Preface

Direct and large-eddy simulations of turbulent flow form the subject of this book. These simulation strategies are focused on capturing the primary features of unsteady flow through computation rather than to aim for a complete statistical modeling as in Reynolds averaged Navier-Stokes approaches. In direct numerical simulation the governing equations are represented with sufficiently high temporal – and spatial resolution to capture all dynamically relevant flow features. The basis for large-eddy simulation is somewhat different in nature. Next to an element of numerical modeling, the large-eddy approach is characterized by an element of mathematical-physical modeling.

A major step in the large-eddy approach consists of the smoothing and regularization of the dynamical complexities of the full flow equations. This is achieved through some form of explicit or implicit filtering. A closure problem arises as a consequence of the filtering which introduces the element of modeling into the simulation strategy. In fact, an external length-scale, identified with the width of the filter, is introduced, which offers a control over the smallest features in the flow description. The dynamical effects of flow structures that are smaller than this filter width constitute the closure problem which needs to be properly parameterized through the explicit introduction of a so-called subgrid model.

To complete the simulation approach, a physically relevant numerical representation needs to be created to render a computational dynamical system with which the primary properties of the fluid flow are mimicked. The simulation is aimed to be consistent with the flow only to a degree which suits the central research questions that one may have in relation to a particular flow problem. Hence, in the large-eddy approach there is some room for 'bargaining'; by removing the smaller details from the flow description the simulations become computationally much less demanding but this comes at the price of having to deal with the closure problem and extracting predictions from flow fields that contain less information.

The search for a proper and acceptable balance between the reduction of information content on the one hand while retaining sufficient accuracy on the other hand is at the heart of large-eddy simulation. These are recurring topics in this book and express themselves, e.g., in attention for the mathematical properties of the modeling process, the development of accurate numerical methods, the construction of suitable subgrid models to represent the dispersive and dissipative effects of small-scale turbulence and the analysis of the interaction between discretization and modeling errors that complicate the interpretation and reliability of actual large-eddy simulations.

The material in this book is organized in four parts. In the first part some basic phenomenology of turbulence is described together with the governing equations and the introduction of the filtered flow representation. The second part addresses the main numerical elements associated with direct and large-eddy simulation, i.e., the time-integration and the spatial discretization. Subgrid modeling is discussed in the third part, including the mathematical-physical aspects of the modeling process as well as a collection of basic – and more involved subgrid models. Finally, in the fourth part the central validation and interacting error-dynamics are illustrated.

This book has arisen from courses that were given in recent years for PhD students of the J.M. Burgers Center, a research-school for fluid dynamics in the Netherlands, and lectures compiled in the context of an ERCOFTAC summer-school (European research council for flow, turbulence and combustion), held in Gliwice, Poland. The choice was made to provide a perspective of modern turbulent flow simulation that encompasses all relevant elements, rather than to isolate one single aspect and aim for its exhaustive discussion. Obviously, not every aspect of this wide-ranging and rapidly developing field of research can be covered in a comprehensive way in a single book. Therefore, the emphasis has been put on making the basic problem-areas in large-eddy simulation transparent and accessible. It is hoped that this book provides a sufficiently detailed exposition of the material to allow an easy access to this more specialized literature and form a reliable point of departure from which successful large-eddy approaches can be developed.

My personal road into turbulence simulation dates back some 10 years. The close collaboration with a large number of PhD students, post-docs and members of staff at the University of Twente formed a continuous source of questions and installed a humbling respect for the complexity of turbulence and its practitioners. As such, this book documents some of our joint journey, illustrating not only the beauty and elegance of this field of study but also, at times, the fact that the road can be quite narrow and slippery, awakening the necessary sense of perseverance in all of us. I would like to mention Hans Kuerten with whom I have had the great pleasure to work with over a number of years as close colleagues. Together we supervised a number of PhD students. For this book the following are particularly relevant: Bert Vreman, Bono Washisto, Ruerd Heeg, René van Buuren, Wilbert IJzerman and Irene de Bruin. I especially cherish the ongoing cooperation with Bert Vreman who has the special talent to perceive the simple basic questions behind complex problems. Some parts of this book rely directly on our joint work and reflect our common 'struggle' and mutual developments. More recently, my horizon broadened, partly as a result of participating in the turbulence program at the Isaac Newton Institute in Cambridge where I came into contact with a number of inspiring scientists. I would like to mention especially Darryl Holm (LANL) and David McComb (Edinburgh) who both have the remarkable talent and courage to address turbulence from a coherent and encompassing theoretical framework.

The wide scope of turbulent flow and its applications also seems to transfer to the people working in this field. These range from theoreticians concentrating on fundamental aspects of turbulence to engineers working in the context of quite specific applications. This contributes to the appeal of the 'turbulence community'. The beauty, challenge and relevance of turbulence and the variety of interactions among people working in this field appears to provide its own source of energy to keep the flow of research going.

This book aims to appeal to a broad audience of applied scientists and engineers who are involved in the development and application of computational fluid dynamics for turbulent flows. The intended readership includes academic researchers as well as CFD practitioners in industry. It is intended to constitute an introduction for PhD candidates and can also be used as a complementary textbook at the level of MSc (or MEng) studies in engineering, applied mathematics and physics departments. It is hoped that this book provides a good introduction to large-eddy simulation as well as offer some stimulation for further research into numerical methods and turbulence modeling, and their application in technology and natural sciences.

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