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Correspondent Report

The first of two meetings of the 1980-1981 AFOSR-HTTM-Stanford Conference on Complex Turbulent Flows: Comparison of Computation and Experiment is described. The Conference is a cooperative research effort involving a major fraction of research workers in turbulent flow. It has three objectives: (i) establishment of trustworthy data sets that can be used as the basis for modeling complex turbulent flows and as standard trial cases for checking output of computations in such flows; (ii) the creation of a data library in standardized, machine-readable form on magnetic tape of the trustworthy cases; (iii) the comparison of current computational output from many groups with the standard trial cases. The meeting on data held at Stanford University, Sept. 3-5, 1980, is described in this paper, including: a short history of the problem, difficulties in turbulence research and recordation of adequate data sets, organization and special procedures in the conference, the trial cases established for the 1981 meeting on computation, a number of other specific results from the meeting, and conclusions. It is concluded that the 1980 meeting was successful not only in meeting goals (i) and (ii) but also in clarifying many other issues that have been troubling the research community and clarifying needs for future researches. The Proceedings from the 1980 meeting will be published in spring, 1981 and may be ordered from the first author.

Correspondent Report

On the Initial Meeting, Held September 3–6, 1980, of the 1980–1981 AFOSR-HTTM-Stanford Conference on Complex Turbulent Flows: Comparison of Computation and Experiment[1]

by

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1 Introduction

The meeting at Stanford University from September 3–6, 1980 completed the first stage in the *1980–1981 AFOSR-HTTM-Stanford Conference on Complex Turbulent Flows: Comparison of Computation and Experiment.* The major goal of this initial meeting was to reach a consensus in the research community on trustworthy experimental data sets that can be used as inputs for modeling of turbulence in complex flows and as a basis for standard "trials" for checking outputs of computations. In order to achieve this aim with impartiality, the cooperation of scientific and engineering communities was sought and generously given, forming the foundation for the September, 1980 meeting.

The Conference as a whole is best viewed as a cooperative learning process within the research community. The second and final meeting of the Conference will be held on September 14–18, 1981. The complete, detailed goals of the Conference are given below.

At the conclusion of the September 1980 meeting it was possible to select some 50[4] trustworthy experimental data sets of complex turbulent flows which will form the standard "trial" cases for comparison with the outputs of computations from many groups of computors.[5] The output of these computations will be compared with the standard cases in the September, 1981 meeting.

An essential component of the 1980–1981 Conference has been the creation of a "Data Library" on magnetic tape. This library holds the data selected as trustworthy in a standard and normalized form. The data will be computer-readable and the tapes will be held in repositories in USA and EEC countries and will be generally accessible for a moderate fee. The establishment of the Data Library is well advanced. It is intended that the library should be an ongoing function whose contents will be periodically updated using methods for the establishment of trustworthy data sets similar to those used for the 1980 meeting. The future home for the Data Library and its funding are matters for further consideration.

The aims of the September, 1980 meeting stated above were met, as can be seen by reference to the lively and pertinent discussions which followed each presentation and which are recorded in the *Proceedings* of the 1980 Conference. The September, 1980 meeting also achieved several other useful results. The bringing together of so many experienced experimentalists in the field of fluid mechanics became an important opportunity to explore many of the problems facing anyone setting up experiments involving turbulent flows. Arising from the several discussions, many suggestions were made regarding instrumentation and calibration for specific flows. Perhaps of more importance, these needs were identified: to plan the experiment carefully; to record in detail the initial or entry flow characteristics, as well as the downstream conditions; to set up a systematic analysis of uncertainty in the proposed measurements and, from trial runs, to make explicit that these uncertainty estimates are realized, or to determine what is needed to reduce uncertainty. It was agreed that such considerations are essential to the production of trustworthy experimental turbulent flow data but regrettably have often not been fully implemented in the

[1] The financial sponsorship of the U.S. Air Force of Scientific Research and the NASA Ames Laboratory are gratefully acknowledged.

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[4] The number of data sets is approximate, since it depends on how one counts "sub-cases."

[5] "Computor" is used to describe individuals using computers.

past. This deficiency made the work of the Data Evaluators for the 1980 Conference more difficult but, at the same time, more important. Further details of these suggestions and recommendations are given below.

The September, 1980 meeting was also useful in providing increased understanding between experimentalists and computors. The interaction between these two groups became important in drawing up the specifications for the "trials" which the computors will undertake. This interaction was badly needed, in that it helped data takers appreciate what information needs to be supplied about a flow in order to provide satisfactory initial and boundary information[6] needed in experiments intended as input for turbulence modeling, for checking output of computation, or both. The data needs for these purposes in Computational Fluid Dynamics differ markedly with regard to demands on recordation of initial conditions, documentation of uncertainty, and verification of experimental control from the needs for experiments intended to provide direct data for engineering design or to increase understanding of fluid motions. Both a position paper (composed through seriatim revision by a number of workers) and discussions in sessions and ad hoc committees in the 1980 Meeting thus appropriately focus on "Data Needs for Computational Fluid Dynamics."

There was general agreement that although the range of computational methods in fluid mechanics will greatly increase within the next decade and beyond, it will not replace the need for high-quality experimental results. Thus there is a continuing need for closer contact between experimentalists and computors. The two groups of workers have much to give and learn from each other. Improvements in turbulence modeling techniques will inevitably come from closer collaboration between these two groups of workers. It cannot be over-stressed that an individual computor *does not have sufficient resources to assess the reliability and accuracy of data*; the task is not only arduous, but requires considerable experience in both experimental technique and the specific flow type considered. Hence it is essential that the experimental research community furnish computors with information on which flows are trustworthy. This was the central work of the 1980 meeting and the two-year-long preparation for it.

2 History

The study and prediction of the flow of Newtonian fluids have advanced greatly in recent years with the advent of fast methods of computation. Computational methods in fluid dynamics (CFD) now provide an appropriate and reliable tool for the prediction of a wide range of fluid-flow problems in many industries. This is particularly so if the fluid flow may be regarded as inviscid or if viscous effects are confined to regions whose geometries are relatively simple, for example, thin shear layers. Even so, there remain certain classes of inviscid flows, notably those containing free vortex sheets, which continue to present formidable problems in CFD.

In the case of turbulent flow, development of CFD methods for their prediction have depended on an adequate and trustworthy experimental data base. Such a data base has not always been available. It is therefore not surprising that a wide range of turbulence models and methods has been developed, presenting a confused picture as to which method or class of methods is best suited for the accurate prediction of a given fluid-flow problem. In order to make any significant advance, it is agreed that the available prediction methods need to be critically examined and compared with trustworthy experimental data. This conclusion is fully borne out by the experiences of the 1968, 1969, and 1972 Conferences.

In 1968 the AFOSR-IFP-Stanford Conference was set up to clarify the state of the art in prediction of incompressible turbulent boundary layers.[7] Its success may be measured not only by the establishment of similar NASA Conferences in 1969 and 1972 on turbulent compressible boundary layers and free-shear layers, respectively, but even more from the fact that the three Conferences showed that, contrary to prior common wisdom, adequate programs for computing shear layers did exist.[8] The *Proceedings* of these conferences still provide important reference works governing the structure and prediction of these initial types of flows, including satisfactory calculation methods.

The "trial cases" from these three meetings still serve as the functional standards for testing computational models of thin shear layers. Thus, experience shows: (i) standard trial cases composed of data known to be trustworthy are necessary in order to clarify the state of the art; (ii) such cases tend to remain a useful basis for a considerable period of years.

The 1980-81 AFOSR-HTTM-Stanford Conference has similar objectives with respect to a wide range of internal and external, incompressible and compressible, complex turbulent flows. However, the principal problem facing the Organizing Committee, when it first met in 1977, was the lack of trustworthy experimental data sets. The data base had to be created first. The first two years' work and the 1980 meeting were accordingly devoted to exploring the reliability of available data sets.

3 Difficulties in Turbulent Flow Research Affecting the Conference

Even though excluding turbulent flow involving changes in phase, heat transfer, and chemical reactions and limiting consideration to turbulent flow of a single, pure Newtonian fluid, the 1980–1981 Conference still faced a wide variety of complex flows which occur in practice and for which the characteristics must be known. Experiments have shown that turbulence does not have a single, simple structure, and its structure is greatly influenced not only by the initial and boundary conditions, but also by a score of effects such as body forces, surface roughness, curvature, etc.[9] There are therefore many flows requiring experimental investigation. Many of these flows present severe set-up problems in conventional laboratories. In most cases the laboratory experiment needs to be idealized in order to help clarify the phenomenon to be investigated. However, the idealization can change the phenomenon to be be investigated. Thus, the practical case may only be uncovered when a sufficient range of conditions have been explored in the laboratory tests. Consequently, a large number of experiments are required in order to clarify the description of the turbulence structure and its influence on the flow fields for practical situations. The 1980–1981 Conference has considered some 40 different classes of turbulent flows. These classes were of necessity constrained by the existence of adequate data, rather than by an ideal taxonomy of constraints and effects. Thus, other

[6] The remarks of D. Humphreys and B. van den Berg on three-dimensional boundary layers are particularly detailed and thorough.

[7] The 1968 Conference was fortunate in being able to use more than a decade of insightful work by D. E. Coles of C.I.T. on the relevant data, thus providing an existing data base.

[8] Certain exceptions were noted; specifically, detachment, reattaching layers, and the near zone of free shear layers. This information has helped to focus research during the following decade, with the result that important progress on all these problems has been made and efforts on the already solved problems have greatly diminished.

[9] A list of such effects is given in the Introduction to the 1980 meeting by the first author.

flows still need detailed investigation in order to provide a basis for trial cases.

Measurements within turbulent flows have always presented difficulties in the data collection, and even with modern methods of data-taking continue to do so. The instruments used, whether hot wires or laser anemometers, need frequent calibration, and have considerable uncertainty in resulting measurements. Thus, analysis of uncertainty becomes important in judging adequacy of computation.[10] The assessment of the uncertainties in the data for the test cases presented at the 1980 meeting was a major task for the Data Evaluators. A paper by R. J. Moffat at the 1980 meeting provides two major advances beyond the existing JFE standards for uncertainty analysis.[11] In particular, Moffat provides: (i) a method for systematic incorporation of uncertainty analysis into data-collection and reduction processes; (ii) the construction of a hierarchy of levels of replication, each of which has a specific use as the basis for operational checks on the adequacy of actual experimental control.

This brief section states only some of the difficulties in turbulent flow measurement that affect the work of the conference. A more complete discussion of the difficulties is given in the Introduction to the Proceedings of the 1980 meeting by the first author. Discussion of particular problems occurs at numerous places in the reports on data evaluations, discussions, and reports of ad hoc committees.

4 Organization of the Conference

An Organizing Committee was set up in 1977 to create the workshops for the 1980 and 1981 meetings. The Organizing Committee includes: S. J. Kline (Chairman), P. Bradshaw, B. Cantwell, B. Launder, E. Reshotko, M. Rubesin, and G. Sovran.

The task before the Organizing Committee for the 1980–81 Conference was far more complex than in the previous conferences held in 1968, 1969, and 1972, for four reasons:

- The flows needed for consideration were more diverse and complex and were selected as representing examples of most of the basic turbulent flows occurring in practice.
- No sound data base existed in 1977; accordingly, one had to be created.
- Computational methods have advanced considerably since the 1968–1972 era and are now more complex, more varied, and far more expensive to run.
- Adequate review procedures for very large programs did not exist.

The plan of work created by the Organizing Committee set three goals:

(1) The creation of a data base of trustworthy experimental cases and specifications of "trials," using those cases against which computations can be tested comparatively (task of data evaluators and the 1980 meeting).

(2) The creation of a data library on magnetic tape which will hold those trustworthy cases, together with complete descriptions and data lists. The tapes will be held in repositories in USA and EEC countries and will be generally accessible, for a moderate fee (an ongoing task).

(3) Comparison of outputs of computations from many groups of computors with the standard "trial cases" of item (1) (Task of the 1981 meeting).

Work toward Goal (1) included the efforts of some 30 groups of data evaluators during 1979 and 1980. Each flow was evaluated by a leading expert (the Data Evaluator) and reviewed by several other experts. The combined evaluations and reviews were presented to the 1980 meeting in twelve sessions and were followed by evening meetings to establish a consensus on which flows met the criteria for trustworthy data adequate to be used for test cases and in the formulation of new computer models of turbulent flows.

The 1980 meeting also brought into sharper focus a number of underlying but sometimes neglected questions, including:

(*a*) The uncertainty in various classes of critical measurements, such as in hot-wire measurements.

(*b*) Procedures for improving uncertainty estimates of data.

(*c*) Discussions of appropriate means of comparison of computations and experiments in the light of uncertainties in both.

(*d*) The establishment of general rules and guidelines for future data-takers concerned with experiments intended to be the basis for turbulence modeling or comparison with computations.

(*e*) Detailing the needs for data in computational fluid dynamics as a class of experiments, and delineating flows needing improved data bases.

(*f*) An increased emphasis and understanding of the need for iterating between data and computation.

(*g*) Focusing on the need for a means to differentiate errors arising from "numerics" from those owing to deficiencies of turbulence models.

The 1980 Conference was attended by 181 invited participants from 12 countries (Australia, Canada, France, India, Japan, Norway, Sweden, Switzerland, United Kingdom, United States of America, West Germany, and Yugoslavia).

5 Test Cases for 1981

As a result of the work of the Data Evaluators and the presentations and discussions held at the 1980 meeting, approximately 50 Test Cases (30 incompressible plus 20 compressible) have been selected as broadly meeting the criteria laid down for "trustworthy experimental data sets." A detailed specification is being provided for each test case delineating computations to be done, and plotted in prespecified form for comparison. Except in a few special cases, computations are specified only where trustworthy data exist.[12]

The Test Cases have been subdivided as follows:

A. Simple Case: Shear layers or homogeneous flows (at the level of the 1968, 1969 and 1972 meetings).

B. Entry Case: A test case that is more complex than type A and thereby meets the entry requirement for presentation at the 1981 meeting.

C. Central Case: Four entry cases (two incompressible, two compressible) selected by the Organizing Committee as being sufficiently important as a test of turbulence modeling, numerics, and the current state of the art to warrant requesting as many computers as possible to submit computations in order to provide dense results to improve the learning process.

D. Predictive Case: A case for which only the initial conditions and geometry are given in the specification. Data are being taken in parallel with the computations and will be compared in the 1981 meeting. Four such cases will be used in the 1981 meeting.

The *Simple Cases* include attached, two-dimensional

[10] In the 1968 cases, the data uncertainties are generally small compared to uncertainty of computation, so that the issue of uncertainty analysis was far less important.

[11] "Analysis of Uncertainty in Single-Sample Experiments," S. J. Kline and F. A. McClintock, in *Mech. Engrg.*, Jan. 1953, or equivalent.

[12] The second author collated, integrated, and in some instances arbitrated the numerous recommendations for improvement of test cases arising during the 1980 meeting.

boundary layers with pressure gradient in incompressible flow and a considerable number of incompressible homogenous flows. (The homogeneous flows are particularly important to model formation, and computors requested extensions of the data set; this has been done.)

The *Central Cases* for incompressible flow include a curved free-shear layer and a backward-facing step, while for compressible flow they include a well-documented transonic airfoil and a compression corner at $Ma = 3$.

The *Entry Cases* in incompressible flow include: conical diffusers with low and high inlet turbulence; the effect of freestream turbulence on a boundary layer; separating and separated flow in a passage; boundary layers with strong convex and concave curvature; boundary layers with blowing and suction; the near-wake of a circular cylinder; a stalled two-dimensional airfoil; secondary flows in a wing-body junction, in a curved rectangular channel, and in a square duct; equilibrium, self-preserving, and three-dimensional wall jets; relaminarizing boundary layer; relaminarizing tube flow; development and asymptotic state of a mixing layer; symmetric and asymmetric two-dimensional wakes, and other cases.

The *Entry Cases* in compressible flow include: a supersonic boundary layer with blowing; boundary layers with three-dimensional and axisymmetric shock impingement; shock-separated boundary layer on transonic airfoils at zero lift and incidence; normal shock wave/boundary layer interaction; transonic flow over axisymmetric and two-dimensional bumps; cone at incidence in supersonic flow, and other cases.

The *Predictive Cases* for incompressible flow include: the developing flow in a square duct with a non-uniform velocity profile at inlet; sudden expansions in ducts of varying geometries. Unfortunately, no predictive cases for compressible flow will be completed soon enough for use in the 1981 meeting.

It is expected that about 50 computor groups will provide computations in time for the 1981 meeting. Of that number, about 16 groups have declared an intention to tackle ten test cases or more. Standard plots are being supplied for each case, so that direct comparison of results will be possible. Problems concerning difficulties in numerics, methods for disclosure of numerical codes, computing times, and computing difficulties (including methods which do not work) are all matters which will be discussed at the 1981 meeting.

The 50 Test Cases chosen for the 1981 meeting do not exhaust the data sets available which meet the criteria discussed previously. Some 20 other Test Cases are available for inclusion in the Data Library. In addition, more than a dozen other classes of flow have yet to be evaluated and remain as possible future additions to the library.

It will be noted that the 50 selected Test Cases do not include incompressible flow in three-dimensional attached boundary layers and flows with swirl. (Such flows form a vital component in the prediction of airfoil and wing performance at subsonic and supersonic speeds and in combustion systems, respectively.) These flows were studied by Data Evaluators and were presented at the 1980 meeting. They were recommended by the 1980 meeting, but regrettably were not completed soon enough to be available for selection as Test Cases for the 1981 meeting. They will be made available for later testing and discussion through the data library and will, therefore, be available as a basis for later meetings.

In addition, several important classes of flows were evaluated in which the Data Evaluators reported deficiencies in all data so severe that they did not meet the criteria laid down for possible Test Cases. These flow cases include: three-dimensional flows other than boundary layers; complex wakes, including ship wakes, wakes from buildings, and the flow around protuberances from solid surfaces: turbulence-turbulence interactions; strongly non-equilibrium flows; laminar-turbulent transition; and flows with distributed buoyancy effects. Further experimental work on each of these flows is an urgent task for the future. Experimental groups engaged in work on these flows are advised to refer to the reports of the Data Evaluators and to the Proceedings of the 1980 meeting, to ascertain the nature of the deficiencies in the existing data sets as a guide to future research. They are also urged to note the recommendations for future data-takers, with particular reference to uncertainty checks and experimental control.

6 Special Problems Discussed at the 1980 Meeting

Because of the presence of so many experienced experimentalists, the 1980 meeting provided a special opportunity to discuss and report on difficulties that frequently arise in experiments on turbulent flows. The following account includes brief remarks on several such topics and issues which arose during the course of discussion or were the subjects for the Special Committees set up during the meeting. The complete reports will appear in the Proceedings.

(*a*) *The Effect of Initial Turbulence Conditions on the Development of Free-Shear Layers and Wall Boundary Layers.* This question arose several times during the meeting and was the subject for a Special Committee under the chairmanship of Professor H. Nagib. The problem is not one of academic importance only; there have been several recent applications which rest on modification of the large-scale turbulent structure in a shear flow, with subsequent significant changes in the downstream development. The possible applications include enhanced mixing, increased heat transfer rates, and reductions in surface drag. The Committee proposed that advanced computer-prediction schemes for turbulent flow should be tested for their sensitivity to the initial conditions, specifically changes in the spectral distribution of the turbulent energy over the "inlet" flow plane.

(*b*) *Uncertainties in Hot-Wire Fluctuation Data at Low Mach Numbers.* This was the subject of a Special Committee chaired by Professor B. G. Newman. The complete report includes much important practical information for use by experimenters relating to: uncertainty analysis; drift; measurement of dissipation; integrating times; measurements in high-intensity turbulent flows; measurements in reversed flows; and the circumstances which warrant replacement of the hot wire by the laser.

(*c*) *Turbulence Measurements in Transonic and Supersonic Flows.* This was the subject of a Special Committee chaired by Professor E. Reshotko. There was general agreement that the continued use of the hot wire is recommended, even though output uncertainty is more than 15 percent in the transonic zone. The laser-doppler anemometer is found to give only limited information on temperature and density fluctuations. Some redundancy checks using both the hot wire and the LDA are badly needed at this time.

It was also agreed that turbulent flow measurements in transonic and supersonic flows require more careful preplanning than in low-speed flows; a greater number of measurements are required, although the usable data are fewer than in low-speed flows; the experiments are much more expensive to run; as a result of these factors, more attention to the uncertainty analysis is needed.[13] As a result of these factors, there is much less agreement concerning what

[13] Paradoxically, uncertainty analysis appears to have been used far less in these difficult compressible cases than in incompressible flows, apparently owing to historical rather than logical reasons.

constitutes "trustworthy data" in transonic and supersonic flows.

(*d*) *Experiments and computations on Free-Shear Layers or Mixing Layers.* This Special Committee was chaired by Professor F. Champagne. The Committee made recommendations with respect to suitable "trailing edge" geometry for both two-dimensional and axisymmetric flow where, in the latter case, the first two diameters are assumed to be a reasonable simulation of a two-dimensional (planar) mixing layer. Also discussed were levels of free-stream turbulence which are likely to have little effect on the structure of the mixing region and the initial conditions for the boundary layer at the trailing edge.

(*e*) *Shock Waves in Turbulent Flows.* In discussing transonic and supersonic flows at the 1980 meeting, the question of the location of the shock wave and its independence with respect to time was raised frequently. No clear answer was forthcoming to this question. Many experimentalists were agreed that, where the mean flow field remained steady, observations of the shock wave appeared to show it was steady also. However, others suggested some residual unsteadiness of shock waves is generally observed, and there was no evidence available to prove conclusively that a shock wave immersed in turbulent flow does not undergo oscillations owing to effects of turbulent fluctuations. This is a topic that also calls for future careful experimentation.

(*f*) *Two-Dimensional Flow.* Recurrent questions were, "What constitutes a two-dimensional flow?" and "What measurements need to be made to provide acceptable experimental confirmation that a given flow is two-dimensional?" The meeting agreed that the questions can be answered only by taking suitable control-volume measurements of rates of mass and momentum flux. There was agreement that a flow could not be certified as two-dimensional simply because the mean flow was relatively independent of the spanwise location.

7 Position Papers Presented at the 1980 Meeting

Three Position Papers were presented to the 1980 meeting and will be reported in full in the *Proceedings* of that meeting. They are:

(i) The Data Library, by B. Cantwell

(ii) Contributions to the Theory of Uncertainty Analysis for Single-Sample Experiments, by R. J. Moffat.

(iii) Experimental Data Needs for Computational Fluid Dynamics, by P. Bradshaw, B. Cantwell, J. Ferziger, S. Kline, M. Rubesin, and C. Horstman.

Some information on (i) has been given above indicating the importance of the existence of the library for the work of the 1980–81 Conference and its continuing function.

The importance of uncertainty analysis in controlling experiments, the need for wider use of such analysis, the importance of uncertainty bands in comparing computation with experiments, and the nature of the new contributions by R. Moffat have all been covered earlier in paper (ii).

Paper (iii) provides a starting point for the clear delineation of the interaction between experimental data and computational fluid dynamics which is central to the 1980–81 Conference. Study of this paper should be useful for nearly anyone involved in experimental or computational fluid dynamics at this time.

8 Conclusions

(i) The 1980 Stanford meeting is best looked on as a successful, impartial, cooperative effort of a large fraction of the experimental fluid mechanics experts in reaching a consensus concerning: "what currently available experimental data on turbulent flows are sufficiently trustworthy to be used as inputs to turbulence modeling and/or a basis for standard "trials" for checking outputs of computations?"

(ii) The central conclusion of the meeting was that about 70-100 sets of such data are suitable as Test Cases within the framework of Complex Turbulent Flows; of these sets, about 50 will be used as Test Cases for the 1981 meeting.

(iii) No adequate data exist for some complex flows nor in general for any *very* complex flows such as flow behind three-dimensional bluff bodies; collection of such data remains a task for future research. The 1980 meeting showed there is need for many more experimental investigations of high quality for some classes of turbulent flows. Recommendations regarding the planning of these experiments, the care needed in setting up the initial conditions and in continuously monitoring uncertainty analysis and deserve checks are all matters considered at the Conference. Considerable detail on these matters are reported in the *Proceedings*.

(iv) Increased interaction appears to be needed between computors and experimentalists in fluid dynamics in order to close the loop iteratively between experiment and computation and thereby speed progress.

(v) Contributors to the 1980 meeting repeatedly stressed the importance of initial and boundary conditions in many complex turbulent flows. They also emphasized the need for more careful reporting and documentation of those conditions than has usually been the case in the past.

(vi) The period involving preparations for the 1980 meeting as well as the meeting itself appears to have been a period of great stimulation and hence of accelerated learning in turbulent flow research. The full fruits of this learning will not be evident until the 1981 meeting is completed and the results digested. What the learning process has already made very clear is that turbulent flow research is of such magnitude that the resources of one laboratory are insufficient to the totality of problems in providing and assessing reliable data sets, or in evaluating the many developing methods of CFD to practical applications. Thus, cooperation among research workers on the scale associated with the 1980 meeting has many advantages and is probably essential if the opportunity to move toward adequate prediction of complex turbulent flows is to be realized in an effective manner.

(vii) It seems likely that the 1981 meeting will confirm that the progress made in CFD is such that, given time, many complex turbulent flows of the types used as Test Cases for the 1980–1981 Conference will be computable to an accuracy satisfactory for engineering and other applications, provided the initial and boundary conditions are adequately specified. Major questions remaining to be assessed by the 1981 meeting include: (i) the current extent of progress in predicting complex turbulent flows, (ii) the likelihood of constructing a single turbulence closure model that is both sufficiently accurate and computationally not-too-slow for a wide variety of flows, or on the contrary, whether a variety of closure models will be needed to fulfill the requirements of engineering prediction.

(viii) At this stage of the 1980–1981 Conference, it is important to emphasize that neither the requisite experimental data base nor CFD methods will be completed by the 1980–1981 Conference. Further work on the Data Library will be required, and development of the computational methods will be far from concluded. Despite this, if the rate of progress in the highly useful assessment of the 1980 meeting can be maintained, the 1981 meeting will conclude with a state-of-the-art in the prediction of, and a solid core of test cases for use in assessing further progress in, computation of complex turbulent flows. The authors are grateful for having had the opportunity to play a role in this challenging and important research task.