REVIEWS

Elements of Gasdynamics, by H. W. LIEPMANN and A. ROSHKO. New York: John Wiley & Sons, 1957. 439 pp. $11.00 or 88*s*.

The term *gas dynamics*, which Liepmann and Roshko have chosen to combine into a single word, is now widely used to denote that area of fluid physics which deals with compressible flow and includes some of the more basic applications to aerodynamics. It is perhaps not more than a decade since the subject blossomed forth as a major category of aeronautical science, somewhat distinct from the more classical parts of fluid mechanics, and it is also a decade since the predecessor to the present book was published, namely Liepmann and Puckett's *Aerodynamics of a Compressible Fluid.* In 1947 and subsequent years, this work helped to fill an obvious need for an introductory gas dynamics book written in English. It gave an admirable treatment of the fundamentals and showed a wise choice of applications. Prior to 1947, coverage in the book literature was inadequate (with some exceptions such as Sauer's book *Theoretische Einführung in die Gasdynamik* (1943)), which is curious considering that the subject has roots extending well into the past century; for example, the work of St. Venant and Wantzel, Riemann, Mach and Rankine. Also, such investigations as Prandtl's schlieren measurements of waves in supersonic channel flow (1907) and Meyer's basic theoretical work on supersonic plane flows (1908) were four decades old at the end of World War II.

There are two principal reasons why the writing of a gas dynamics book represents a greater challenge now than ten years ago. Firstly, a number of authoritative books on the subject have already appeared during the past decade, which give a rather wide coverage and diversity of emphasis among component topics. The authors or editors, as the case may be, include Ferri, Courant and Friedrichs, Howarth, Oswatitsch, Shapiro, as well as Emmons, who edits the forthcoming gas dynamics volume of the Princeton series. Secondly, the discipline itself has been extended in scope. The subject matter has grown in volume and its conceptual boundaries have penetrated more deeply into the realm of particle physics, as energies and transit times have approached those characteristic of molecular processes. Thus, the problem of optimizing the choice of material for a book of reasonable size is more severe. According to the preface, it was the first of these reasons which led the authors to write a completely new book rather than revise the Liepmann–Puckett work. The second reason generated the decision to divide the material into two independent volumes of which this is the first, with the second yet to be written.

In this reviewer's opinion, the authors have, in fact, implemented effectively their aim of providing a working understanding of the essentials of high speed flow. The book combines an approach characteristic of a first class textbook with a careful choice of subject matter based on considerable classroom experience. As such, it should be appreciated particularly by new students of gas dynamics. On the other hand, much of the contents should be largely familiar to those who already claim some competence in the field, and such persons will find that the book is well suited as a reference and review text.

The organization of material is largely parallel to that in Liepmann and Puckett. This is, if anything, another point in its favour. Part I of the older book has been replaced by the first six chapters of the present work and part II by the last eight chapters. The early chapters deal with one-dimensional flow where construction of the equations of momentum, continuity and energy is feasible in conjunction with simplified physical concepts. As is known, much ground can be covered before further generalization becomes necessary, and good advantage is taken of this opportunity here. A broader treatment of the basic equations takes place in two widely separated steps. The first of these occurs around the middle of the book and deals with the equations of frictionless flow. Some instructive features of the presentation at this point are the introduction and use of tensor notation, and an explicit comparison between the control surface or integral method of deducing the equations and the use of the Eulerian derivative. In connection with the tensor formulation, the reader may wonder whether the authors succumb to an aesthetic urge to use mathematical finery at the expense of physical concepts; he can be assured that this is not so, for Liepmann and Roshko are too much concerned with the clarity of the underlying physics.

The second step toward generalization occurs near the end of the book and deals with the formulation of the complete Navier–Stokes equations. Here, the tensor notation introduced earlier is put to work, and by means of a skilful presentation, the authors rapidly produce these equations. The treatment is somewhat more sophisticated here and, accordingly, the section in question is officially included among the more advanced ones which may be omitted at a first reading. This is, perhaps, consistent with the authors' inductive approach, at least in the sense that it progresses from one-dimensional gas dynamics to the introduction of the Navier–Stokes equations over a span of twelve chapters. It is possible, however, that the development of the basic physical theory would be strengthened by including a preliminary discussion of the Navier–Stokes equations at an earlier point. As it stands now, this material is somewhat removed from the main stream of the book. Even the bare outlines of a formulation from the basic stress–strain dynamics of a fluid element would provide an initial framework for subsequent special cases, such as the excursion into one-dimensional ideal gas flow. That this approach gives the reader a broad perspective of physical concepts at an early stage has already been shown by other authors such as Prandtl in his article "The Mechanics of Viscous Fluids", Volume III, Section G of *Aerodynamic Theory* edited by Durand (Berlin: Springer, 1935).

The many satisfying features of the book include two chapters dealing with the similarity rules of high-speed and transonic flow. The former presents a unified discussion which treats regimes from subsonic through to hypersonic. It is limited to small perturbation theory but, as the authors point out, this is not especially restrictive from a practical point of view since modern aerodynamics is concerned mainly with thin wings. In the chapter on transonic flow, good use is made of the potential for plausibility arguments inherent in this branch of the subject. There is also a fruitful comparison between transonic flow over wedges and cones, a subject which has been of particular interest to the senior author in connection with his own experimental work in this area.

Turning to the matter of high speed flows with viscosity and conductivity, we recall that Liepmann and Puckett present an abbreviated treatment, too much so in the light of recent extended interest in the subject of boundary layers and other varieties of dissipative flows. Boundary layer theory is of engineering importance not only because it yields numerical results for friction drag and heat transfer but also, as the present authors emphasize, since it confirms that viscosity does not influence the pressure field in high Reynolds number flow past a slender body. In addition, the discipline harbours a variety of physical concepts whose explicit treatment should be of considerable pedagogical value, and nowhere is the interplay of dynamic behaviour and intrinsic physical properties in better evidence. The reviewer has in mind, for example, such matters as the variation of shearing stress distribution with temperature dependence of viscosity, interpretation of Prandtl number, its role in boundary layer energetics, and the examination of boundary-layer type flows as diffusion processes.

The treatment of non-ideal gas flows in the present book is, in fact, another one of its strong points. The boundary layer concept is developed in a way calculated to give the reader a proper physical insight, and newer material presented includes recent measurements of turbulent boundary layers at high Mach numbers, as well as a discussion of Couette flow of a dissociating gas.

The last mentioned topic reminds us that a growing variety of so-called ' real gas ' effects is now under investigation as a result of greater interest in high temperature gas dynamics. Their proper incorporation as part of the formal analytical foundation of the subject is not at all complete, as yet, but the authors manage to supply some clear thinking in their discussion of the problem. It seemed to the reviewer that their remarks will be particularly instructive to those who have tended to equate real *vs* ideal gases with particle *vs* continuum gas theories. Difficulties of this type arise because a particle theory is used to define the nature of various physical properties of the gas, such as those concerned with the transport of momentum and heat. It is possible of course to account for these two in particular on the basis of bulk coefficients which appear in the continuum equations. Also, the ' imperfections ' of dissociation, ionization and condensation can be treated by a continuum analysis. However, in the case of, say, viscous shear by itself, one can visualize a rather satisfactory macroscopic physical model, whereas proper physical insight as a prelude to correct continuum-type treatment of several other real gas phenomena does require an evaluation of the molecular behaviour of the gas. The intrinsic non-equilibrium character of the effects in question does not make the analysis any easier. That the dynamics, and particularly the energetics of high temperature gas flow, does rest on this more complex foundation is a point which Liepmann and Roshko manage to transmit successfully to the reader. The same cannot be said for other current books in gas dynamics.

The authors stress the point, and correctly so, that the key to the relationship between the continuum formulation and that of the kinetic theory lies in the effect of fluctuations due to molecular structure on the ability of measuring instruments to obtain correct mean values. With this as the proper criterion, they suggest that it is possible to apply a continuum analysis even to rarefied gas flows in which the Knudsen number is appreciably larger than unity. This is done by measuring for a sufficiently long period of time and applying the ergodic hypothesis, which establishes an equivalence between time and space averages. (The approach is not new to the turbulence investigator who performs a statistical evaluation of hot-wire fluctuation data.) Beyond a certain point, however, the molecular fluctuations would grow so large that it is not practical to attempt the correct measurement of mean values. The kinetic theory treatment then becomes the proper one. The motivation on the part of some for stating unequivocally that the continuum theory breaks down for rarefied gas flow probably stems, in the authors' opinion, from attempting to use a solution of the Navier–Stokes equation, e.g. a high Reynolds number solution, which does not apply in the first place.

Each succeeding book in gas dynamics these days appears to include a correspondingly larger chapter devoted to a discussion of methods of physical measurement. This is entirely warranted as there can be little doubt that the developing nature of the science places ever-growing stress on the results of pertinent experiments. The discussion here is meant to centre around experiments of the wind-tunnel type. Except for omitting free flight techniques, this is not too restrictive, since shock tubes and other variations of the more conventional tunnel now require a wide variety of experimental techniques. There is probably a need for a completely new book in this field to supplement the 1954 volume of the Princeton series, *Physical Measurements in Gas Dynamics and Combustion*. An extended list of contents for such a work would, indeed, include several intriguing topics, such as recent experimental work in magneto-gasdynamics. The admittedly limited treatment by Liepmann and Roshko is, nevertheless, a substantial one marked by an excellent choice of material which is well presented. It represents a most suitable introduction to experimental problems for the student. This is hardly a surprise as both authors are first class experimentalists in their own right.

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