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Book Review

"Turbulence in the Atmosphere", by John C. Wyngaard, Cambridge University Press, 2010; ISBN 978-0-521-88769-4 (hardback), USD 75.00

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I will start with a quotation from a Peter Bradshaw paper: "the whole phenomenon of turbulence [was] probably invented by the Devil on the seventh day of Creation (when the Good Lord wasn't looking)" (Bradshaw, P., Turbulence: The chief outstanding difficulty of our subject, Exp. in Fluids, 16, 1994, 203).

Understanding of fluid turbulence is one of the most intriguing problems of contemporary mathematical and theoretical physics. While turbulent motion is usually, in practical terms, an intuitively perceived phenomenon, its fundamental nature is still controversial and a notoriously difficult subject.

This book is based in large part on the graduate course in atmospheric turbulence delivered by the author at Penn State University. It is aimed at being an introduction to the fields of turbulence and atmospheric turbulence modelling. The book is divided into three self-contained parts.

Part I, "A grammar of turbulence" concerns basic aspects of turbulence description and consists of seven chapters. Chapter 1 is the concise presentation of characteristic properties of turbulent fluid motions. After discussing the turbulent pipe flow, this chapter introduces the transport equations of a constant density, Newtonian fluid. The main types of numerical approaches to turbulence are also mentioned briefly.

The phenomenology of turbulence is largely concerned with various statistical quantities, such as mean values, probability distribution functions, spectra, correlations, the only ones that can be measured in a turbulent flow. Chapter 2 gives a terse presentation of averaging procedure, from ensemble average (over all possible states of the system) to time-averaging. The following notions are introduced and explained: ergodicity, the eddy velocity scale, the power spectral density of the velocity field, turbulent vorticity, the eddy diffusivity and coherent (or localized) structures. These concepts are often sufficient to reveal some of the most important universal features of turbulent motions.

Chapter 3 sets a foundation of turbulence dynamics. First, the equations for the ensemble-averaged fields of velocity and a conserved scalar in an incompressible turbulent flow are derived. Next, the spatially filtered equations are obtained. The resulting turbulent flow models fall into two distinct classes: Reynolds-averaged Navier–Stokes (RANS), based on ensemble averaging, and large-eddy simulation (LES) using space averaging. Such formulation of turbulent flows problems provides a theoretical basis for developing relevant numerical methods.

Chapter 4 discusses turbulent fluxes and Taylor's idea of the "mixture-length"—a key notion in Taylor's 1915 paper. In chapter 5, the transport equations for turbulent fluxes are derived, discussed and interpreted. It ends with a critical discussion of the history of the subject.

Chapter 6 presents some arguments of the advantages of LES over other methods. It contains rather extensive discussion of the filtering operation, with the application of filtering to the transport equations. The calculations are carried out in a physical space representation of filtering and in wavenumber space, which helps to understand the physical mechanisms

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of interscale energy transfer. The calculations are carried out in physical space representation of filtering and in wavenumber space, which helps to understand the physical mechanisms of interscale energy transfer.

Since the Kolmogorov 1941 papers, there exists the almost mystical belief in some universal, in a statistical sense, properties of turbulence. In chapter 7, the important contribution given by A.N. Kolmogorov on the statistical theory of the fully developed small-scale turbulence is reviewed. Topics include: the spectral energy cascade, the Kolmogorov hypotheses about the inertial subrange, dissipation and dissipation-intermittency models and some aspects of two-dimensional turbulence theory by Kraichnan and Batchelor (in the spirit of the Kolmogorov phenomenology). The significance and impact of Kolmogorov ideas on modern turbulence research, in both experiments and numerical simulations, as well as in the theory, are also presented. However, we will quote Professor A.N. Kolmogorov himself: "I soon understood that there was little hope of developing a pure, closed theory." (Tikhomirov, V.M. (ed.), Selected works of A.N. Kolmogorov, I, Kluwer, 1991, p. 487).

The next five chapters form Part II, entitled "Turbulence in the atmospheric boundary layer". In chapter 8, the dynamic equations for atmospheric turbulence are derived. First, the basic equations for a dry atmosphere are presented. Next, the moist-air equation set is treated. The dynamics of cloud air (dry air, water vapor, and water droplets) is also described.

Chapters 9–12 deal with structure and characteristics of atmospheric boundary layer (ABL). Chapter 9 discusses, among others, the stable ABL, the convective ABL, the Ekman spiral and the Ekman pumping. The following chapter presents the famous Monin–Obukhov (M–O) similarity theory, which has the key meaning for understanding of the atmospheric surface layer. It should be underlined, however, that at the present time, the use of the M–O theory is limited to the constant-flux surface layer, and over homogeneous surfaces. Moreover, even under perfect,"bookish", conditions, the theory has an accuracy of only about 10–20% (Foken T., Boundary-Layer Meteorology (2006) 119, 431–447).

Chapter 11 concerns convective boundary layer (CBL), where large-scale motion known as thermal convection is generated. The focus is mainly on the physical parameters of the layer, including mean wind profiles, turbulent stress profiles and the profiles of the mean value and vertical flux of a conserved scalar, as calculated in the field and through large-eddy simulation. The CBL is characterized by intense mixing leading to mix heat, momentum, moisture, etc. The stable boundary layer (SBL) is created under conditions where the radiative cooling of the ground makes the near the surface air cooler than the air above. The last chapter overviews the energetics of stably stratified turbulent layer and presents some utilizations of second-order closure schemes and LES to the SBL modelling. An approach to treating gravity waves by means three-part decomposition of flow variables in the nocturnal SBL, is described also. To characterize the construction of quasi-steady SBL, the evolving SBL and the equilibrium height of SBL, some models have been developed to capture the essential dynamic mechanisms responsible for the internal layers structure.

Part III "Statistical representation of turbulence" presents an assortment of statistical tools that are permanently used in the study of turbulence. Chapter 13 covers random variables, probability densities, distributions, moments and stationary random processes (with illustrative figures). The Lundgren, "one-point" evolution equation for the probability density of the velocity field is sketched also. Chapter 14 is about isotropic tensors. The concept of local isotropy and local anisotropy in the context of turbulence models is elucidated briefly. Various types of correlation functions and their Fourier—Stiltjes representations are discussed in chapter 15 with applications to isotropic spectra and their inertial subranges. The final chapter deals with spectral equations for the scalar in steady, isotropic turbulent flows. Some remarks about the analysis and interpretation of turbulence measurements are given as well.

Prof. Wyngaard's book is very clear and masterfully written. It must be mentioned that this book includes stimulating problems and exercises at the end of each chapter. The book assumes a basic knowledge of fluid mechanics and atmospheric physics, both mathematically and in physical discussion. It does not assume a deep insight into the field of turbulence modelling. However, a general understanding of numeric methods and principles of modelling is important for working with this book. The text can be recommended not only for graduates studying atmospheric physics. It should also be useful for students of geophysical fluid dynamics, applied mathematics, and engineering who have an interest in the atmosphere.