

The mathematical modelling of turbulent flows

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(Received July 1985)*

This paper reviews the problems and successes of computing turbulent flow. Most of the flow phenomena that are important to modern technology involve turbulence. Apart from pure academic interest, there is therefore a practical need for designers to be able to predict quantitatively the behaviour of turbulent flows. The review is concerned with methods for such computer predictions and their applications, and describes several of them. These computational methods are aimed at simulating either as much detail of the turbulent motion as possible by current computer power or, more commonly, its overall effect on the mean-flow behaviour. The methods are still being developed and some of the most recent concepts involved are discussed.

The basic points to be made are:

- Turbulence computations are needed for practical simulations of engineering, environmental, bio-medical, etc. processes.
- Some success has been achieved with two-equation models for relatively simple hydrodynamic phenomena; indeed, routine design work can now be undertaken in several applications of engineering practice, for which extensive studies have optimized these models.
- Failures are still common for many applications particularly those that involve strong curvature, intermittency, strong buoyancy influences, low-Reynolds-number effects, rapid compression or expansion, strong swirl, and kinetically-influenced chemical reaction. New conceptual developments are needed in these areas, probably along the lines of actually calculating the principal manifestation of turbulence, e.g. intermittency. A start has been made in this direction in the form of 'multi-fluid' models, and full simulations.
- Although some of the latest concepts hold promise of describing some of the most important physical consequences of turbulence, they have not yet reached a definite stage of development. From this point of view, the older and simpler methods can still be recommended as the starting point (and sometimes the finishing point) for engineering simulation.

Despite the relative novelty of the subject, the relevant material is already too much to be reviewed in a single paper. For this reason the author confines attention to what he considers the better-established or more promising models. No disrespect is therefore implied for the models that are scarcely — or not at all — mentioned. Extensive use has been made of the published literature on the topic and in particular of two recent reviews by Reynolds and Cebeci¹ and by Kumar.² Extensive use is also made of the work of Spalding and of the recent work of Malin. Turbulent heat and mass transport are not explicitly covered in this review; the interested reader is directed to the review by Launder.³ Further details on turbulence models may also be found in the lecture course by Spalding.⁴ The review concludes with a summary of the advantages and disadvantages of the various turbulence models, in an attempt to assist the potential user in choosing the most suitable model for his particular problem.

Key words: turbulence, mathematical modelling, field models, stress equation, multi-scale, kinetic energy, dissipation, inhomogeneities, intermittency, large-eddy, time scales, effective viscosity

Introduction

The partial differential equations for turbulent physical systems

Turbulence is the most complicated kind of fluid motion, making even its precise definition difficult. A fluid motion is described as turbulent if it is rotational, intermittent, highly disordered, diffusive and dissipative.

It is generally accepted⁵ that turbulence can be described by the Navier-Stokes momentum-transport equations (the second-order Chapman-Enskog approximation to the Boltzmann equation for molecular motion), which express the conservation of momentum for a continuum fluid with viscous stress directly proportional to rate of strain. This description is the simplest that can be imagined. According to this principle, the 'Eulerian' equations governing the

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Mathematical Modelling Of Turbulent Diffusion In The Environment

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Analysis Leon Aganesovich Petrosiān,V. V. Zakharov,1997 Presents mathematical ideas and models that can be used to facilitate rational environmental policy making Describes classical models for biological community performance ecological system stability and population dynamics presents air pollution models and methods for solving emission problems and highlights major results of the application of **Environmental Fluid Mechanics** Hayley H. Shen,Alexander H.D. Cheng,Keh-Han Wang,Michelle H. Teng,Clark C. K. Liu,2002-01-01 Sponsored by the Fluids Committee of the Engineering Mechanics Division of ASCE This report provides environmental engineers with a comprehensive survey of recent developments in the application of fluid mechanics theories to treat environmental problems Chapters cover principles of fluid mechanics as well as contemporary applications to environmental problems involving river lake coastal and groundwater areas Topics include turbulent diffusion mixing of a turbulent jet in crossflow the advected line puff multi phase plumes in uniform stratified and flowing environments turbulent transport processes across natural streams three dimensional hydrodynamic and salinity transport modeling in estuaries fluid flows and reactive chemical transport in variably saturated subsurface media heat and mass transport in porous media parameter identification of environmental systems finite element analysis of stratified lake hydrodynamics water quality modeling in reservoirs and linear systems approach to river water quality analysis In addition to providing valuable information to practitioners this book also serves as a text for an advanced undergraduate or introductory graduate level course

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