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Book reviews

New Tools in Turbulence Modelling, edited by **O. Métais, J. Ferziger** (Springer-Verlag GmbH & Co. KG, Heidelberg, 1997, 298 pp.) DM 128.00 ÖS 934.40 sFr 113.00 GB£ 49.00 US$ 84.00 pb ISBN 3 540 63090 2.

This book summarizes recent progress in modelling of turbulence flow phenomena in so diverse fields as astrophysics, geophysics, plasma physics and engineering sciences like aerodynamics, aeroacoustics and combustion. It contains fifteen lectures presented during a Spring School in 1996 at the 'Centre de Physique des Houches' located at the foot of Europe's highest mountain. There is hardly a scenery more appropriate than the majestic Mont-Blanc to discuss and to think about turbulence, which is generally considered as one of the important unsolved problems of physics. Yet the last 10-15 years of turbulence research have seen considerable progress in understanding turbulence flow phenomena, especially through direct numerical simulation (DNS) and large-eddy simulation (LES). With the aid of DNS it was possible to demonstrate that the appearance of coherent (streaky) structures is a consequence of strong mean shear near walls (rather than of wall-blocking or viscous wall effects) and that homogeneous shear flow with comparable mean shear produces the same structures. It is this search for structural similarities that should guide the development of new turbulence models in the future. Besides DNS and LES, statistical simulations have been successful for certain classes of problems. These tools and their refinements are mostly used in the book under review.

The first lecture by M. Lesieur provides a thorough discussion of the Large-Eddy Simulation (LES) formalism for incompressible turbulence both in physical and spectral space. The spectral eddy viscosity concept, originally due to Kraichnan, is adapted to various kinetic energy spectra and to the transport of a scalar. In the context of decaying isotropic turbulence the issue of infrared backscatter is then discussed. A new subgrid scale model that is presented, the spectral dynamic model, is suitable for non-developed turbulence and looks promising. In it the exponent of the kinetic energy spectrum is determined through the LES with the aid of least-squares fits close to the wavenumber cutoff. Finally, the counterparts of spectral models, namely selective and filtered structure-function models are considered before applications to mixing layers, channel and backward-facing step flow are presented. The reliability of subgrid scale (SGS)models is an important issue in LES. But there are further crucial points to be taken care of, as pointed out by J. Ferziger in the second lecture; namely the accuracy of numerical schemes (discretization and aliasing errors), the relation between SGS models and numerical methods, the generation of unsteady initial and inflow conditions, the proper modelling of near wall regions (which helps to save computer time and storage) and, finally, the difficulties with the dynamic procedure of computing eddy viscosities locally and temporarily during the LES. This procedure principally allows for positive and negative viscosities. The latter reflect a transfer of fluctuating kinetic energy from the unsolved to the resolved scales (back-scatter). If the eddy viscosity remains negative over too large a domain or for too long a time, the computation gets numerically unstable. Techniques to cure this problem are discussed. Complementary aspects of LES and statistical simulations (on the two-equation and the second-order closure level) are brought out in the third lecture by W. Rodi, based on computations of flows that are of practical interest to engineers. These are flows through square-ducts, 2D separated flow, flow past a square cylinder or a surface-mounted cube and flow in a baffled stirred tank reactor. The quality of the computations (in comparison to experimental data) and

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the computer resources required by both tools are used to assess their relative performance and potential. The author concludes that LES is superior to statistical simulations when the flow is really complex, *i.e.* statistically time-dependent and three-dimensional. This is the area where LES most likely will become the method of choice in practical applications. An appealing, because cohesive overview of compressible turbulence research related to DNS, LES and statistical simulation, is given by T. Gatski in lecture 4. A discussion of recent DNS and LES results for isotropic turbulence, homogeneous shear and compressed turbulence, shock-turbulence interaction and wall-bounded turbulence aims at providing a better understanding of the flow dynamics. It hence forms an information basis for improved model development. The second half of the lecture is devoted to statistical modeling, with a particular focus on the correlations that are unique to the compressible regime as e.g. dilatation dissipation, pressure-dilatation and mass-flux. The lecture also addresses the fact that some incompressible closures can easily be extended to supersonic flows through variable-density extensions. This is especially true for near wall turbulence. The LES approach essentially follows the same lines focussing on variable-density extensions for subgrid scale models. Lecture five presented by D. Veynante and T. Poinsot starts with a brief description of laminar flames and the influence of turbulent motions on low-speed combustion processes. Various statistical models for premixed and non-premixed combustion are discussed ranging from algebraic closure via a transport equation for the flame surface density to probability density function (PDF) approaches. The last two approaches were recently shown to be related. An interesting discussion of LES models for combustion follows, comprising simple applications of statistical models to the subgrid scale terms, an extension of the dynamic model, flame front tracking (via a filtered G-equation) and PDF methods adapted to the unresolved scales. Lecture six by G. Comte-Bellot *et al.* comprehensively describes the most efficient techniques which are presently available for theoretical analyses and engineering noise predictions. The most prominent and in some sense complementary approaches which permit to obtain the far field noise generated by turbulent flows are Lighthill's analogy and the SNGR model which is based on the linearized Euler equations. Three examples are chosen to illustrate these approaches: Noise generated by isotropic turbulence, by sub- or supersonic free jets and by a diaphragm mounted in a square duct. Thanks to DNS it is possible to show for the first time that the acoustic pressure spectrum resulting from isotropic turbulence peaks at a frequency four times the inverse eddy turnover time. This means that eddies which are about 10 times smaller than the most energetic eddies contribute most to the emitted noise. The other important topic treated in this lecture concerns the propagation of acoustic waves through turbulence over long distances, *i.e.* distances of the order of hundred integral length scales of the turbulent field. The most useful tools described are the ray tracing method, the Helmholtz equation with a random index of refraction and the parabolic approximation deduced from the Helmholtz equation. It is shown that the parabolic equation has to be solved for individual turbulent field realizations before the solutions are ensemble averaged, if nasty closure problems are to be avoided.

The remaining half of the book contains mostly shorter contributions related to industrial applications. In lecture 7 P. Comte extends the LES formalism to compressible flows in curvilinear coordinates and obtains results for the transition to turbulence of a boundary layer at Mach 4.5 and of a transonic mixing layer forced by acoustic modes (case of a planar model of the solid-propellant boosters of ARIANE V). The latter example shows how LES can contribute to an improved understanding of the vortex shedding mechanism and the structural vibrations it induces. P. Sagaut *et al.*'s lecture 8 identifies the needs for improved CDF tools to predict aerodynamic flows that are typically 3D, time-dependent either laminar, transitional or turbulent and appear in complex geometries. The ONERA strategy and status concerning the development of LES and DNS techniques and the extension of LES to engineering purposes is also discussed. B. Aupoix *et al.*'s lecture 9 deals with aeronautical flows as well. It concentrates on wall flows and there on the statistical modeling of the dynamical problem. The authors analyze the reasons for the deficiencies of two-equation turbulence models and provide corrections for compressible boundary layers. A comparison of various Reynolds stress models is performed for three-dimensional boundary layers showing that this flow type still forms a challenge for turbulence modeling.

A field of research that has been largely supported for the past twenty years in France and elsewhere is the Inertial Confinement Fusion. Lecture 10 by D. Besnard *et al.* comments on current developments related to problems of instability and turbulence in this context. An example where these problems occur is the design of a laser target for a Megajoule laser. The LES technique is used to explore the transition to turbulence via Rayleigh-Taylor instabilities, presently under somewhat idealized circumstances (Navier-Stokes and concentration equations). Thermal-hydraulic phenomena which occur in various components of nuclear reactors are addressed in lecture 11 by D. Grand and G. Urbin. LES is demonstrated to be a powerful tool to predict a number of single phase prototype flows, relevant to reactor components such as the backward facing step, the flow of the hot liquid sodium in a rectangular box, natural and exited turbulent jets. The computation of flows in reactor vessels (4 m internal diameter) with LES seems feasible around the year 2000.

The remaining four lectures are devoted to geophysical flows and to turbulence phenomena in the deep atmospheres of stars and in the interstellar medium. O. Métais and E. Lamballais demonstrate in lecture 12 the ability of LES to correctly reproduce, in high Reynolds number flows, the detailed vortex topology in the presence of solid-body rotation and density gradients. It is in particular shown that LES techniques can be successfully applied to the computation of atmospheric and oceanic mesoscale eddies resulting from different instability mechanisms such as the baroclinic and the convective instabilities. A review on LES of air pollution dispersion in the atmospheric boundary layer is given by F. T. M. Nieuwstadt and J. P. Meeder in lecture 13. It concentrates on situations of neutral and unstable stratification, since stable stratification with its possible collapse of turbulence seems beyond the capabilities of LES. The Eulerian and Lagrangian techniques to predict turbulent dispersion are first discussed along with their advantages and disadvantages, before examples of dispersion simulations are presented, namely dispersion of an instantaneous line source in the convective boundary layer, dispersion of a plume in the neutral boundary layer and dispersion in combination with chemical reaction. The work of D. H. Porter and P. R. Woodward presented in lecture 14 is related to compressible convection as it appears for instance in the deep atmosphere of the sun with Rayleigh and Prandtl numbers ranging from $4 \cdot 10^{12}$ to $2 \cdot 10^{15}$ and from $4 \cdot 10^{-2}$ to $7 \cdot 10^{-5}$, respectively. The convection layers are heated from below, well mixed and nearly adiabatic. The authors outline results of simulations on grids with up to $512^2 \times 256$ cells obtained with the PPM algorithm to solve the Euler equations. Velocity power spectra and correlations between vorticity and the large scale convective motion are discussed. The last lecture by A. Pouquet *et al.* is devoted to the most complex turbulent motions, namely those in the interstellar medium (ISM) which is highly compressible, has pervasive magnetic fields, abundant energy sources such as supernova blasts, expanding HII regions, bipolar outflows, large-scale shear and a range of densities spanning at least nine orders of magnitude. The mathematical models used to describe turbulence in the ISM with rms Mach numbers around 4, with structures ranging in size from the scale of the galactic disc of tens of kiloparsecs down to 0.01 parsec, provide interesting properties of star formation, but of course leave many questions open which will be tackled in the future.

This book gathers a really wide range of fascinating topics which should make it attractive to a broad audience. The articles are carefully written. Some of them have review character, others represent the specific view of the authors, based mainly on their own work. This is acceptable, since the book is not written for beginners in the field of turbulence and needs further reading anyhow. Altogether it is an authoritative and up-to-date book and thus a valuable addition to the literature.

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