ERCOFTAC's role in promoting Computational Fluid Dynamics

Le rôle d'ERCOFTAC dans la promotion de la dynamique des fluides numériques

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La simulation numérique des fluides est de plus en plus importante pour les projets industriels. En Europe ERCOFTAC s'occupe d'un grand nombre de secteurs industriels qui pourront avoir des demandes spéciales pour simulations numériques. La promotion de la simulation numérique en mécanique des fluides par ERCOFTAC dans le domaine de l'écoulement, la turbulence et la combustion se passe de quatre façons. Ce sont le Développement des modèles et Calculs de Comparaison, la Qualité et Fidélité pour la dynamique des fluides numérique (CFD), la Collection de Données d'écoulements numériques et expérimentales et l'incorporation de résultats dans les logiciels commerciaux. Le rôle important des Groupes d'Intérêt Spécial (SIG) pour le Développement des modèles et Calculs de Comparaison est clarifié. L'initiative de "Qualité et Fidélité" a produit un Guide pour simulations numériques de qualité. Le produit suivant sera une série de Procédures d'Application de CFD. La Collection de Données d'écoulements numériques et experimentales est disponible sur le Web. Une étude locale aux Pays-Bas montrera les possibilités d'incorporation des résultats dans les logiciels commerciaux.

I ■ INTRODUCTION

ERCOFTAC, the European Research Community On Flow, Turbulence and Combustion, was created in June 1988. An important objective of this community with members from research institutes and industry is to strengthen the research base on Flow, Turbulence and Combustion and to improve the quality and relevance of its output to industry and government. This means involvement in both generation and transfer of technology on Flow, Turbulence and Combustion. This objective is achieved by working on a European scale with Pilot Centres (PCs) and Special Interest Groups (SIGs). For exchange of information and stimulating research ERCOFTAC conferences, workshops, summerschools and courses are being sponsored. The Pilot Centres are the national/regional contact points within ERCOFTAC, responsible for co-ordinating local research activities and arranging local meetings. They stimulate the local members to transfer technology to the local industries and government institutes and participate in Special Interest Groups. Reports on activities of the Pilot Centres and SIGs are published in the ERCOFTAC Bulletin that is widely distributed amongst the members and is available at a modest fee to non-members.

The Special Interest Groups are international groups with industry and research members. Special Interest Groups (SIGs) cover a specific topic or application area in Flow, Turbulence and Combustion, and may undertake collaborative programmes of research or technology transfer arising from common interest. A full description of SIG activities may be found in the survey that Wolfgang Rodi assembled together with the SIG co-ordinators on the occasion of ERCOFTAC's 10th anniversary [1]. SIGs currently are active on :

- Large Eddy Simulation,
- Turbulent Boundary Layers,
- Turbulence in Compressible Flows,
- Atmospheric Flow, Turbulence and Dispersion,
- Turbomachinery,
- Transition Modelling,
- Dispersed Turbulent Two-Phase Flow,
- Stably Stratified and Rotating Turbulence,
- Turbulence Modelling,
- Parallel Computing in CFD,
- Drag reduction and flow Control,

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- Vortex Dynamics,
- Variable Density Turbulent Flows,
- CFD for Ship Hydrodynamics,
- Aerodynamics and Steady State Combustion Chambers and Furnaces,
- Wind over Waves,
- Particle Image Velocimetry,
- Transition Mechanisms, Prediction and Control,
- Quality and Trust in Industrial CFD,
- ERCOFTAC Database.

As noted by Julian Hunt in his speech on the occasion of ERCOFTAC's 10th Anniversary [2] :"SIGs were not envisaged in the original planning for ERCOFTAC. At the time the founding fathers saw Pilot Centres in each country as driving forward our collaboration. However, Phil Hutchinson at Cranfield suggested that SIGs would be the best way for involving a wider number of groups in ERCOFTAC including those who were not necessarily working closely with the PCs. He has been proven quite correct."

II ■ NUMERICAL SIMULATIONS

In his 10-year anniversary speech Julian Hunt notes that the most striking change in the research papers in the ERCOFTAC Bulletin and all other journals in our subject has been the increasing use of numerical simulation to supplement and even replace experiments and statistical modelling. This has been particularly marked in studies of turbulence and combustion. He also quotes some impressive achievements : "Computational processing speeds having increased by about 100 times over this period, Direct Numerical Simulation can now completely describe many flows of practical significance up to Reynolds numbers (based on eddy scales) of the order of 300. In a recent study with 50 x 10^6 points it was possible to simulate turbulent spots in a boundary layer undergoing forced transition, but it took more than 600 hours. DNS simulations of combustion now model the flickering flame with 60 or more chemical reactions added to the fluid and thermo-dynamics. It has been possible to use the method of Large Eddy Simulations in flows with more complex geometries such as round pipes, engine systems and bluff bodies and at higher Reynolds numbers. New techniques have been developed for modelling the smallest scales of motion including so that they can adjust automatically to the flow situation, especially near rigid surfaces and, for some purposes, have an appropriate stochastic element". For further information I refer to the details and the references that can be found in the article in the Bulletin [2].

Also in the field of computational two-phase flow impressive progress can be reported [3]. Thanks to the developments in the numerical simulation of turbulence in complex geometries with Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES) it now becomes possible to study the effect of fluid and solid particles. Sommerfeld [4] has studied the importance of inter-particle collisions in horizontal gas/solid channel flows with due account of the wall roughness. EDF-Chatou has derived a new expression of the fluid eddy-viscosity for the k-epsilon turbulence model accounting for the modulation of turbulence by the particles. This expression, consistent with single-phase flow modelling approach, has been derived from the Reynolds stress transport model equations. The modification was written as a function of the correlation between the particle and fluid turbulent velocities and might be important for flows highly laden with coarse particles, strongly de-correlated with the gas [5]. Using a Lagrangian approach and DNS/LES calculations for turbulent flow in a vertical tube the effect of particle segregation could be shown to be highly dependent on the particle size distribution [6]. This aspect of segregation was novel, since it was at the time beyond our experimental capabilities.

These examples, however impressive they may be, are achievements of the fluid flow community. That they are reflected in the ERCOFTAC Bulletin indicates that the members make progress in line with their scientific peers, but they are not as such a special credit of ERCOFTAC. What is the role of ERCOFTAC in promoting numerical simulations of Flow, Turbulence and Combustion ?

III ■ ERCOFTAC'S ROLE IN PROMOTING CFD

In promoting numerical simulation of Flow, Turbulence and Combustion a vital part is played by the SIGs. If we look at the fields currently covered by the SIGs 6 out of 20 have a direct relation with CFD : Large Eddy Simulation, Turbulence Modelling, Parallel Computing in CFD, CFD for Ship Hydrodynamics, Quality and Trust in Industrial CFD and ERCOFTAC Database. There are also SIGs, for which the emphasis lies on experimental techniques (i.e. PIV : Particle Image Velocimetry) or in studying a specific technology (i.e. Drag reduction and flow control). In most of the other SIGs CFD plays a key role as well, since it is widely recognised that an effective means for enabling technology transfer from academia to industry is via the development of flow simulation codes and the associated computational infrastructure.

When one studies the SIG reports over a 10-year period, you see that most of the SIGs address their subject by a balance between numerical simulation, experimental research and theoretical modelling. At the workshops the SIGs organise the members from research and industry are invited to bring along test cases for evaluating numerical procedures. Requiring contributors to also submit results obtained with standard models identifies the effect of numerical errors. This aspect is particularly important for engineers from industry, who use the user-friendly commercial codes, and are curious to obtain insight into the reliability of the results for flow conditions of their interest. It is important to decide together on the flow configurations that are used as benchmark cases. For the complex industrial flow problems quite often a suite of flow configurations with varying complexity is required to gain sufficient insight into the numerical capabilities of the computer codes. Whenever the experimental data are judged reliable, while performance of the models is deemed insufficiently established, the test case in question is carried over to the next workshop.

The outcome of the workshops is summarised in various issues of the ERCOFTAC Bulletin. Regularly a SIG is asked to publish its findings in a theme issue of the Bulletin. In 1999 the March and September issues were devoted to the themes Turbulence modelling and Turbomachinery. They show the state of the art of numerical simulation for these topics. They also show, however, new developments in experimental techniques and theoretical modelling. It is a strong feeling that the quality of your CFD development very much depends on your capabilities in doing experiments and modelling of Flow, Turbulence and Combustion. There is an old saying: "He or she, who does not value experiments is not worthy of doing simulations". CFD can always provide nice, colourful pictures of your flow, but for keeping in touch with reality the results of experiments and understanding of the physics are indispensable !

That is also the reason why so much attention is being paid to organising summerschools. Pilot Centres and SIGs receive funds to organise summerschools on a regular basis and publish the handouts as widely as possible. The summerschools are very popular, since they provide the opportunity to present recent developments to scientists and engineers from industry and discuss the needs for further developments as seen by scientists from research institutes and engineers from industry. Typically 30-40 people from all over Europe attend these summerschools. It is an excellent opportunity to meet people, to exchange experience on Flow, Turbulence and Combustion and, perhaps make plans to formulate research programmes to be sent for funding to the EC. In fact, the composition of the SIG membership is precisely compatible with the EC requirements, since it is a group of people from research and industry from a wide number of European countries. In membership status, we are ahead of the EC, since many European countries from the eastern part of Europe are already highly appreciated, and often very active, members of ERCOFTAC.

Still, having the right people meet regularly and generating the right sub-models for numerical codes to address industrial flow problems of increasing complexity is one aspect. Subsequently, ensuring that the new software can be used in practice (i.e. is user-friendly, robust, not too time consuming and provides accurate data) is quite a different matter. It requires some further actions. Important initiatives by ERCOFTAC have been taken for these steps in the technology transfer.

One is the activity on Quality and Trust in industrial computational fluid dynamics [7]. The first phase of this initiative has produced the Best Practice Guidelines, which provide generic advice on how to perform quality CFD calculations [8]. The guidelines address mesh design; construction of numerical boundary conditions where problem data are uncertain; preliminary information regarding the limitations of turbulence models, etc. These guidelines will be made widely available to the European community. ERCOFTAC members receive copies at a special reduced fee, while the paying members of the SIG receive a number of free copies. The phase-2 objective is the compilation of a set of Application Procedures, which will enable engineers to interpret CFD results (carried out according to the Best Practice Guidelines) from a secure position of trust.

Another interesting initiative is that of the ERCOFTAC Database Interest Group, co-ordinated by Peter Voke of University of Surrey. It has as objectives: co-ordinating the evolution of the ERCOFTAC Data Base systems; maintaining the quality, accessibility and relevance of the data sets; raising awareness of the ERCOFTAC Data Base system among users; promoting the creation of suitable data by experimental, DNS, LES, CFD, PIV and flow visualisation specialists; co-ordinating the collection, organisation, formatting and imbedding of data sets in the system; and finally, preparing proposals to raise funds for Data Base activities. Some EU funding is available for this work. (More on the ERCOFTAC database on http://ercoftac.mech.surrey.ac.uk/).

An interesting initiative to bridge the gap between novel model developments hidden in academic, often user-unfriendly, software and the commercial codes that industry uses has been taken by Gijs Ooms, director of the J.M. Burgers Centre, ERCOFTAC's Pilot Centre in The Netherlands. He has set up a CFD Centre, with financial support from Shell, Philips and The Institute of Applied Physics to address the incorporation of recent CFD software, generated by members of the Pilot Centre, into commercial codes. The offered software is in the areas: multiphase flow, combustion, free surface flows, rheology, and advanced numerical mathematics. The first academic software has been built into a commercial code. In September the first year of this CFD initiative ends; it will then be decided on how to continue. It requires support both by industry and the commercial code vendors. The latter are not interested in nice, sophisticated model developments, but in substantial improvements of their capabilities to address complex industrial flow problems. The code vendors are only willing to invest time and money, when there is a considerable market for the enhanced CFD capability. A complication is that ERCOFTAC members span a wide range of industry related sectors: aerospace technology, power generation, automobile and ships, classical and renewable energy generation, chemical processes, civil engineering, environmental measures. These have strongly varying demands for CFD on flow, turbulence and combustion. It would be worthwhile to bring this initiative to a European level and involve all industrial sectors and code vendors to identify academic software generated by the SIGs for implementation into commercial codes. This should occur in close cooperation with the developments on the Quality & Trust and Data Base initiatives. By involving all stakeholders you hope to ensure that we work according to "L'Art pour l'Argent" and not "L'Art pour l'Art" as we are inclined to do, when we are carried away by our scientific curiosity. The ERCOFTAC organisation is well suited to make such an initiative a success. A proper implementation asks for the involvement of specialist software engineers. Funds will have to be raised from industrial members and code vendors. This should not be too difficult, once the impact of code enhancements on industrial sectors has been clarified.

IV ■ EXAMPLE

I will consider the activities of the Special Interest Group on Turbulence Closure Modelling as an example to illustrate how the promotion of CFD for industrial and environmental problems on Flow, Turbulence and Combustion works. I base myself on the special issue of the ERCOFTAC Bulletin of March 1999 on turbulence modelling. In this issue 8 articles were published on the activities of the various participating groups and on special cases of applying turbulence models to already rather complex flows. Examples being strongly swirling confined flows subjected to an anisotropic compression and film cooling at the leading edge of a turbine blade. The editorial article gives a very good impression on the successes and frustrations of promoting a certain kind of turbulence models for complex industrial and environmental flows [9]. Below I will summarize and comment on their findings.

The emphasis of this Special Interest Group was on turbulence closure models for RANS (Reynolds-Averaged-Navier Stokes) equations for the computation of complex turbulent flows of practical relevance. Hanjalic and Laurence observe that "While, admittedly, the RANS turbulence closures have not fulfilled the early expectations, some recent advancements in the second-moment closure and non-linear eddy-viscosity level offer significant improvements and broaden the range of applicability, as compared with the standard linear eddy-viscosity models used by industry". In various workshops over 40 test cases have been considered for which the solutions by different models have been analysed. Early simple benchmark test cases have gradually been replaced by more complex 3D industrial flows, which attracted a larger number of participants. On the other hand, the outcome of the workshops exhibited 'a large scatter of solution'. This seems to have puzzled, if not disappointed, a number of participating academic researchers. They also note "insufficient participation from industry and code vendors".

Now, here a problem from the industrial user's perspective is optimism about model developments, however cautious the scientists may have been in presenting their first results with a new model. We have seen that upon the introduction of the well-known, immediately popular, k-epsilon model as well. Engineers and their managers were impressed by the possibilities and inclined to consider such computational opportunities as the way to get rid of numerous experiments required for scale-up from laboratory to practice. Development of complex closure models for RANS equations requires careful step-by-step comparison with well-defined, often rather simple flow configurations (in the eyes of industry). So, much time and effort has to be spent, before you can endeavour to address the more complex flow problems. We see that industry has become impatient and tends to place all their bets on 'industrial LES (Large Eddy Simulation)'. The authors quite rightly point out that support for both RANS and LES is the way to go to address industrial flows. "While there is some overlapping of LES and RANS approach, each technique has its own field of application, complementing each other. LES and DNS which allow better understanding of turbulence phenomena are limited to cases where the scale of the largest eddies are not less than, say, one tenth of the domain size. In contrast, the turbulence models for RANS aim at producing predictions for high-Reynolds-numbers industrial applications. They are best applicable when the size of the eddies is small compared to the inhomogeneity of the mean flow (they were calibrated mainly in homogeneous and near-equilibrium thin shear flows)." They make a plea for a better collaboration between LES/DNS and RANS model developers to meet the industrial needs. Within ERCOFTAC this means there should be a closer cooperation between the SIGs on Large Eddy Simulation and Turbulence Modelling.

V ■ CONCLUDING REMARKS

CFD is an increasingly important tool in design and operation of industrial equipment. ERCOFTAC spans a wide range of industrial research sectors, which may have their specific CFD needs. ERCOFTAC promotes the use of CFD for industrial and environmental problems in the field of Flow, Turbulence and Combustion in a number of ways. These could be classified as: Model Development and Benchmarking, Quality & Trust in industrial CFD, Data Base Management and Commercial Code Enhancement.

Model Developments and CFD Benchmarking occur in the workshops that are organised by the Special Interest Groups (SIGs). The SIGs consist of European members from research and industry and cover a wide range of topics related to Flow, Turbulence and Combustion. In benchmarking attention is given to detailed test cases for model calibration as well as complex, industrial flow problems for validation. Technology transfer occurs via summerschools and articles in the ERCOFTAC Bulletin.

The first phase of the Quality & Trust in industrial CFD initiative has produced Best Practice Guidelines, providing generic advice on how to perform quality CFD calculations. The phase-2 objective is the compilation of a set of Application Procedures, which will enable engineers to interpret results from a secure position of trust.

The Data Base Management ensures the availability of high quality experimental and numerical (DNS/LES) data for model calibration and industrial code validation purposes. The data can be accessed via the ERCOFTAC web.

Commercial Code Enhancement requires close cooperation and special funding by all stakeholders: members from industry and commercial code vendors. Academic software, generated by the SIGs, qualifies for implementation when clear benefits for industrial sectors can be demonstrated. One could think of generic and sector-specific versions of commercial codes. ERCOFTAC's Dutch Pilot Centre carries out a feasibility study.

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