Turbulence

Frans T.M. Nieuwstadt · Bendiks J. Boersma
Jerry Westerweel

Turbulence

Introduction to Theory and Applications of Turbulent Flows

Springer

Frans T.M. Nieuwstadt
J.M. Burgers Center for Fluid Mechanics
Delft University of Technology
Delft
The Netherlands

Jerry Westerweel
J.M. Burgers Center for Fluid Mechanics
Delft University of Technology
Delft
The Netherlands

Bendiks J. Boersma
J.M. Burgers Center for Fluid Mechanics
Delft University of Technology
Delft
The Netherlands

Original Dutch text translated by Just van der Wolf.

Frans T.M. Nieuwstadt is deceased.

ISBN 978-3-319-31597-3 ISBN 978-3-319-31599-7 (eBook)
DOI 10.1007/978-3-319-31599-7

Library of Congress Control Number: 2016938387

This is an updated and augmented translation of the original Dutch work “Turbulentie” by Frans T.M. Nieuwstadt, published by Epsilon Uitgaven, 1998.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

The original version of this book was revised:
An Erratum to this can be found
at DOI 10.1007/978-3-319-31599-7_11

In memoriam,
Frans T.M. Nieuwstadt
April 8, 1946–May 18, 2005

Photo by Sam Rentmeester / FMAX

Preface

Turbulence is a part of fluid mechanics. Therefore, in this book, it is assumed that the reader is already familiar with the fundamentals of fluid mechanics. There are many books that the uninformed reader can consult. A first introduction is provided by the book of White (2011), which also can be recommended for its practical approach, or the books by Acheson (1990), Faber (1995), or Kundu and Cohen (2004), which can be recommended to the reader interested in the physical aspects of fluid mechanics. Standard text books on fluid mechanics are those by Landau and Lifshitz (1959), and especially by Batchelor (1967), which contains a solid mathematical treatise of fluid mechanics.

We are only able to dwell briefly on the results of linear stability theory and the solution to Burgers equation. For further details on stability analysis the reader is referred to the book of Drazin and Reid (1981), while for the Burgers equation the reader is referred to the book of Whitham (1974), where a comprehensive treatise on the Burgers equation is given. An introduction to nonlinear dynamical systems and chaos theory is given in the books by Schuster (1984) and Bergé et al. (1984).

On the topic of turbulence, several text books can be recommended to be used simultaneously with this book; it is often very clarifying when the same material is considered from different viewpoints. Foremost, we suggest the book of Tennekes and Lumley (1972), which has been among the most cited books on turbulence for decades and which has been the inspiration for certain parts of the present book. Traditional descriptions of turbulence that originate from statistical mechanics can be found in the books by Monin and Yaglom (1973) and Landahl and Mollo-Christensen (1986). Also, there are a number of standard works in the field of turbulence, which can be consulted for various topics. Classic text books on turbulence are those by Townsend (1976) and Hinze (1975), while more recent books are those by Pope (2000) and Davidson (2004), which all can be used by those who wish to continue on the topics introduced in this book. There are also several books on specialized topics in turbulence, such as the book by Batchelor (1953) on the theory of homogeneous turbulence, while developments in the field of spectral models can be found in the book by Lesieur (2008) and in the field of

renormalization methods in the book by McComb (1990). Also, much attention in physics has been devoted recently to scaling of the microstructure, following the theory of Kolmogorov. An overview of this modern theory can be found in the book by Frisch (1995).

This book was originally written by Frans T.M. Nieuwstadt to support his lectures on turbulence at the level of master students at the Delft University of Technology. It was based on his lecture notes for a course taught at the University of Utrecht before he was appointed at the Delft University of Technology. His objective had been to write a concise introduction on the physical aspects of turbulence (partly inspired by the work of Tennekes and Lumley), but substantially extended to include insights from nonlinear dynamical systems and chaos theory, stability analysis, modern numerical methods, and an overview of current turbulence *closure models* used in *computational fluid dynamics* (CFD) codes. Besides, he wanted to have a book that was also affordable to students.

The original work was written in Dutch, and it was used also at other Dutch universities. However, since around the year 2000, courses had to be taught in English, and we resorted to English language textbooks. Although various excellent books have been available, we could not find the mix of topics that we were used to in the original book by Frans T.M. Nieuwstadt. Since long we had planned to translate, update, and extend the book. Also, we received requests from colleagues to make available a translation of the book. The present book is the result of this effort.

We are indebted to many colleagues who contributed to the completion of this book; in particular we would like to thank Gijs Ooms for proofreading this book and Herman Clercx of the *Vortex Dynamics and Turbulence Group* at the Eindhoven University of Technology for writing a special topic on *rotating turbulence* (Sect. B.4).

Delft
April 2015

Bendiks J. Boersma
Jerry Westerweel

Contents

About the Authors

Frans T.M. Nieuwstadt (1946–2005) was director of the *Laboratory for Aero and Hydrodynamics at the Delft University of Technology* from 1986 till 2005. Previously he worked at the *Royal Netherlands Meteorological Institute* (KNMI), where he conducted research on the atmospheric boundary layer. After completing his studies in Aeronautics in Delft, he worked for 2 years under the supervision of Anatol Roshko at the *California Institute of Technology*. At KNMI he obtained his Ph.D. under the supervision of Henk Tennekes, Jakob Steketee and Jeff Zimmerman. In Delft his interest in turbulence expanded to various areas, such as polymer drag reduction, transition to turbulence in pipe flow, disperse multiphase turbulent flows, and turbulent reacting flows, while maintaining an interest in atmospheric turbulence. He was one of the initiators of the *J.M. Burgers Centre*, which is the Netherlands research school for fluid mechanics that encompasses the activities of entire fluid mechanics community in the Netherlands. Also he was chairman of the *Foundation for Fundamental Research on Matter* (FOM) from 2000 till 2005. He was one of the founding editors of the scientific journal *Flow, Turbulence & Combustion*.

Bendiks J. Boersma (1969–) studied mechanical engineering at the *University of Twente* under supervision of Leen van Wijngaarden. He obtained his Ph.D. at the *Delft University of Technology* in 1997 under supervision of Frans Nieuwstadt. His main interests are the numerical simulation of turbulent flows, including aeroacoustics, drag reduction, and supercritical fluids. After his Ph.D. he worked for 2 years at the *Center for Turbulence Research at Stanford University*, and then became a *Research Fellow* with the *Royal Netherlands Academy of Arts and Sciences*. He was appointed full professor in 2007 at the *Delft University of Technology*, and currently leads the *Energy Technology* section.

Jerry Westerweel (1964–) studied applied physics at the *Delft University of Technology*. He obtained his Ph.D. in 1993 under supervision of Frans Nieuwstadt. As a *Research Fellow* with the *Royal Netherlands Academy of Arts and Sciences he*

worked at Stanford University, the *California Institute of Technology*, and the *University of Illinois at Urbana-Champaign*. He became an *Anthony van Leeuwenhoek* professor at the *Delft University of Technology* in 2002, and leads the *Fluid Mechanics* section since 2005. His scientific interests are turbulence and coherent flow structures, and optical measurement techniques for quantitative measurements in flows.