Numerical Simulation of Unsteady Flows and Transition to Turbulence

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Table of Contents

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Preface

Following the formation of ERCOFTAC it was decided to organise a major ERCOFTAC workshop comparing experimental measurements of complex fluid flows with computations. The organisation of the meeting was entrusted to EPFL under the shared responsibility of Professors I.L. Ryhming (EPFL) and O. Pironneau (INRIA). The ERCOFTAC Scientific Committee was charged with the selection of suitable 'test cases' in the areas of turbulence and combustion. The committee met several times under the chairmanship of Professor B. Spalding which eventually decided that, ideally, three sessions would be needed: one exclusively concerned with turbulent flow phenomena, another involving combustion only and, lastly, to bring the communities of turbulence and combustion specialists together, to have a session dedicated to the study of combustion in strongly turbulent flow fields. However, since flows involving both turbulence and combustion have not yet been investigated in sufficient detail to enable comparisons to be made with computational models, this aspect of the workshop was postponed until the ERCOFTAC Summer School and workshop on combustion in 1992. This workshop was held on 26-28 of March 1990, at EPFL in Lausanne, Switzerland, and it was attended by more than 90 researchers representing 38 academic and industrial organisations from 12 countries (not only from Europe).

Despite the fact that industrial and academic research groups often focus on quite distinct problems the test cases at this workshop were generally acknowledged to be interesting to both these constituent parts of the ERCOFTAC research community. For the effective evaluation of the computational methods measurements of the test case flows and their documentation were undertaken especially for this workshop and the main results of these studies are published in these proceedings. Most of the computational methods that are in common use by the academic and industrial communities were applied by one or other of the 'computer' groups to the different test cases; the reader of this volume will have a unique overview of the different methods. The Workshop concentrated on the following turbulence test cases:

T1: Boundary layer in an S-shaped duct
T2: Periodic array of cylinders in a channel
T3: Transition in a boundary layer under the influence of free-stream turbulence
T4 & T5: Axisymmetric confined jet flows

In the first test case the object was to predict the flow at high Reynolds number of a three-dimensional boundary layer in an S-shaped duct, the turbulence modelling required for this flow was either a general 'Navier-Stokes' solver, or a code specific to three-dimensional boundary layers. The S-duct geometry allows one to follow the continuous development of the mean-flow and of the Reynolds stress fields over a significant downstream distance (of the order of 30-40 boundary layer thicknesses). In particular, the flow field develops 'cross-over' velocity profiles along the boundary layer, a feature that has not previously been investigated in detail. In this type of three-dimensional boundary layer flow the pressure gradients and shear stress drive a secondary flow motion, while the action of the side walls further add to the secondary flows, a common feature of flows in curving ducts. Such three-dimensional flows have to be calculated in many engineering designs such as industrial aerofoils, centrifugal impellors, and complex forms of ducts. This flow is also useful for testing the prediction of viscous internal flows in ducts as well as for general three-dimensional turbulent boundary layer flows in the presence of confining side walls.

The second test case involved transition to turbulence in a complex geometry, and the ability of direct simulation, using the full Navier-Stokes equations, to predict it. The proposed problem arises in the study of the cooling of computer boards where it is desirable to increase the efficiency of air mixing induced by the introduction of metallic rods between two parallel plates. It is not obvious, without calculation or experiment, whether these will retard or enhance mixing. Hence the importance of the study. An idealised flow was considered consisting of a periodic array of cylinders between two infinite parallel walls. These studies are of considerable relevance not only to industrial applications but also to computational studies involving internal boundary conditions in infinitely long domains. In this case turbulence modelling is not relevant because in the industrial application the problem of the Reynolds number range is too low for the fully developed turbulence to exist, but high enough for the flow to be unstable and for the cylinders to have a significant effect on the growth of instabilities. Therefore conventional methods for the time mean quantities in fully developed turbulence are not appropriate; instead computational models have to solve the equations fully inducting all the unsteady effects.

The third test case dealt with the effect of free stream turbulence on the transition to turbulence in a laminar boundary layer on a flat plate and was intended to evaluate methods which can reliably predict transition and the consequential variations of the boundary structure and surface skin friction. Interest in studies of transitional boundary layers is motivated by the quest for improvements in the performance, in the handling flow qualities and in the control of boundary layer flows in engineering applications. In the complex physical processes involved in the transition phenomena, the main mechanism responsible is the Tollmien-Schlichting instability in low free-stream turbulence intensity. At higher free-stream turbulence intensities the linear stage of the transition is bypassed in favour of some other transition phenomena. This switch-over in transition mechanism presents severe problems for prediction methods since the models were primarily developed for fully turbulent flows. Two approaches were used by the 'computers', one based on the empirically adjusted use of ensemble averaged turbulence models and the other on the full simulation of the time dependent flows.

Finally the fourth and the fifth test cases concerned the prediction of confined axisymmetric jet flows with varying degrees of geometrical complexity: in T4 the jet is within a slightly divergent duct and the conditions approximate to those of the Craya-Curtet similitude theory, whereas in T5 the jet exhausts into an open space. The flow T4 occurs in many mechanical and chemical engineering flows, while the flow T5 is found in axisymmetrical burners. The difficulties of computing confined jets are caused by the presence of adverse pressure gradients, the recirculation with unfixed separation and reattachment points as well as the coexistence of both strong and weak shear regions. The prediction of all these factors depend sensitively on the turbulence models, on numerical schemes, and on the boundary conditions.

For test cases 1 and 3, the computers were not informed of the data before the workshop (though experienced groups had a shrewd idea of what they might be and adjusted their codes appropriately). Concequently the workshop was quite an exciting event as the data and the predictions were compared. In the other test cases many (but not all) of the computers were aware of the experimental data.

As will be seen in the pages that follow, the current prediction methods when used with skill by experienced users are capable of predicting well some general features of flows selected for the Workshop. Improvements in accuracy are shown to result from newer prediction methods which take more account of the flow history. Specific computational aspects, such as grid dependence and sensitivity on initial conditions, require further development. These limitations are most marked in flows affected by separation. The workshop also indicated that more detailed experiments are required to shed further light on the relative performances of various prediction methods with different turbulence models.

At the conference three general lectures were given on 'Developments in Computational Modelling of Turbulent Flows' by Professor J.C.R. Hunt, on 'Transition Description and Prediction' by Dr. D. Arnal, and on 'Recent Numerical Simulations of Compressible Navier-Stokes Flows' by Dr. J. Périaux. These lectures are included in these proceedings and provide an introduction to some of the developing techniques used in computational modelling of complex industrial flows at high Reynolds number and the assumptions and difficulties associated with their use.

Despite the success of the Workshop, much still remains to be done before reliable simulations can be carried out in any one of the areas of turbulence covered by this first ERCOFTAC Workshop. The Workshop identified both strong and weak aspects of computational modelling which was one of the main objectives of the ERCOFTAC Scientific Committee.

Prof. I. L. Ryhming