REVIEWS

Fluid Mechanics. By R. H. F. PAO. John Wiley, 1961. 502 pp. 60*s*.

Elementary Fluid Mechanics (4th ed.). By J. H. VENNARD. John Wiley, 1961. 570 pp. 64*s*.

These two text-books by Prof. Vennard and Prof. Pao, like most elementary texts in fluid mechanics, are so deeply entrenched in a conventional rut that they and their successors may well lose their central position in engineering education. More aggressive, more imaginative approaches from other branches of engineering are likely to win out in the competition for the student market. A lag behind the rapid increase in the mathematical and scientific level of the student is only one factor. More serious are the emphases on facts and procedures instead of on the utilization of concepts, and the continued exaggeration of the approach and applications to civil engineering.

Both books are straightforward examples of a familiar kind. Each contains numerous admirable elements and occasional novel touches. However, almost all the material is abundantly familiar to workers in this field including examples, illustrations and references. Consequently, the following comments are restricted primarily to general criticisms of the kind of text and to specific illustrations supporting these criticisms.

Each book begins with an introductory chapter, a long chapter on hydrostatics, and a development of the kinematics of fluid flow. The middle halves of the books are devoted to the central theme of fluid mechanics—the equations of motion and their use in analysing the flow of fluids through conduits. The last part of each book contains chapters on open channel flow and on flow around bodies, including discussions of drag and lift. Each author has inserted after the introduction of viscosity and its effects, a chapter on dimensional analysis. The principal differences between the two are: (1) Pao has introduced a few elements of classical hydrodynamics near the beginning of his book, whereas Vennard has presented these and a few additional topics near the end of the book; (2) Vennard has included a chapter on flow measurement, Pao has not; (3) Vennard has presented in more detail than has Pao the various properties of fluids; and (4) Vennard holds to a pattern from earlier editions for presenting the energy equations and flow in conduits which is consistent but long and seemingly repetitious, Pao's shorter development seems more straightforward.

Both books are cluttered with residual material from hydraulics which cannot appeal strongly to engineers from disciplines other than civil engineering. Open channel flow is narrowly interpreted, and is not a treatment of free-surface or of interfacial phenomena. Stability could be an exciting concept with allusions to current developments; the stability of a floating body is an intriguing exercise, but leads nowhere. Hydrostatics, which is only a special case of the equations of motion expressible as $-\partial p/\partial z = \rho g$, is overemphasized, particularly by Vennard who devotes over 50 pages and 166 problems to the topic. Hydrostatics is not easy, and leads readily to tricky problems; but these are often sterile exercises in

special techniques with little significance and rare application. The appeal of familiar problems about forces on oddly shaped gates or about double manometers is only nostalgic. The standard table given for valves, and the charts for diffusers are presented without reference to such effects as roughness or Reynolds number, or to a number of studies since Gibson's, published in 1912.

The inclusion of chapters on dimensional analysis and similitude is questionable, but for a different reason. The beginning student has neither the knowledge nor the attitudes required to react to the subleties of such questions as how many and which variables are independent. Vennard's footnote on page 269 alludes to this shortcoming. A student who has little basis on which to decide between using the two variables ρ and g separately or in such combinations as γ, for example, is merely keeping busy if he solves a set of simultaneous equations for the exponents to be used in combining a set of such variables into dimensionless parameters. About all he can do at this stage is recognize the role of the key parameters of Reynolds, Froude and Mach.

The heritage from hydrodynamics, the more sophisticated parent of fluid mechanics, produces some odd traits in such offspring as these. An intriguing cross-breed is the graphical flow net which has been put to such effective use by Rouse and by a few people in Europe. Unfortunately for most of us, it depends crucially upon graphical accuracy both for utility and for pedagogical effectiveness. The inadequacy of the nets in both books is discouraging; none is sufficiently accurate to serve as a proper example. I was unable to obtain the results Pao depicts in Fig. 4-13 from the flow net in that figure. He allows a streamline to intersect a solid boundary (Fig. 4-7) and another, which divides two parts of a stream, intersects a plane boundary at an incorrect angle (in the figure for Illustrative Example 4-13). Vennard presents an inaccurate net in an example on page 487, and then ignores the essential two-dimensionality of the net in assuming the existence of one-dimensional flow at the crucial throat section.

Even more disturbing is Vennard's mistaken treatment of the irrotational vortex in which he depicts a small square element as going full circle without turning or distorting. Not the least of the problems that this improper representation raises is one of intersecting streamlines. More than a decade ago in Grenoble, France, I denied Pierre Danel's allegation that authors in the States were prone to make this basic conceptual error. Then and now, he wins. Pao's derivation of a modified Euler equation on page 76 contains a comparably basic error. He incorrectly relates the differential force due to shear to the shearing stress itself rather than to its gradient. And in Fig. 3-7, he uses almost identical patterns of streamlines to represent both irrotational and rotational flow.

Broad criticisms should properly be aimed not at one or two authors but at a trend which is quite pronounced in the field of mechanics. The system of education in the States depends too heavily upon text-books. Too many instructors proceed with a day-to-day and a page-by-page dependence upon the text. The resultant burden upon the author makes it almost impossible for him to exercise originality or leadership. With a few notable exceptions, the transition in text-

books from hydraulics to fluid mechanics has been tediously slow, and even worse, after more than 30 years it is still far from complete. Such elements as the boundary layer, compressibility, partial derivatives, the Froude number, the flow net and the stream function have entered texts by way of footnotes, appendices or back chapters which can be omitted. Others are waiting to be admitted. Even after important concepts have been introduced, their use is often restricted to a more sophisticated introduction to otherwise conventional material. The student is too often left without any real insight into the broader implications of a more general approach. Like American cars, American texts are too close to the centre of gravity of the market, universal appeal requiring that each have all the elements which are in vogue.

The manner of presentation is usually one of delineating a segment of knowledge rather than one of exposing a set of concepts with which one can attack new problems. One finds too little acceptance of the idea that students may deal with other than pipes, flumes, and possibly airplanes. Perhaps even more troublesome in the presentation of conventional, over-specialized material as though it were complete and closed like a forme full of linotype ready for the press. A body of knowledge and a set of techniques for applying it to a variety of type problems is not an adequate goal.

Why do authors of text-books refrain from discussing ideas or knowledge in such a way that the reader also learns something of what we do *not* know? Occasionally they mention advanced topics briefly and then dismiss them as being beyond the scope of the text; rarely do they make informative statements about limitations to our understanding of the stability of laminar flow, the effects of unsteadiness, the mechanics of turbulence, the value of secondary flow and other topics. Such a practice seems dangerously unbalanced. Any course, even an elementary one, can be related to current publications and to live people with first names who are working at the frontiers right now.

The acquisition of knowledge, important though it is, should be subjugated to the self-development of the student. To be in accord with this premise, good text-books must contain more than examples for the student to try, they must provide opportunities for him to test what he is learning, to make assumptions, even to make mistakes. Problems or approaches which can be classed as 'supplying the missing number' provide useful drill for the student but do not educate him. He needs less material than is usually presented, much less in fact, but many more challenges. Such a shift would lead to texts which would be more difficult for the teacher to use, but they would be more provocative to the student. One of A. N. Whitehead's many pungent comments (from his essay *The Aims of Education*) is relevant. He wrote; 'Whenever a text-book is written of real educational worth, you may be quite certain that some reviewer will say that it will be difficult to teach from it.' Further on, he decried an 'evil path' whereby a book '...will practically enable the student to learn by heart all the questions likely to be asked at the next...examination'. We often allude to the process of covering a subject. The meaning of the verb 'to cover' in this connexion can only be opposite to that of the verb 'to uncover'.

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Progress in Astronautics and Rocketry. Vol. 3, **Energy Conversion for Space Power,** edited by N. W. SNYDER; 779 pp., 58*s.* or $7.25. Vol. 4, **Space Power Systems,** edited by N. W. SNYDER; 632 pp., 48*s.* or $6.00. Vol. 5, **Electrostatic Propulsion,** edited by D. B. LANGMUIR, E. STUHLINGER, and J. M. SELLEN; 579 pp., 46*s.* or $5.75. Academic Press, 1961.

This set of volumes sponsored by the American Rocket Society contains papers presented at meetings in September and November 1960. The authors of the 108 papers have been encouraged to include thorough referencing so that the volumes constitute a substantial reference source for workers in the fields of technology associated with space-power sources and electrostatic propulsion.

Apart from their value as a reference the group of volumes affords to those not immediately concerned a fascinating survey of the efforts which are being made to solve some of the difficult problems of space requirements. The requirements are stringent and include, although not necessarily all in the same system, long life, low weight, robustness, ability to operate in zero-gravity conditions, low sensitivity to radiation and an unattended reliability surpassing anything existing on earth except perhaps the hydroelectric generator. Many of the papers are reports of design studies rather than completed pieces of experimental or theoretical work. The style of the papers varies considerably and a few are obscure and contain an unnecessary amount of jargon.

For those whose main interest is fluid mechanics only a few papers are relevant, and reference to these has been emphasized in the summary of the contents which follows.

For long-term use the source for satellite power systems is either solar or nuclear energy; for short durations chemical fuels can be used. The first group of papers in volume 3 is devoted to thermoelectricity and begins with a paper on the physics of the process. The remainder of the papers deal with aspects of thermoelectric materials. High temperature materials are important because of the need for high rejection temperature in space radiators. New findings on the properties of rare earths and the effect of nuclear radiation are presented. The last paper reviews thermoelectric materials for cooling space vehicles and their equipment.

Heat may be converted directly to electric power by means of a diode either evacuated or filled with an ionized gas. The first two of the eight papers on thermionic generation are on the physics of such devices, of which the latter, the plasma diode, is most attractive. Two papers in this group deal with the special materials problems arising when the diode is in a nuclear reactor.

There are ten papers on solar or photovoltaic cells in the third group covering theory, materials and radiation damage.

Fuel cells, batteries and accumulators are the subject of the group of papers on electrochemical cells. In this group experience to date on the practically important nickel-cadmium battery is well covered.

Papers on vapour turbines, Stirling engines, piston engines and an electromechanical storage system form the fifth group. The new environment of space has forced the authors of these papers to look at the old problems of these engines

in a refreshingly new manner. In a paper comparing turbine engines with positive displacement, i.e. piston engines, the author describes the performance of a piston engine in terms of new parameters which take into account the effect of different working fluids.

An interesting paper contains the preliminary results of some experiments on the boiling and condensing of mercury in zero-gravity conditions produced in an aircraft for periods lasting between 15 and 30 sec.

The sixth group of papers on magnetohydrodynamic power generation begins with a paper on its prospects, the relevant theory, and the materials and practical problems which have to be solved. The second paper surveys the problems and the work in progress. Experimental work on a 10 kW generator is described in the third paper which also gives a résumé of the theory. The last two papers summarize theoretical work on a vortex MHD generator in which a hot conducting gas spirals between an outer and inner electrode in the presence of a magnetic field. The papers in this group afford an interesting summary of the prospects for and achievements of MHD generators; it is agreed that their application to stationary power generation is far more promising than their application to space.

The volume concludes with two papers on electrostatic generators in which projected machines suitable for use in space are described with supporting theoretical work and experimental results from earlier work for other applications.

Volume 4 contains papers which discuss the problems of incorporating the power-generating components described in volume 3 into complete systems for use in a space vehicle. The papers are grouped in accordance with the three main sources of energy, solar, nuclear and chemical. The last group, on space-power requirements, defines the objectives of the work described in volumes 3 and 4 in two papers. The first outlines the requirements of the NASA programme up to 1965 showing how the power level rises from 10 W in 1960 to 1 kW in 1965. The second paper forecasts future requirements, and, on the basis of an estimated development time of ten years, suggests that work should start now on the 10 kW systems and in four years' time on systems of 100 kW or more. The type of system to be used for differing space vehicles and life is also discussed.

The only power system in practical operation is the photovoltaic cell. Several papers describe the experience with and design of such systems for various satellites. Secondary batteries for storage form an essential part of each system, and the correct estimation of their capacity is a major design problem. Other considerations discussed include radiation damage, orientation, circuits and reliability. Other solar systems except for thermoelectric collectors require the concentration of the sun's rays. The design of collectors and systems for plasma diodes, Stirling engines and engines working on the Rankine cycle are discussed. The papers demonstrate the considerable effort being made to design light-weight, highly accurate mirror systems for this purpose.

The section on nuclear systems is extensive and covers many aspects, including that of safety, of the work on the Atomic Energy Commission's SNAP (Systems for Nuclear Auxiliary Power) programme. Readers can get some impression of

the difficulties of choice from the comparisons between nuclear-heated thermonic diodes and vapour cycle turbines.

A paper in the section on chemical systems compares a combustion gas-driven turbine with a turbine and a three-cylinder radial engine driven by liquid hydrogen which may be gasified in the heat exchanger used for cooling the cabin, by burning with oxygen in a combustion chamber, or in a regenerator. Only a fraction of the power produced in the space vehicle is radiated externally; the larger part will simply heat the vehicle. The need to remove the heat, and the presence of an environment at zero pressure, introduce criteria for assessing the effectiveness of the thermodynamic processes which differ from those normally used in earthbound power plants. The other paper in this section discusses methods of containing liquid hydrogen and oxygen and the problem of expelling the liquids in a zero-gravity environment.

Volume 5 on *Electrostatic Propulsion* contains 30 papers divided into four groups with an introduction to each group. The first group of papers is on the generation of ions or charged materials. The topics involving experimental work include electron-bombardment ion sources, the production of a dense plasma from a low-pressure arc discharge (the Duoplasmatron), the production of negative ions and charged droplets of liquid metal, and oscillating-electron plasma sources. A paper on the theory of ion emission from porous media is followed by a critical review of the factors which enter into the calculation of the performance of porous surface ion emitters, and a paper on the effects of surface heterogeneity on the ionization efficiency of a surface ionization source, and on the methods used and the results obtained in a study of the adsorption of caesium.

In the second group of papers the problems of accelerating the ions are discussed. Sputtering, the erosion of the target material by the impact of high-energy ions, is a serious practical problem in ion accelerators. Results of the effect of ion beams in the energy range 5–40 keV on several materials are presented in two papers. An analysis of the flow of ions in circular trajectories is given in a paper which shows how the results may be applied to the design of electrodes for ion accelerators. In another paper experiments with multi-beam accelerators are reported.

The third group of papers is on the neutralization of the space charge in the ion beam which is essential if a space vehicle is not to develop a charge which would attract ions back to the vehicle thereby reducing the thrust. Theoretical analysis of this problem has proved too difficult except when unrealistically simple assumptions are made. The content of the ten papers in the group on neutralization ranges from analysis to discussion of various schemes for injecting electrons, e.g. transverse to the beam, spirally, and from grids in the beam. Another possible technique is to use trapped electrons, and the section includes theoretical and experimental work on the filling and emptying of electron traps together with the associated oscillatory phenomena.

In spite of their sophistication these papers give no assurance that beam neutralization is possible in space. The ease with which neutralization can be achieved in the laboratory may be misleading, because the elimination of the

effects of walls, supports and residual gases is remarkably difficult in the laboratory and in most experiments ion beams have been at least partially neutralized by stray effects.

In the fourth group of papers, entitled 'Techniques and testing', there are three papers which describe methods of measuring ion beam performance in the laboratory, two which discuss the problems of testing in space, and two on engineering techniques related to caesium ion sources.

Each group of papers is preceded by a summary which together with Ernst Stuhlinger's concluding remarks place the papers in perspective.

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Magnetohydrodynamics: Proceedings of the Fourth Biennial Gas Dynamics Symposium. Edited by A. B. CAMBEL, T. P. ANDERSON and M. M. SLAWSKY. Northwestern University Press, 1962. 393 pp. $15.00.

The twenty-four papers in this volume were presented at the fourth of a series of symposia sponsored jointly by the American Rocket Society and the Gas Dynamics Laboratory at Northwestern University. Magnetohydrodynamics was the theme of this particular symposium, held at Evanston in August 1961. The subject was interpreted widely, and many of the papers are concerned with plasmas and particle properties. About the volume as a whole, one can say only that the printing and binding are of a reasonable standard, and that the purpose of enshrining these twenty-four papers in a special publication, out of the mainstream of scientific literature, is not evident.