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A Pragmatic Approach to Turbulence

A Short Course in Fluid Mechanics

PHI

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LEIF N. PERSEN

Professor Emeritus
Department of Energy and Process Engineering
Norwegian University of Science and Technology (NTNU)
Trondheim, Norway

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PREFACE

This book is written for students, teachers and scholars of fluid mechanics. It is to be considered an advanced course and presumes familiarity with elementary fluid mechanics on the part of the students. Emphasis is laid on experimental results in the lab as the most reliable source of information on the physics of turbulent fluid flow. No attempt has been made to review in the text the vast amount of experimental information gathered by the profession over the last century, but the gist of these experiments is extracted from published articles. This limits the need for extensive referencing without impairing the reliability of the conclusions drawn. Wherever needed, the major stages in the development of the subject are outlined with no claim at being exhaustive. Instead, great emphasis has been laid on the mathematical description of the flow physics, the idea being that only by expressing the results in a mathematically dimensionless form can real understanding and general applicability be achieved.

The text is not conventional. It is really to be considered as a first step in a process to explore the carrying capacity of the new interpretation of turbulent fluctuation terms as energy terms replacing the conventional concept of these terms as being stresses (Reynolds stresses). This inevitably makes it imperative to examine the theoretical background from the very basic stage onwards.

Chapter 1 examines the fundamental laws of nature, the conservation of mass, momentum and energy. It has been imperative for the deduction to examine these separately and no introduction of experimentally based phenomenological relations is entered. This is done separately by introduction of the Stokes' hypothesis which leads to the Navier–Stokes equations, the conventional basic equations of laminar flow. The text stresses that the mechanical energy equation does not have any term in it that reflects dissipation of energy, a fact that at a later stage becomes important. Appendix 1 to this chapter elaborates on the physical interpretation of the different terms in the equations.

Chapter 2 is concerned with the establishment of the basic equations of turbulent flow in general. The fundamental approach to the problem by O. Reynolds is adopted as are his rules for taking averages. However, here the first divergence from conventional procedure is found. These rules apply only to the fundamental laws of nature, i.e. a phenomenological relation, which originates from specific experimental observations or is introduced as a hypothesis valid for laminar flow, does not become a valid expression for turbulent flow by applying the averaging process to it. This is the reason for keeping the strict distinction between what is fundamental and what is specific for the case at hand. In anticipation of the later introduction of the concept of virtual velocities, the equations of motion are expressed as energy balances. Appendix 1 is an illustration of the complexity of the averaging process based on data obtained in the wake of an ordinary fan. It also touches on the problem of whether or not the conventional approach (averaged Navier–Stokes equations) really is representing properly the turbulent flow it is supposed to govern.

Chapter 3 is where the more fundamental difference between the conventional approach and the present 'pragmatic' approach is expressed. A brief historic survey of the efforts put in by the profession during the 20th century to bridge the closure gap is given to serve as a background for the proposed concept of virtual velocities replacing the concept of Reynolds stresses. This concept has withstood every attempt by the profession to verify it or to give it experimental support, which really invites the re-introduction of the original concept of the fluctuation terms in the equations as forms of kinetic energy. Appendix 3 and the way in which the mathematical deduction is presented and solved exhibit the experimental evidence' influence behind this line of thinking.

Chapter 4 is devoted to the examination of data gathered in free turbulence, i.e. the free jet flow. The mathematical representation of experimental data shows that: (i) the flow in the free jet exhibits similarity in its total kinetic energy field (not in its velocity field), and (ii) the discrepancies that originate from the concept of Reynolds stresses are non-existent with this new interpretation of the fluctuation terms. Beyond a downstream distance from the jet's nozzle, determined from the experimental data, it shows that the energy field is governed by an energy potential, and the consequence is that the total kinetic energy in the flow is being redistributed and not dissipated. The gist of the deduction lies in the interpretation of the measuring device's signal and the proposed concept of virtual velocities finds its experimental support.

Chapters 5 and 6 give a detailed account of the author's approach to the turbulent boundary layer problem. It was presented to the profession for the first time at the AGARD specialist meeting in den Haag, Holland, in 1976, and was at that time presented with the Reynolds stress concept still accepted. The approach is now being re-examined in the light of the new concept of virtual velocities introduced in Chapter 3. The approach is characterized as 'pragmatic' since it is built on the accumulated experimental knowledge produced by the profession up to the time of presentation. The highlights of this process are:

1. Acceptance of the inner variables (u^+, y^+) as proper non-dimensional variables for a mathematically acceptable description of the flow. The velocities used in their definition are replaced by the virtual velocities since these are the velocities actually sensed by the measuring probes, and it is these velocities that express the experimental evidence

on which their definition is based. The work done by the ISI group in Calcutta under the leadership of Professor H.P. Mazumdar has used new experimental evidence to show support for this approach.

2. The replacement of the old concept of the boundary layer exhibits three distinct regions (i) the inner laminar layer, (ii) the outer wake region, and (iii) the buffer zone between them (without actually defining mathematically either of them) which is replaced by the experimentally supported concept of the boundary layer exhibiting two distinct regions: (a) an inner region near-to-wall region where the Spalding formulation of the flow (with the author's modified constants) governs the flow, and (b) an outer wake region where the flow is (according to Prandtl's concept) uninfluenced by viscosity. The two regions are strictly defined so that at each position downstream a point is defined, where transition from one region to the other occurs. The flow in the wake region is governed by the author's suggested flow profile built on an analogy with free turbulence. It is also shown that the outside manipulation of the boundary layer (adverse pressure gradients, etc.) affects only the wake region leaving the inner wall region unaffected. Furthermore, the mathematical formulation of the wake profile remains the same irrespective of the manipulations, i.e. only the constants in the formulation are adjusted to each case in question.

3. The pragmatism of the approach may be best illustrated by observing that the boundary conditions at the outer edge of the layer are moved from infinity to the finite distance from the wall where, for all practical purposes, the wake flow merges with the outside flow. Since the boundary conditions are expressed in terms of virtual velocities, not only the velocity but also the fluctuations are matched at this location—an improved situation as compared with the conventional approach. It turns out that the outer edge of the boundary layer is located on a curve called the locus of ξ and that this curve indicates in each case what boundary conditions the manipulated layer must satisfy, i.e. the locus of ξ expresses the boundary conditions that the manipulation of the layer introduces. Chapter 5 covers the case of a flat plate (zero pressure gradient), Chapter 6 deals with most of the cases of manipulated layers presented as benchmark cases at the Stanford Conference, 1969. A complete formal solution is presented for the turbulent boundary layer in Chapter 5 and the flat plate case is solved from first principles. Chapter 6 presents the loci of ξ for the adverse pressure gradient, the relaxing flow, and the favourable pressure gradient cases and the corresponding mathematical solutions are presented from first principles. At this point, special attention is drawn to the fact that the solution gives the shear stress distribution across the entire boundary layer. This means that the phenomenological relation which, in the laminar case is furnished by the Stokes hypothesis, is in the turbulent case coming out of the solution to the problem. In this perspective, the search for a relation between the flow field and the stress field must be considered a side issue. This is of fundamental importance. Appendix 5 discusses the origin of the turbulent boundary layer and introduces its fictitious leading edge from which the downstream distance is to be measured if the result shall have general applicability. Appendix 6 gives a complete examination of the Stanford Conference cases insofar as they belong to the cases relevant to the presented solutions. Finally, the

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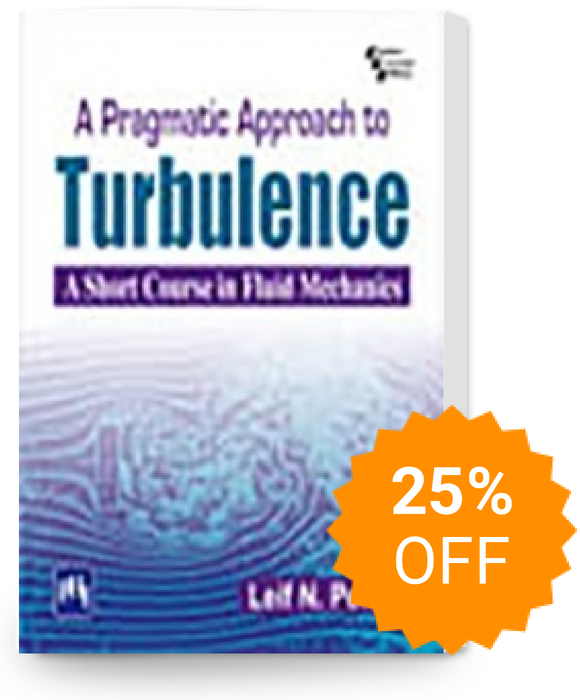

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