J. Fluid Mech. (1985), *vol.* 153, *pp.* 500–503
Printed in Great Britain

REVIEWS

The 1980–81 AFOSR–HTTM Stanford Conference on Complex Turbulent Flows: A Comparison of Computation and Experiment, Volumes I, II and III. Edited by S. J. KLINE, B. J. CANTWELL and G. M. LILLEY. Stanford University, 1981. 632 pp., 416 pp. and 503 pp. $50.00 per vol., $125 the set, $150.00 for the data library on tape.

In 1968 an unusual conference was held at Stanford, California at which the different methods for calculating the flow in two-dimensional turbulent boundary layers on flat surfaces were compared with each other and with standard sets of measurements (described by Kline, Moffatt & Morkovin, *JFM* **36**, 481–484). Since then there have been many other conferences and workshops at which computation and measurements of standard flows have been compared in many different branches of fluid mechanics. This general approach has helped considerably in the development of reliable and useful methods for computing and measuring flows, but the standards set by that Stanford conference for thorough and systematic comparison have never, to my knowledge, been exceeded.

So, many research workers in turbulence were pleased to hear that another conference was to be held in 1980 and 1981 at Stanford to compare calculations and measurements in complex turbulent flows. These three volumes are an edited account of the proceedings. Volume I covers the 1980 conference, which concentrated on establishing which existing measurements should be regarded as reliable enough to be standards against which computations can be compared. The conference also agreed that computational methods needed to be tested against flows that had not been measured before. Computational predictions were to be compared in 1981 with these new measurements, to see whether these methods could really be used as *predictions* not merely as postdictions or interpolations. As a result of much labour by the staff and students in the Stanford Engineering Departments, data tapes are now available of both of these sets of measurements.

Volumes II and III cover the 1981 conference. Volume II begins with six review papers on various aspects of modelling turbulent flows; overview of taxonomy (Ferziger, Bardina & Allen), integral techniques (Cousteix), velocity scales and lengthscales in turbulent flows (Hanjalic), stress/strain relations in differential methods for turbulent flows (Rodi), turbulence modelling in the vicinity of a wall (Launder), complex strain fields (Bradshaw), compressibility effects in turbulence modelling (Rubesin). There are other reviews later in the volume on the influence of numerical methods and other computational procedures on the computation of turbulent flows *using the same models* (Launder) on the direct 'simulation' (i.e. computation of the full Navier–Stokes equation without approximation, except numerical) of homogeneous turbulence at low Reynolds number (Rogallo), large-scale numerical simulation of wall-bounded turbulent shear flows (Moin & Kim), and displacement effects in transonic airfoil flows (Melnik).

The volume also contains the main conclusions of the technical reporters (named in parentheses) and the subsequent discussion about the comparisons of the measurements with the calculations by the various models. The following classes of complex flows were considered: incompressible free shear flows (Chevray); incompressible wall bounded flows, I – boundary-layer flows and diffusers (Simpson); incompressible wall-bounded flows, II – boundary layers on curved surfaces and with suction and blowing, and wall jets (Nagib); homogeneous flows, namely distorted and undistorted grid turbulence (Lumley); transonic flows (P. Kutter); simple compressible strains (Bushnell); relaminarizing flows (Kays); incompressible separated flows – a stalled aerofoil (McCroskey) and a backward-facing step (Eaton); incompressible duct flows (Jones); supersonic flows (Marvin). In all cases the only measurements considered were mean-velocity profiles, surface shear stress and one-point moments of the fluctuating velocity (e.g. the Reynolds stress).

The details of the turbulence models and the numerical methods used in the computations are well described in Volume III. The computations of different research groups using similar methods have been collected and discussed together. The discussions of the limitations of the methods are reasonably candid, though the discussion of the success of the methods in terms of doing or not doing a 'good job' is hard for an outsider or perhaps a practical user to assess.

The kinds of turbulence models that were used by computers were (i) integral methods for calculating the mean velocity and shear-stress profile (which were mainly for boundary layers and contained various assumptions about entrainment processes or the 'shape factor' of the boundary layer profile); (ii) eddy-viscosity methods, which assume a local relation between shear stress and velocity gradient; these range from those where it is prescribed to those where it is computed from two differential equations, for example the turbulence kinetic energy k and rate of dissipation ϵ of turbulent energy per unit mass, or the lengthscale (l); (iii) equations for the Reynolds stresses in conjunction with an equation for ϵ or l (in this case the stresses need not be proportional to local velocity gradients); there is a halfway house between methods (ii) and (iii) in which Reynolds stresses are calculated from algebraic equations plus differential equations for k and ϵ; (iv) equations for two-point closures or spectra.

In the methods of types (ii) and (iv) approximations are made both about the linear processes governing the rates of change of second-order moments of the fluctuating velocity in terms of their values at that time, and about the nonlinear processes connecting these rates of change with pressure–velocity correlations and third-order moments (or spectra). Neither of these two classes of approximation is 'rational' in the sense that one can *estimate* the errors mathematically. In some accounts of these methods (such as the good one by Lumley in *Adv. Appl. Mech.* 1978) it is stated that they are implicitly or explicitly based on an assumption that the turbulence scales are small compared with the scale of the inhomogeneity of the flow or distance to a surface, and that certain higher-order moments are related to other moments as if some aspects of the turbulence were Gaussian. In other accounts of these methods there are almost no statements about the physico–mathematical basis of the closure approximations.

A nice feature of the editing of these volumes is that there is enough information for the reader to draw his own conclusions and to compare them with the main conclusions set out in the Proceedings which are:

(*a*) Integral methods continue to be a reliable and widely used method for calculating the mean flow and skin friction in the fairly narrow range of flows represented by unseparated boundary layers on airfoils, including the flow near the trailing edge where the inviscid flow outside the boundary layer is significantly disturbed by the thick boundary layer, i.e. 'viscid–inviscid interactions'.

(*b*) No one turbulence method using the same parameters (or putative 'constants') is appropriate even for the particular range of complex flows considered here. It was generally agreed that at present different methods and different parameters are appropriate for different flows.

(*c*) This led to some discussion of the question of whether it is worthwhile attempting to develop a single general model to describe most turbulent flows. Different answers were proposed. One was that a better adaptation of existing models to describe different flows is needed; another was that the goal of a single model (based on moment equations) is worthwhile and a great stimulus to a better understanding of turbulent flows; a third was that the advent of large and cheaper computers may make the large-scale eddy simulation possible for practical calculations. The answer recommended in the Preface, based on a paper of Kline, is that if the characteristic flow zones in turbulent flows (e.g. free shear layers, wall layers) are properly modelled, most complex flows can be calculated with different 'constants' for each. But some powerful objections were raised against this idea, which seems to be similar to Morkovin's older concept of flow modules! It is only appropriate if the turbulence or its rate of change (in second-order models) adjust rapidly to a change in the flow, which is generally not true. (Large eddies last a long time, at least 40 diameters along a pipe, so eddies 'remember' the straining they have undergone far upstream. Therefore can models based on local straining and local anisotropy really work, I wonder?)

(*d*) Differences in numerical methods do not typically affect the general results – at least for the better methods used on fine grids – according to Launder's review. For example a number of numerical methods, using the same turbulence model, led to predictions of the length of recirculating flow downstream of a step of about $5\frac{1}{2}$ step heights (± 1), this is somewhat less than the experimental value of ($7\frac{1}{2} \pm 1$), but the main discrepancy is presumably due to the turbulence model.

(*e*) The review of homogeneous turbulence in straining flows suggested that 'rapid' or linear processes are not correctly represented in Reynolds-stress models, nor are the non-linear processes determining the 'return of isotropy' of anisotropic turbulence. The more advanced methods using two-point closures (e.g. methods based on eddy-damped quasi-normal Markovian hypotheses) are significantly better.

Readers of these volumes ought to realize that the emphasis on this conference was on calculations leading to the mean velocity and surface shear-stress profiles and to a lesser extent the Reynolds stresses in the flow. These are undoubtedly the parameters of great importance in many practial problems, and the organizers deliberately limited the scope of the meeting to predictions of these aspects of the velocity field. But there are other practical problems where it is more important to calculate spectra or two-point moments (for example in sound generation, or diffusion from localized sources, or structural loading). Different calculation methods, different flows and different experiments would have been more appropriate for these problems. So I would say that from many practical as well as theoretical points of view, the review features in Volume II treat too lightly or omit altogether important aspects of practical turbulence research.

However, I found these volumes interesting and informative reading, and I am sure that the data they contain will be highly valued by experimenters and modellers for many years. The editors are to be congratulated on finishing their Herculean task rather faster than this dilatory reviewer took to undertake his minor task! A smaller follow-up meeting, to discuss improvements in calculation methods since the Stanford meeting, is being organised by Professor G. M. Lilley, and will probably be held in Southampton in September 1985.

J. C. R. Hunt

Cascade Aerodynamics. By J. P. Gostelow. Pergamon, 1984. 270 pp. £25.00 (hbk), £12.50 (pbk).

The branch of aerodynamics devoted to the study of flow through blade cascades is of great importance to the gas- and steam-turbine industries as well as to the design of many other products such as fans, pumps, propellers, windmills and turbochargers. The subject involves almost all aspects of fluid flow, and this is the first English-language book to attempt to review the whole field. As such it fills a significant gap in the literature, but suffers in having to cover an enormous amount of material published over the last 50 years. The amount of material covered is illustrated by the 749 references cited in the book, and these include material published up to two years ago.

The book is aimed at postgraduate students, research workers and design engineers working in the field of turbomachinery aerodynamics, and a knowledge of fluid mechanics up to at least that reached in an engineering degree course is assumed. Only brief reviews of such basic topics as compressible-flow theory are given before making extensive use of its results. The historical development of the subject is well described, but it is not always made clear which methods and theories are of purely historical as opposed to current interest. In fact much of the material in the book falls into the former category, and could usefully have been condensed.

Both theoretical and experimental aspects of cascade flow are covered for both compressors and turbines, and the author sometimes strays from consideration of pure cascade flows to discuss related aspects of machine design. On the whole, the emphasis is on the theoretical aspects, and whilst numerous experimental results are quoted the discussion of experimental techniques is rather limited. In particular, there is little discussion of the instrumentation, especially probes, used for aerodynamic measurements in cascades. The theoretical work covers both low- and high-speed flows, with most methods being described only in outline. Most attention is in fact devoted to conformal-transformation methods for incompressible flow, which are scarcely used nowadays, whilst the numerical methods that are now universally used for the calculation of high-speed flows are only covered rather briefly. Useful examples of the comparison of numerical solutions with test results are, however, included. Viscous effects are well described, including boundary-layer prediction methods and a discussion of the difficulties in predicting transition and of the application of the Kutta condition to inviscid-flow calculations. The estimation of blade loss is an important topic which is not given sufficient attention.

A chapter on stalled and unsteady flow includes a detailed discussion of vortex shedding from blunt trailing edges and of the complex flow around a supersonic trailing edge, but the sections on stall and flutter are little more than a list of references. The final chapters of the book are rather disjointed, but include sections on tandem cascades, blade cooling, effects of sweep and dihedral, endwall profiling, prediction accuracy and design applications, all of which contain useful information.

The book will prove extremely useful to anyone working in the field of turbomachinery aerodynamics; all aspects of the subject are covered, many of them rather superficially, but the very comprehensive list of references will enable more details of virtually any topic to be readily unearthed.

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