REVIEWS

Handbook of Engineering Mechanics. Edited by W. FLÜGGE. New York: McGraw-Hill, 1962. 1632 pp. £10. 13*s*. 6*d*.

This formidable and well-printed book, in seven parts, contains eighty-eight chapters contributed by as many mathematicians and engineers, most of them well known in their own fields. Part 1, on mathematics, has twenty chapters. Five chapters on the mechanics of rigid bodies constitute Part 2, and forty-two chapters are devoted to the theory of structure (Part 3), elasticity (Part 4), plasticity and viscoelasticity (Part 5), and vibrations (Part 6). Fluid mechanics (Part 7) occupies the remaining twenty-one chapters.

Looking over the table of contents, one wonders immediately why this thick book had not been divided into three volumes, on mathematics, solid mechanics, and fluid mechanics, respectively, especially since a handbook of fluid mechanics has actually been published by the same publisher. As it stands, the extensive coverage makes the space devoted to each chapter so very small that one wonders to what extent the editor's first aim—to make the book useful to the expert in his work—is fulfilled. The other two aims of the editor, to stimulate the expert in one field by the thoughts, methods, and results in other fields and to provide a bazaar for window-shopping students of engineering mechanics, seem more assured of fulfilment.

The part on mathematics deals with a number of subjects ranging from the very elementary to the advanced. The effect of space on style is exemplified in the extreme by chapter 15 on special functions, which is more a collection of formulas than an exposition on the origin of special functions and their application to problems in engineering mechanics. The formulas are doubtless useful, but unlikely to be attractive to a window shopper. One notable omission in the chapter on ordinary differential equations is the Sturm–Liouville theory. Another is the theory of differential equations with a large parameter. However, the amount of information packed into the twenty thin chapters is really amazing, and represents a laudable achievement. The same is also true of the chapters on solid mechanics.

The part on fluid mechanics, with which this review is principally concerned, begins with a chapter on the basic concepts and equations. This is followed by a chapter of two pages on dimensionless parameters, in which, curiously enough, the concept of similarity is not even mentioned. The next two chapters deal with ideal-fluid flow, expertly written by Professors V. L. Streeter and I. Flügge-Lotz. Perhaps the only important criticism of the two chapters on ideal-fluid flow is that irrotational flows are introduced without a derivation of the theorem of persistence of circulation (and hence, in particular, of irrotationality). This practice has made it difficult for students to differentiate between potential flows and the flows of an inviscid fluid of constant density. Otherwise I find the two chapters perfectly readable and digestible.

In the attractively written chapter on airfoil theory by Dr A. Robinson, more use of singular integral equations in the theory of thin airfoils would have been welcome, particularly since the section on singular integral equations in chapter 17 is quite sketchy.

The next eight chapters, two on thermodynamics and six on compressible-fluid flows, constitute the middle third of the part on fluid mechanics. The latter group progresses from subsonic through transonic and supersonic to hypersonic flow, and, after a brief interruption (the chapter on slender-body theory), ends in flutter (chapter 80). These are in general systematic, informative, and attractively written. It is, however, rather regrettable that there is no discussion of non-homentropic flows.

The rest of the chapters deal mainly with viscous fluids, with the exception of a chapter on surface waves and one on cavitation. The chapter on flow at low Reynolds numbers, particularly the second half of it, is a pleasure to read—in spite of the editor's warning that this book is not for readers. The next three chapters, on boundary layers and turbulence, cover more or less the familiar ground. On the first page of chapter 85 (on lubrication) there appears a footnote to the effect that Dr Poritsky's original manuscript has been greatly abridged. What a pity! It is regrettable, too, that we are not to benefit more from Professor T. Y. Wu's mathematical power and physical insight by having a longer chapter on surface waves, and that the chapter on cavitation is so short that it hardly reflects the amount of significant work done on cavitation at the California Institute of Technology. In the final chapter, on flow through porous media, one misses the modern results on instability, fingering, and the movement of fluid masses in another fluid (also flowing in the porous medium).

Looking at the contents as a whole, the most striking omission seems to be open-channel flow. Shallow-water theory, flood waves, back-water curves are completely absent, and even the old hydraulic jump has been moved out for being a bore, along with the instructive and important concept of subcritical and supercritical flows. Missing too is a chapter on water hammer. Has civil engineering become too old-fashioned to be represented? On the other end of the spectrum, a chapter on stability would be welcome; or one on geophysical fluid mechanics, which is having an increasing bearing on engineering. But surely it is easier to review a book than to edit one, and very much easier to criticize a thick book than to write a chapter in it. There is no doubt that this is a useful book.

CHIA-SHUN YIH

Mécanique de la Turbulence. Paris: Centre National de la Recherche Scientifique, 1962. 470 pp. 60 F.

This valuable document contains critical reviews of current theories concerning turbulent flow. The organizing committee of an International Colloquium held under the auspices of C.N.R.S. set the invited participants the task of assessing the present understanding of turbulent processes. With few exceptions, the most distinguished contributors to turbulence theory accepted both the invitation and the set task. They assembled in Marseille, in the last week of August 1961, on the occasion of the formal opening of the Institut de Mécanique

Statistique de la Turbulence. *Mécanique de la Turbulence* contains their manuscripts and comments.

The Colloquium was divided into seven sessions. The chairman of each session was responsible for the topic emphasized at his meeting, exercising this responsibility through introductory comment and in the choice of speakers. The list of sessions and chairmen is: 'Diffusion and Lagrangian effects', S. Corrsin; 'Energy transfer in homogeneous turbulence', G. K. Batchelor; 'Steady fully developed turbulence', R. W. Stewart; 'Free turbulence', H. W. Liepmann; 'Turbulent boundary layers', H. W. Liepmann and H. Schlichting; 'Turbulence in compressible and electrically conductive media', L. S. G. Kovasznay; 'New concepts and recent contributions', J. Kampé de Fériet and L. S. G. Kovasznay.

In this review I have tried to interpret views expressed at the Colloquium on two facets of turbulent inquiry. The first concerns deductive theories and the isotropic turbulence to which they have been addressed. The second facet is a collection of other problems, claimed by more than one participant to offer unusual rewards or unusual simplicity in the attempt to understand turbulence.

In 1935, G. I. Taylor constructed the descriptive framework for a statistical theory of turbulence. This description suggested both a vast new set of measureable quantities and a 'simplest' problem to be attacked deductively; isotropic-homogeneous turbulence. The Colloquium report suggests that, with the passing years, many of the first-line soldiers have grown weary struggling to mount this non-linear wall. There are whispers in their ranks of retreat. Weapons rust as they contemplate the non-deductive tunnels constructed by hypothesis.

Other theoreticians, yet unscarred, are exploring new approaches to the problem. A brief address at the Colloquium by R. H. Kraichnan, on his work and that of H. W. Wyld, clarifies several earlier studies and suggests a formal path of promise. The various expansion procedures proposed for the non-linear moment equations, e.g. cumulant discard approximations and 'direct-interaction' approximations, can be related to partial sums of the terms in an appropriate Reynolds number expansion of the exact problem. Kraichnan shows that approximation schemes which correspond to a truncation of the Reynolds number expansion lead to negative energy densities somewhere in the energy spectrum. The cumulant discard approximations of Millionshtchikov, Proudman and Reid, Tatsumi, and Chandrasekhar unfortunately prove to have this unphysical property, even though they are infinite partial sums. In contrast, that sequence of approximations, whose first term is called the 'direct-interaction' approximation, is a member of a class of infinite partial sums which have local energetic consistency in wave-number space. I. Proudman criticized all present approximations on the grounds that neglected terms may be as large as those retained. Without a doubt he is correct. However, the important measure of any 'free' expansion scheme is the degree to which the first approximation retains the essential physics. If this first approximation leads to results near observed fields, both qualitatively and quantitatively, then there can be hope that a second approximation will improve matters. Yet another promise of near success on a first try, is that similar approximation schemes can be constructed which retain even more of the physics in their first terms.

At each degree of approximation, all the deductive theories correspond to some model of the real flow. The model flow corresponding to the 'direct-interaction' approximation is the only consistent quantitative picture of isotropic-homogeneous turbulence yet produced. However, it is not 'correct', for it leads to a $k^{-\frac{3}{2}}$ law in the inertial range rather than the observed $k^{-\frac{5}{3}}$.

The only 'correct' theory of the inertial range follows, by dimensional argument alone, from A. N. Kolmogorov's hypothesis. T. H. Ellison discusses the considerable success of this qualitative theory in interpreting observations in the atmosphere and ocean. A principal assumption of the Kolmogorov picture is that the macroscale velocity v_0 does not influence energy transfer in the inertial range. If v_0 entered this transfer process as v_0^n, then the spectral law would be $k^{-(5+2n)/(3+2n)}$. Note that the 'direct-interaction' approximation corresponds to $n = \frac{1}{2}$. It is probably a kindness of fortune that $n \approx 0$ in real flows. In recent work of A. Obukhov, generalized and rephrased by Kolmogorov at the Colloquium, the macroscale motion is introduced into his hypotheses in order to interpret the observed dispersion of regions of dissipation. It is not clear to me that Kolmogorov's rephrasal is consistent with the concepts of a universal equilibrium theory, or that, in its present form, it adds to his grand intuition of 1941. G. K. Batchelor summarized efforts in the study of the universal equilibrium range with a list of possible applications. I interpreted his call for careful measurement of third and fourth power velocity derivatives as a desire to rule out at least some of the abundant speculation concerning the dissipation range.

Under the heading 'other problems' discussed at the Colloquium, I isolate three classes. The first contains diffusion and 'free' turbulence. These are joined as the topics most dependent upon the language of, and achievements in, homogeneous turbulence. The second class contains steady-state turbulence and boundary-layer turbulence, both dominated by inhomogeneity. Due to the slow downstream development of the boundary layer, it has proved possible to exploit steady-state theory in rationalizing boundary-layer data. The last class contains the 'novel' topics of sound generation and turbulent plasmas.

Despite the observation that diffusion in natural flows is dominated by large-scale inhomogeneous motions, diffusion theories usual start out by assuming an isotropic-homogeneous velocity field. Even so, following the probable position of a passive tracer poses formidable mathematical problems. J. L. Lumley points out that approximation schemes which appear reasonable from an Eulerian point of view, may be quite unphysical in Lagrangian interpretation. This observation was related to the problem of energetically consistent approximation schemes discussed in connexion with homogeneous turbulence. In summary S. Corrsin suggests further exploration of the role of the Prandtl number, and 'Monte-Carlo' machine analysis to face the mathematics. The diffusion problem seems badly in need of reformulation, if its supposed simplicity is to be recaptured.

'Free' turbulence refers to the important practical problems of jets and wakes. The decay of homogeneous turbulence behind a grid may be the simplest flow of this type. H. Liepmann believes that the absence of new energy sources in these flows justifies the search for similarity laws in terms of the bulk parameters. Yet, earlier in the Colloquium Batchelor pointed out that the correlation time and the decay time of a characteristic element in such flows were of the same order. He felt that the attainment of dynamic similarity was unlikely. Nevertheless, Liepmann recounts considerable success in interpreting wakes and jets, based on geometric and inviscid argument. It was also suggested that the considerable structure of these flows, e.g. turbulent vortex streets and the regions of laminar-turbulent intermittency, made them valuable objects for basic study. I am led to observe that the optical spectrum of iron has much more structure than that of hydrogen, but would have been a poor choice as the starting point of the theory of optical spectra. My eye was caught by an interesting suggestion of Liepmann's; that a study of the growth and decay of disturbances, artifically introduced into fully turbulent flows, would increase our knowledge of the preferred stable structure. I assume he would include disturbances of the mean fields as well as the fluctuations.

The most frequently studied examples of steady-state turbulence include Poiseuille flow, Couette flow, and thermal convection between parallel surfaces. As objects for elementary consideration of the turbulent process, their advantage of simple geometry and statistical steadiness is countered by dramatic inhomogeneity in one dimension. Classical similarity arguments and mixing-length theories have adequately rationalized some of the qualitative data from the shear flows, but have proved less successful for thermal convection. Quite generous interpretations of my quantitative theory of these flows were presented at the Colloquium. The interpretation due to A. A. Townsend discussed the qualitative consequences of the assumptions that these flows approach marginal inviscid stability and have a sharp cut-off in their transport spectra. The interpretation due to E. A. Spiegel, departing from the restrictive Fourier representation, discussed the theory and described the flow in terms of those collective co-ordinates naturally arising in the generalized stability problem. The principal contention in my studies is that statistical stability is achieved by flow fields of maximum 'flux' for a given 'force'. This contention is based on a rather fragile relative stability analysis. Hence, I was disheartened that there was no reported criticism of this vital element, for it is both the generalizable and the quantifying feature of the theory.

The critical assessment was of similar character in the session devoted to boundary layers. Several reports concurred that almost all was well with the steady-state semi-empirical theory, even when extended to supersonic flows with heat or mass flux at the boundary. The practical importance of these flows impose a severe restraint, but one may still hope that a broader framework of interpretation will increase the knowledge gained in such study.

The 'novel' topic of sound generation was discussed by J. Laufer. It appears that dissipation by acoustic radiation from jets can alter the turbulent dynamics only at very large Mach numbers. However, such radiation may prove to be a useful indicator of fluid processes in the shear layers which generate it. The problem of oceanic surface turbulence was not discussed at the Colloquium, but the radiation of surface waves from the generation area is an important dissipation mechanism for the large amplitude, long wavelengths. I mean to suggest that theories of turbulence could be constructed which explore a variety of dissipation processes, perhaps shedding new light on the special role of the viscous sink.

Hydromagnetic turbulence and plasmas were discussed at the Colloquium as exciting explorations, not as part of the search for 'simple' problems. L. S. G. Kovasznay took this view in his report of plasma instability. However, there are plasma physicists who believe that the Boltzmann equation, even without collision terms, will prove to be the best starting point for new understanding of 'turbulence'. Their views were not represented at the Colloquium. In a restrained account, H. K. Moffatt treated the magnetic field in hydromagnetic turbulence as a 'passive vector contaminant' on one hand and as a turbulent suppressant on the other. Equipartition of energy at high wavenumbers was the maximum role he permitted magnetic fields in the dynamical problem. Yet here we sit atop the geomagnetic dynamo, where the magnetic energy density exceeds the kinetic energy density by a factor of a million. Clearly magnetic instability can play a dominant role in the release of available energy and in the turbulent dynamics.

The Colloquium presentations do have merit as aware assessments. However, their value may be greater as side by side displays of the many points of view. We learn that a successful treatment of turbulence as an aspect of macroscopic, irreversible, statistical physics, is not in sight. But, slowly, slowly our language of inquiry evolves. A thoughtful reading of *Mécanique de la Turbulence* can serve all students of the turbulent process, and will uncover the bias of this cursory review.

W. V. R. MALKUS

Fundamental Problems in Turbulence and their Relation to Geophysics.

Edited by F. N. FRENKIEL. American Geophysical Union, 1962. (Also published as Number 8, Volume 67, of *Journal of Geophysical Research*, July 1962.) 235 pp. $5.00.

Following on the heels of an international Colloquium assembled to assess the present state of turbulence theory, this symposium organized jointly by IUGG and IUTAM was held at Marseille in September 1961 and attended by many distinguished contributors to the literature of geophysical turbulence.

Two themes appear isolatable in the proceedings. The first is that the geophysical setting produces turbulent phenomena which are not realized in the laboratory. The second theme is that the semi-empirical theories of the laboratory can be successfully modified and applied to turbulence in nature. Although apparently contradictory, one finds that proponents of these separate views usually address their efforts to phenomena of different scale.

The large-scale geophysical 'turbulence' is dominated by the rotation of the earth. These quasi-geostrophic flows usually are interpreted with the classical language of the laminar idealization. Since man is a speck inside the huge 'weather' systems, studies of the time-dependent details of these flows will continue to concern him. However, the climatologist explores mean properties. He is the forerunner of those fluid dynamicists who treat the entire atmosphere as a statistically-steady turbulent process, controlled by slowly changing insolation and boundary conditions. A contribution to the symposium by Davies and Oakes is an example of this global viewpoint, a viewpoint slowly helping us to understand the role of turbulent heat and momentum transport in shaping the general circulation of atmosphere and ocean.

The many Symposium papers in which semi-empirical turbulence theory is applied to natural flows indicate considerable success in rationalizing the transport data of 'small-scale' motions near the earth and ocean surface. The practical importance of this work is not to be underestimated, yet, unfortunately, it has played a negligible role in advancing our knowledge of the turbulent process.

In contrast, a report on the study of ocean waves dealt directly with process, and straddled the two themes of the Symposium. In the empirical theory, the transfer of momentum at the air-sea interface is characterized by a 'roughness length'. The complex process of wave generation at sea, the acceleration of the surface layers, and the creation of spray are all hidden in this one parameter. New understanding of these turbulent phenomena has come from the work of Miles, Phillips and Hasselmann. It is now believed that only the initial development of waves on a quiet sea is caused by the pre-existing turbulent pressure fluctuations in the air above. The significant momentum transfer to the sea is achieved by the growing instabilities at the interface. These instabilities appear to cause a relaxation of the rigid boundary conditions on the flow in both the air and sea, permitting a large increase in the momentum flux. The theory has been developed for the initial phase of this process only, with two exceptions. The first exception is the dimensional argument of Phillips which leads to the equilibrium spectral shape of the high-frequency wave components. This argument differs from, but is comparable in kind to, the Kolmogorov hypothesis for isotropic turbulence, the latter having been confirmed by Stewart and Grant in the air directly above the sea and the former having been confirmed by Hicks for the surface waves. The second exception is the work of Hasselmann on the non-linear interaction between the waves themselves. He has been able to construct an energetically consistent description of interacting wave trains which produce another wave train growing exponentially in time.

These dynamical studies of air and sea in interaction are still far from predicting the equilibrium momentum transfer. However, the vitality of this inquiry will add much to the intellectually quiet waters of the conventional turbulence work ten metres higher up.

The Symposium proceedings offer a most non-uniform, but typical, picture of the slow progess one must expect in this difficult field.

W. V. R. MALKUS