

Turbulence

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Turbulence

Introduction to Theory and Applications
of Turbulent Flows

 Springer

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Frans T.M. Nieuwstadt is deceased.

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

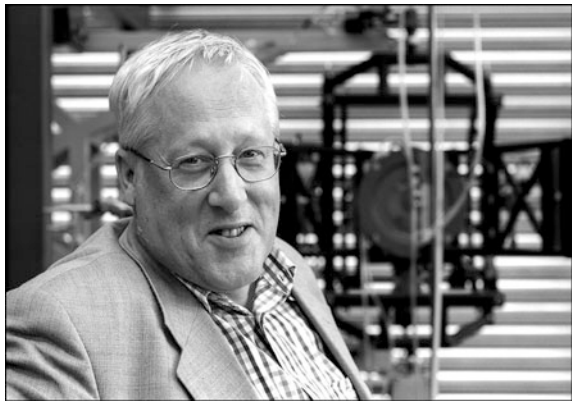


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Preface

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).

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April 2015

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Contents

1	Introduction	1
2	Equations of Motion	9
2.1	Incompressible Flow	9
2.1.1	Problem	11
2.2	The Boussinesq Approximation	12
2.2.1	Problems	15
2.3	Coordinate System	17
3	Stability and Transition	19
3.1	Stability Analysis	19
3.2	Kelvin–Helmholtz Instability	20
3.3	Stability of a One-Dimensional Flow	28
3.3.1	Tollmien–Schlichting Instability	33
3.3.2	Rayleigh Stability Criterion	35
3.4	Routes to Chaos	38
3.4.1	The Logistic Map	38
3.4.2	The Lorenz Equations	43
3.4.3	Transition in Pipe Flow	48
4	The Characteristics of Turbulence	55
4.1	The Burgers Equation	55
4.2	Phenomenology	60
4.3	Experimental and Numerical Methods	66
5	Statistical Description of Turbulence	75
5.1	Statistics	75
5.2	Stationarity and Homogeneity	78
5.3	The Reynolds Equations	80
5.4	Kinetic Theory of Momentum Transfer	83

6	Turbulent Flows	87
6.1	Channel Flow	87
6.2	Mean Velocity Profile.	89
6.3	Scaling of Turbulent Wall Flows	95
6.4	Wall Roughness.	101
6.5	Pressure Gradient.	104
6.6	Free Turbulent Flows	107
6.7	The Free Jet	113
7	Kinetic Energy	125
7.1	Kinetic Energy of the Mean Flow	125
7.2	Kinetic Energy of Turbulence	128
7.3	Prandtl's One-Equation Model.	132
7.4	Energy Equation per Component	134
7.5	Convective Turbulence	138
7.6	The Convective Boundary Layer	145
8	Vorticity	151
8.1	Vorticity Equation	152
8.2	Coherent Structures	156
8.3	Enstrophy	161
8.4	The k - ϵ (e - ϵ) Model.	165
8.5	Second-Order Closure and Algebraic Stress Models	170
8.6	Large Eddy Simulation of Turbulence	176
9	Correlation Function and Spectrum	183
9.1	Time Correlations	183
9.2	The Spectrum	186
9.3	Spatial Correlations and Spectra.	188
9.4	The Taylor Hypothesis	194
9.5	Scaling of Turbulence Spectra	197
9.6	Isotropic Turbulence.	203
10	Turbulent Diffusion	215
10.1	Statistical Approach	215
10.2	The Diffusion Equation.	219
10.3	Inertial Transport	224
	Erratum to: Turbulence	E1
	Appendix A: Equations of Motion	233
	Appendix B: Special Topics	235
	References	267
	Index	273

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

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