REVIEWS

Radiation and Waves in Plasmas. Edited by MORTON MITCHNER. Stanford University Press, 1961. 156 pp. $4.50 or 36*s*.

This is the report of the fifth Lockheed symposium and reflects the current emphasis on the interaction between the radiation and waves on the one hand with the charged particles of the plasma on the other. This kind of interaction is more basic than the earlier picture of interactions between charged particles in terms of collisions and can therefore be used to describe a greater range of phenomena. In the theoretical work there is a wide range of possibilities as to when and how statistics are introduced, depending on the problem. Thus the seven articles in this volume cover a range of phenomena, while all being related to the theme of the title.

The first paper, by Simon, is concerned with the transport coefficients of a plasma and is a necessary preliminary to a complete theory of cyclotron radiation. The work presented had been published previously, but in the hope of attaining improved communication this is an outline in which the notation is simplified by omitting some of the complications. It is still tough reading, but not easy to criticize.

A long paper by Bernstein covers a variety of problems in collisionless plasmas. It begins with a general treatment of the most manageable class of problems in collision-free plasmas, those that have symmetry such that the equations of motion for a particle have integrals. He then deals with non-linear plasma oscillations in one dimension, which are of this class, and then gives quite a detailed account of the theory of probes with cylindrical symmetry. Finally he derives equations for waves with slab symmetry. This paper is particularly clear, even allowing for the relative cleanness of the problems.

Buneman's paper is concerned with the relation between multistream models and the Boltzmann model, particularly in connexion with Landau damping. He stresses the virtue of the variational principle for the stream models and illuminates the mechanism of degradation of energy, but concludes that the stream model is clumsier in the case of energy conservation.

Beard's paper on microwave emission from ultra-energetic plasmas begins with a relativistic calculation of refractive index and absorption coefficient. He then presents numerical results with useful graphs on the spectrum of the cyclotron radiation emitted when particle motion parallel to the field is negligible and discusses the energy loss. This paper is followed by a comment by William E. Drummond reporting some computations which agree with Trubnikov and finding a perfectly feasible value for the minimum size of a reactor.

J. E. Drummond discusses the interactions between electrons and several kinds of wave. He outlines a usable method of calculating the behaviour of inhomogeneous plasmas and is then able to make comparisons with experiments, showing some points of agreement.

Kino describes the thermal generation of a fully ionized caesium plasma and the amplification of microwaves when an electron beam is shot through this plasma. The amplification was measured over a range of frequencies and shows some agreement with theory.

Finally a group from Berkley describe experiments on Alfvén waves using the torsional mode, showing some quite accurate agreement with theory.

Altogether this is a heartening volume and well up to the standard of the four previous symposia.

J. DUNGEY

Axial Flow Fans. By R. A. WALLIS. London: George Newnes, 1961. 361 pp. 50*s*.

What is the difference between an axial flow fan and an axial flow compressor stage? The division between the two is generally set by the magnitude of the design pressure rise. In a fan the low head rise specified requires only small changes in tangential velocity through the rotor, and these can be obtained by using widely spaced blades of low camber. In an axial compressor stage the blade speed is high (tip speeds approach 1000 ft./sec) and the maximum pressure rise consistent with high efficiency is obtained. In aircraft practice the demand for high mass flow rate per unit frontal area also leads to high axial velocity—of the order of 500 ft./sec.

The fan designer has been led by Keller and others to rely on isolated aerofoil data for his design, although he may use Weinig's theoretical analyses of the flow through cascades of flat plates to correct the isolated aerofoil lift, for space-chord ratios less than 1·5. The fan designer's approach has been essentially that of the aerodynamicist, working with lift and drag coefficients.

The axial compressor designer usually bases his design on large numbers of two-dimensional cascade experiments, in which outlet air angles and loss coefficients have been obtained for ranges of inlet angles. He is interested in using the maximum air deflexion that can be obtained efficiently and the maximum blade speed consistent with mechanically sound design and in avoiding the adverse effects of compressibility. It may be noted here that the ducted 'fans' for aircraft engines and the lifting 'fans' likely to be used in vertical take-off aircraft are really high-speed axial flow compressors of advanced aerodynamic and mechanical design.

But consideration of allowable noise, perhaps of allowable stresses, and requirements of cheap manufacture may impose limits on the blade speed that can be used by the fan designer, and he may be forced to blade space-chord ratios similar to those used in axial compressors. The compressor designer's approach has become important to the fan designer.

R. A. Wallis has therefore performed a most useful service in bringing together these two approaches in his book. He has presented both isolated aerofoil data and the correlations of British cascade experiments (principally those of Howell and Carter), and has shown how both may be used in fan design. Design examples and the calculation of off-design performance are clearly outlined, and the careful reader will find that by using this book he will be able to design fans of high efficiency. He will also find that the author has given a comprehensive survey of boundary-layer theory and experiment, together with a lot of practical information on losses in pipes, inlets, pipe bends, ducts with sudden changes of area, on diffuser efficiency, on the optimum spacing of cascade blades in a ninety-degree bend to give minimum loss.

The reviewer's adverse criticisms of this book are minor and are perhaps typical of an axial flow compressor designer. First, the definitions of rotor and stator pressure coefficients (change in pressure divided by rotational dynamic head, $\Delta p/\frac{1}{2}\rho U^2$) are not always the most convenient. Once these are known the overall stage pressure coefficient is easily calculated, but one has to work through the lift-drag ratio, the flow coefficient, and the mean flow angle to obtain these forms of rotor and stator pressure coefficients. It is the pressure change divided by inlet relative dynamic head which is a function of inlet angle alone. The compressor designer's approach using such coefficients appears the more logical.

Secondly, Wallis's three-dimensional analyses are restricted to radial equilibrium flows, usually using a free vortex distribution of tangential velocity or one other particular form of vortex. Are such analyses sufficient for an accurate fan design? Surely radial equilibrium will not always be established at the trailing edges of the blade rows, especially for blades of large aspect ratio. And in calculating the vortex flow off-design, the analysis of Cohen and White, using the flow exit angle distribution with radius, is a more elegant and straightforward approach than that given by Wallis.

Thirdly, it is important to note that the nominal condition (defined by Howell as that at which the deflexion is 80 % of the stalling deflexion) is not the same as the optimum condition (defined by Carter as that of maximum lift-drag ratio), as the author suggests. An optimum design is one aimed at high efficiency; a nominal design is one in which some efficiency may be sacrificed for freedom from stalling.

In summary, this book will be most useful to practising engineers, in particular to heating and ventilating engineers, and to designers of wind tunnel fans. It will be of some interest to designers of axial flow compressors and high duty ducted fans but it is unlikely that such engineers will wish to use Wallis's methods in their work. It will also be of use to many engineers who want ready access to summaries of boundary-layer and loss data.

It will be of less use to the research worker in turbomachines, or to the research scientist in fluid mechanics. He will not be entirely satisfied with the treatment of fundamentals, for the author cannot delve too deeply. For example, the discussion of fan noise, surely a most complex subject, is cursory, and the descriptions of three-dimensional vortex flows and secondary vorticity are not entirely satisfactory as they ignore much recent work.

But Wallis has not written his book for this latter group of scientists and engineers. He has written for the practical engineer, and in doing so he has certainly done a first-class job.

J. H. Horlock

Rarefied Gas Dynamics (Proceedings of the Second International Symposium on Rarefied Gas Dynamics). Edited by L. TALBOT. New York: Academic Press 1961. 748 pp. £6. 16*s*.

Upon opening this volume of *Proceedings*, the reader is confronted at once by a critical analysis of current experimental data on thermal accommodation coefficients, done as only a theorist can do it. Whether by chance or by design of the programme committee and editors, this first paper sets a swift and accurate course toward further appraisal of our understanding of that branch of science now known popularly as 'rarefied gas dynamics'. While some contributors seem to have placed undue emphasis on the spritual connotation of the word 'rarefied', the Second International Symposium again led to a valuable exchange of ideas between aerodynamicists, astronomers, atomic physicists, and their hosts in fluid mechanics.

As on the occasion of the 1er Symposium International sur l'Aérodynamique des Gas Raréfiés two years earlier in Nice, meetings were conducted in very pleasant surroundings. The second symposium, held over a period of four days on the campus of the University of California at Berkeley in August of 1960, was attended by several hundred scientists. Representatives were present from almost all of the centres actively engaged in research on rarefied flows.

Forty-one papers are contained in this volume. Theory and experiment receive almost equal attention. Surprisingly few contributions deal directly with the problem principally responsible for awakening the present widespread interest in rarefied gas dynamics—that of high speed flight through the upper atmosphere. Perhaps this fact reflects a growing realization that more accurate fundamental data is needed to guide scholars along the paths to clear understanding. This seems to be particularly true in considering problems involving boundary conditions, where knowledge of the velocity distribution of particles moving away from a surface is required for determining drag and heat transfer.

Papers are grouped in six sections, corresponding roughly to the sessions in which they were originally presented: molecular beams and surface interactions, free-molecule flow, fundamentals of kinetic theory and fluid mechanics, application of kinetic theory, low-density gas dynamics, and ionized gases. Discussion on the papers is not included separately, but authors were afforded an opportunity to embody relevant points in their manuscripts. The reader will also note many interrelations between papers on the same general subject, again partly a result of each author having had the benefit of hearing the others. Thus, the student may use this book to progress rapidly toward an up-to-date comprehension of nearly any aspect of rarefied flow. Copious references are supplied for the benefit of those seeking deeper understanding in specialized areas.

Notable progress was made during the two years between Nice and Berkeley in developing more intense atomic beams and more sensitive detectors for the study of energy and momentum exchange on surfaces, catalysis, and sputtering. Careful attention to the familiar problem of surface contamination has also helped clarify some old difficulties in interpreting data. Stein and Hurlbut, for example, describe results of an extensive experimental study of the sputtering from a potassium surface by ions of He, Ne, A, Kr, and Xe. Quantitative data on the direction and intensity of sputtered K for various incident beam energies and angles reveals a clear dependence on the momentum of the incident particle. The authors conclude that simple evaporation cannot explain the process adequately and propose that a purely mechanical model of collisions in the surface layers offers a satisfactory theory. Further refinements in our understanding of sputtering may very well contribute to a closely related but even more confusing problem, that of impact by macroscopic particles travelling at meteoric speeds.

Wood and Wise have measured the catalyic efficiency for recombination of atomic hydrogen, nitrogen, and oxygen of a number of metals over a sizeable range of temperatures. Their technique is to introduce a steady, low-density flow of atomic gas into a cylindrical pipe and measure changes in relative atom concentrations along the axis. A striking feature of their data is the total independence of the recombination coefficient upon temperature for some combinations of gas and metal.

Section 4, on applications of kinetic theory, commences with Waldmann's treatment of the motion of a spherical particle in a single gas with temperature gradient and in a binary diffusing mixture. Theory yields the physically plausible result that a particle will drift down the temperature gradient and down the concentration gradient of a heavy gas diffusing through a light one. These conclusions hold for both large and small Knudsen numbers. In the event two diffusing gases have nearly the same mass, the sign of the second-order diffusion coefficient enters as the controlling factor. Experiments with several gases over the range from Kn small to large compared to one give good credence to the theory for free molecule flow but not for slip flow. The problem in the latter instance appears to stem from the inaccuracy of Maxwell's assumption that the 'hydrodynamic' velocity distribution function is satisfactory in treating particles approaching a surface in slip flow.

Once more, Probstein has contributed materially to the very difficult problem of tying together the ends of continuum flow and free molecular flow. Directing attention to pressure distribution, shear forces, and heat transfer on a blunt body in hypersonic flow, he presents a comprehensive analysis and numerical solutions for use in the transition region. Since he previously demonstrated that the gap between applicability of free molecular flow theory and continuum theory was only about one decade in, say, Reynolds number or Knudsen number, matters now appear to be in quite a satisfactory state. In treating the problem of atmospheric re-entry, this decade corresponds to a change in altitude of only about ten miles and will be traversed on most trajectories before either peak heating or peak deceleration are experienced.

A number of problems in classical fluid dynamics for which exact solutions are known have their counterparts in rarefied gas dynamics. Thus, one finds several papers on Couette, Poiseuille, and laminar boundary-layer flows, as well as a few on the structure of shock waves. The same situation exists these days in the field of magnetohydrodynamics with one important difference. Experimental investigations of Couette flow and shock structure are *easier* for rarefied gases than for plasmas or even for continuum flows, at least under conditions which closely approximate the idealized models generally chosen. While the conference produced a wealth of new analysis on all the problems just mentioned, new observational data was forthcoming from the laboratories only on shock structure. Further work on argon reported by Hornig *et al.* indicates that shock thickness, when measured in units of the mean free path upstream, drops to a minimum of 4 at a Mach number between 3 or 4 and then rises slowly for stronger shocks. The number of collisions within the shock, however, undoubtedly continues to increase monotonically with shock speed.

Sphere drag received considerable attention in the western United States during the interval between conferences. Masson, Morris & Bloxsom and Wegener & Ashkenas report extensive experimental results showing the variation of drag coefficient with *Re* or *Kn* through the transition region. The drag coefficient is seen to rise asymptotically toward the value 2 predicted by free molecular flow theory.

The final section of the volume brings together four papers on ionized gases. Three of these fall generally into rarefied plasma dynamics, the other constituting a fine survey by Chapman on dynamical and other aspects of cosmic gases of low density. He introduces the word *ambium* to describe the very extensive and nearly uniform cloud of gas surrounding a stellar or planetary atmosphere. Researches into the nature of ambia and their interactions with the host atmosphere constitute a fascinating subject for astrophysicists and fluid dynamicists alike. Of particular interest to this reviewer are the commentaries on the zodiacal light (illustrated by an excellent photograph) and the streaming of particles outward from the sun's corona.

At the time of this writing, plans are already well underway for a third international symposium on rarefied gas dynamics to be held toward the end of June 1962, in Paris.

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