Int. J. Heat Mass Transfer. Vol. 13, pp. 1509–1513. Pergamon Press 1970. Printed in Great Britain

BOOK REVIEWS

Heat and Mass Transfer in Recirculating Flows, A. D. GOSMAN, W. M. PUN, A. K. RUNCHAL, D. B. SPALDING and M. WOLFSHTEIN, Academic Press (1969). 338 pp, £3.

THIS is an important new book which deserves the attention and use of the scientific and engineering community. It represents a major contribution in the field of applied mechanics as related to the calculation of general flows of mass, energy and momentum. Although the subject of the mechanics of transport phenomena is rather well treated by a number of text and reference books there are too few which are written for the general practioner at an advanced level such as this volume. Rather than emphasizing the theory of transport phenomena and the deduction of governing equations and boundary conditions, the focus in this book is the solution of the equations and the determination of the flow field and the transport rates for quite general conditions. Doubtless some readers will find this emphasis somewhat distracting and would prefer a more detailed description included of the flow mechanics and the underlying postulates and assumptions, especially regarding the role of turbulence. More about this later. Nevertheless, it may be expected that this book will find a welcome audience of those whose daily tasks require them to perform calculations in the laminar and turbulent transport of heat, mass and momentum.

In their preface (also worth reading, by the way) the authors state their book is written for engineers. This intention is faithfully carried out. However, engineers wishing to derive maximum benefit from this volume will be well advised to do whatever boning-up may be necessary on their knowledge of the language of differential equations (parabolic and elliptic), generalized coordinates and coordinate transformations, boundary conditions, turbulence and its representation, finite-difference mathematics and the Fortran IV computer language and programing techniques, among other things.

The title chosen for this book is accurate and to the point. Perhaps this is unfortunate as it may lead to confusion by those who judge a book by its title. What the book describes is a method for calculating steady two-dimensional, single-phase, laminar and (randomly) turbulent flows, including the influence of non-uniform properties. The term "recirculating" is not specifically defined but it includes the concept of "reversed flows" or "separated flows". Unsteady flows, in the sense of requiring time derivatives in the governing equations, are not included. Turbulent flows are treated as time-averaged steady-flows. It is to be hoped the authors will soon issue a companion volume treating general unsteady flows as this subject has great current importance.

The style of writing is quite informal, almost as one might expect a set of lecture notes to be. Throughout the book a semi-colon (;) is employed where a period (.) or a comma (,) would be better. Frequently this grammatical device separates incomplete statements. However, the meaning of the arguments is usually sufficiently clear. The printing style is also informal (doubtless an editorial decision to reduce costs) with ragged right-hand margins and double spacing of lines. Section headings are in bold type. An excellent nomenclature is provided which is not only very complete but also identifies the equation number in which each defined quantity is first mentioned. An unnecessarily complex numbering system for the equations, tables, figures and section headings has been adopted, in this reviewer's judgment. The equation identification 3.43-11, for example, could just have easily been accomplished by a 3-digit representation, the first being the chapter number.

The book consists of 338 pages divided into six chapters. The first three chapters contain the fundamental developments and are entitled: Chapter 1, Introduction; Chapter 2, The Equations to be Solved; and Chapter 3, A General Solution Procedure for the Differential Equations. For the reader wishing to get the general message of the book the 16-page first chapter will serve him well. However, for those with a serious intention of using the authors' material it is essential that the first 3 chapters be studied in depth and understood. The final 3 chapters deal with applications of the authors' method and include several illustrative examples. These chapters are entitled: Chapter 4, Some Illustrations of the Use of the Procedure; Chapter 5, The Basic Computer Programme; and Chapter 6, A Special Computer Programme for Combustion Problems. Each of the six chapters begins with a clearly worded statement concerning the purpose of the chapter, its contents and relationship to the previous chapters. This form will make the book particularly welcome to students or others becoming newly acquainted with the subject.

Using the conservations laws the authors first develop the governing differential equations for mass, energy and momentum, valid for both laminar and turbulent flows. Auxiliary information is provided by thermodynamic relations, property data and boundary conditions. The vorticity and stream function are introduced into the development in a conventional manner. Of particular interest and importance, however, is the derivation of a standard formulation or representation for all the governing differential equations in a general orthogonal coordinate system (p. 55, equation 2.23-9). This is written in terms of a generalized variable φ and 5 coefficients, each of which has a particular definition corresponding to the conservation law the variable φ is chosen to represent. A table is given (p. 55) defining the various φ's and their appropriate constants. The governing differential equations, written for a set of general orthogonal coordinates, is extended to include cylindrical polar coordinates, Cartesian coordinates and spherical coordinates.

The treatment of turbulent transport is introduced into the development by describing a turbulent flow by a set of equations for a time-averaged laminar flow but with augmented coefficients for the transport of mass, energy and momentum. A description of turbulence is used following the Kolmogorov (1942)–Prandtl (1945) model which may be expressed in terms of an effective viscosity defined by

$$\mu_{eff} = \text{constant } \rho k^{\frac{1}{2}} l$$

where ρ is the density, k is the kinetic energy of the fluctuating motion and l is the local length scale of turbulence. The quantities k and l are each fitted to a differential equation of the generalized form (as for φ) for simplicity. This is done more out of convenience in analysis than from precision in phenomenological description, which the authors freely admit. The door is left open for subsequent improvements in computational methods derived from a more complete understanding of turbulence or alternate ways in which it may be described.

It is the authors' handling of turbulence which the reviewer would like to have seen broadened and presented in more detail and depth. The role of turbulence and its treatment in the calculation procedure is pivotal to the principal value of this book. Otherwise, the authors would be writing on laminar flows, a subject not having nearly the need for further written exposition that exists for turbulent flows. The present criticism is not directed at the authors' general approach. This is innovative, relevant, appropriate and guided by a degree of expediency suitably related to the often frustrating complexities of turbulence. However, it is precisely because of this latter point that a more specifically directed presentation of turbulence, as a phenomenon, could have been most useful to this book. The topic is so basic to the present subject that an entire chapter could be devoted to it appropriately. Such a chapter would have the advantage of providing more in-depth presentation of the subject with sufficient background material to focus the discussion ultimately on the reasons for their selection of the Kolmogorov–Prandtl model, as well as its use in the analysis. A further advantage would be the consolidation of the discussion on turbulence into a single section rather than its somewhat scattered presentation in three or four places. The reviewer is aware that a decision must be made on how much to include in a book (the same applies to a review) but he feels in this instance the authors were guided more by their own perspective than that of the general reader.

Because of the inherent non-linearities in the differential equations (and boundary conditions) these expressions have been reformulated into finite-difference forms and then into algebraic equations. The finite-difference equations are formulated by integration of the differential equations over finite areas (corresponding to the grid spacing), a technique which permits a physical interpretation of the results to the conservation laws from which they have been derived. The convection terms in the finite-difference equations are formulated in terms of "up-wind" differences, a technique which contributed to numerical stability. The question of numerical stability is presented thoroughly (p. 107) and three criteria are developed for the convergence of the arithmetic calculation procedures. The solution of the algebraic equations is by an iterative method of successive substitution. The Gauss–Seidel procedure is used because of its demonstrated rapid convergence and reduced requirement on computer storage. Chapter 3 completes the discussion of the fundamentals with a detailed outline of the general solution procedure. This section will be very valuable to someone proposing to follow the authors' method.

Chapter 4 consists of eleven illustrative examples, including laminar and turbulent flows of non-uniform density and viscosity, which demonstrate the general computational procedures in a concrete manner. As an interesting and informative sidelight the computing time (for an IBM 7090) is often cited with the examples. A detailed description of the general computer program and language (Fortran IV) is given in Chapter 5. This includes a glossary of Fortran symbols, flow diagrams, sub-routines and other dictionary-type information necessary to conducting computations. Chapter 6 devotes attention to a specific class of problems, namely, flows in a combustion chamber. In this chapter further development of the computer programming is given, including additional tabulation of Fortran symbols for the particular problems, a flow diagram and computer print-outs related to the computation.

In summary, this book is a welcome addition to the field of mechanics. It may be expected to receive careful attention and much use from research workers and engineers both from the standpoint of an informative study guide and scholarly reference and as a source-book for computational procedures in design. It is written by experienced practitioners of their own experiences and thus possesses that invaluable mark of authority.

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