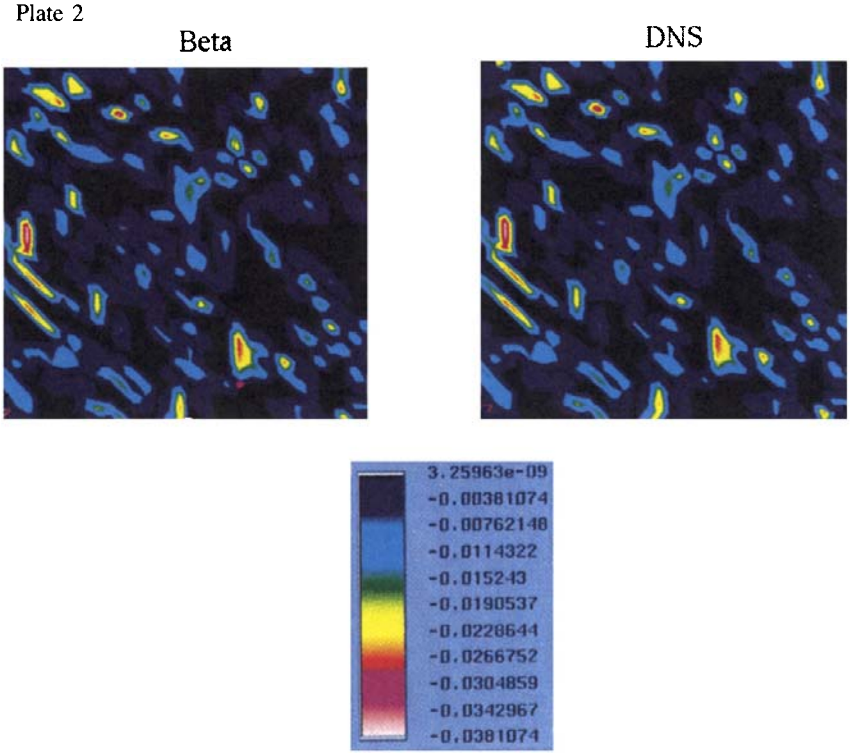

Plate 3

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