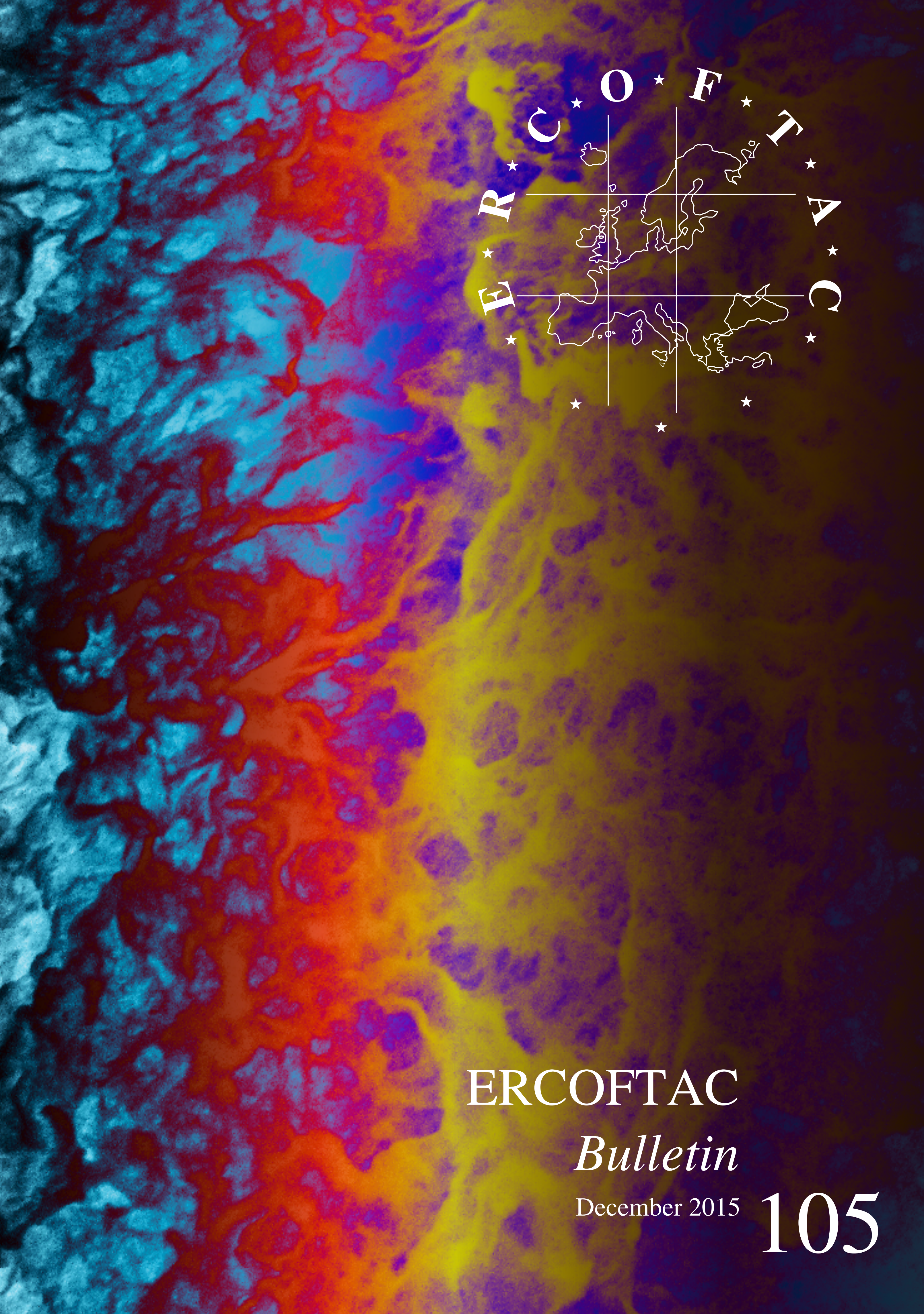

ERCOFTAC

Bulletin

December 2015

105

ERCOFTAC is a leading European association of research, education and industry groups in the technology of flow, turbulence and combustion. The main objectives of *ERCOFTAC* are: To promote joint efforts of European research institutes and industries with the aim of **exchanging technical and scientific information**; to promote **Pilot Centres** for collaboration, stimulation and application of research across Europe; to stimulate, through the creation of **Special Interest Groups**, wellcoordinated European-wide research efforts on specific topics; to stimulate the creation of advanced training activities; and to be influential on funding agencies, governments, the European Commission and the European Parliament.

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Next *ERCOFTAC* Events

ERCOFTAC Spring Festival
April 21st, 2016
Brno, Czech Republic

ERCOFTAC Committee Meetings
April 22nd, 2016
Brno, Czech Republic

The ERCOFTAC Best Practice Guidelines for Industrial Computational Fluid Dynamics

The Best Practice Guidelines (BPG) were commissioned by ERCOFTAC following an extensive consultation with European industry which revealed an urgent demand for such a document. The first edition was completed in January 2000 and constitutes generic advice on how to carry out quality CFD calculations. The BPG therefore address mesh design; construction of numerical boundary conditions where problem data is uncertain; mesh and model sensitivity checks; distinction between numerical and turbulence model inadequacy; preliminary information regarding the limitations of turbulence models etc. The aim is to encourage a common best practice by virtue of which separate analyses of the same problem, using the same model physics, should produce consistent results. Input and advice was sought from a wide cross-section of CFD specialists, eminent academics, end-users and, (particularly important) the leading commercial code vendors established in Europe. Thus, the final document can be considered to represent the consensus view of the European CFD community.

Inevitably, the Guidelines cannot cover every aspect of CFD in detail. They are intended to offer roughly those 20% of the most important general rules of advice that cover roughly 80% of the problems likely to be encountered. As such, they constitute essential information for the novice user and provide a basis for quality management and regulation of safety submissions which rely on CFD. Experience has also shown that they can often provide useful advice for the more experienced user. The technical content is limited to single-phase, compressible and incompressible, steady and unsteady, turbulent and laminar flow with and without heat transfer. Versions which are customised to other aspects of CFD (the remaining 20% of problems) are planned for the future.

The seven principle chapters of the document address numerical, convergence and round-off errors; turbulence modelling; application uncertainties; user errors; code errors; validation and sensitivity tests for CFD models and finally examples of the BPG applied in practice. In the first six of these, each of the different sources of error and uncertainty are examined and discussed, including references to important books, articles and reviews. Following the discussion sections, short simple bullet-point statements of advice are listed which provide clear guidance and are easily understandable without elaborate mathematics. As an illustrative example, an extract dealing with the use of turbulent wall functions is given below:

- Check that the correct form of the wall function is being used to take into account the wall roughness. An equivalent roughness height and a modified multiplier in the law of the wall must be used.
- Check the upper limit on $y+$. In the case of moderate Reynolds number, where the boundary layer only extends to $y+$ of 300 to 500, there is no chance of accurately resolving the boundary layer if the first integration point is placed at a location with the value of $y+$ of 100.
- Check the lower limit of $y+$. In the commonly used applications of wall functions, the meshing should be arranged so that the values of $y+$ at all the wall-adjacent integration points is only slightly above the recommended lower limit given by the code developers, typically between 20 and 30 (the form usually assumed for the wall functions is not valid much below these values). This procedure offers the best chances to resolve the turbulent portion of the boundary layer. It should be noted that this criterion is impossible to satisfy close to separation or reattachment zones unless $y+$ is based upon $y*$.
- Exercise care when calculating the flow using different schemes or different codes with wall functions on the same mesh. Cell centred schemes have their integration points at different locations in a mesh cell than cell vertex schemes. Thus the $y+$ value associated with a wall-adjacent cell differs according to which scheme is being used on the mesh.
- Check the resolution of the boundary layer. If boundary layer effects are important, it is recommended that the resolution of the boundary layer is checked after the computation. This can be achieved by a plot of the ratio between the turbulent to the molecular viscosity, which is high inside the boundary layer. Adequate boundary layer resolution requires at least 8-10 points in the layer.

All such statements of advice are gathered together at the end of the document to provide a 'Best Practice Checklist'. The examples chapter provides detailed expositions of eight test cases each one calculated by a code vendor (viz FLUENT, AEA Technology, Computational Dynamics, NUMECA) or code developer (viz Electricité de France, CEA, British Energy) and each of which highlights one or more specific points of advice arising in the BPG. These test cases range from natural convection in a cavity through to flow in a low speed centrifugal compressor and in an internal combustion engine valve.

Copies of the Best Practice Guidelines can be acquired from:

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The price per copy (not including postage) is:

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WHITHER TURBULENCE AND BIG DATA IN THE 21^{st} CENTURY?

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April 2015, Cargése, Corsica
http://www.nwrcevents.com/

1 Introduction

Motivation and objectives.

In 1989 Prof. J. Lumley organized a symposium at Cornell University to address key fundamental questions in Turbulence. Researchers from around the world gathered to engage in and debate of fundamental questions about the field of turbulence (See Lecture Notes in Physics Whither Turbulence? Turbulence at the Crossroads, Proceedings, Ithaca, NY 1989, and Editor: John L. Lumley). This volume provides a compendium of the state of the art in our understanding of turbulence as at 1989. It consists of six themes:

1. The utility and drawbacks of traditional approaches
2. Future directions in turbulence research and the role of organized motions
3. Can dynamical systems approach turbulence?
4. The potential and limitations of direct and large eddy simulations
5. What can we hope for from cellular automata?
6. Phenomenological modeling: present and future

Each theme was led by an internationally respected researcher from the USA, India and the UK who provided a "state-of-the-art" lecture and within each theme, other well respected researchers provided different perspectives on and complementarity to those lectures. Each theme was then opened for discussion, and these discussions were dutifully recorded.

While the 1989 meeting was a forum for researchers, it was also one for funding agencies. For the 2015 symposium, it can be definitively stated that with advances in High-performance-computing (HPC) and experimental techniques and theoretical analysis, the field has advanced well beyond what was envisioned 1989 both in the science, and globally in how it is funded. However, the meeting planted seeds in those assembled, which led to the explosion of significant advances since that meeting. We have witnessed the extraordinary insights gained from large numerical databases, how control was improving the efficiencies of what were considered intractable flows (e.g. noise in jets), the emergence of lattice Boltzmann methods as a replacement to cellular automata for multicomponent DNS calculations, and significant advances in LES as a standard for more traditional RANS modeling.

Aims of the event: The 2015 Symposium.

The 2015 Symposium followed the successful workshop at Cornell in 1989 by assembling world leading researchers to discuss turbulence in the 21st century. **The 2015 congress was dedicated to the 70th birthday of Professor W.K. George.**

Turbulence and Intensive Data Management:
Research into the flow physics of turbulence has grown drastically over the last 25 years mainly in part due to the advances in computational fluid dynamics and new experimental capabilities. Yet, it is growing but not at rate one would like especially in terms of societal impacts. The importance of turbulence is evident in many of the areas that impact our daily lives. For example, energy, weather forecast, bio-fluids, aerospace industry and micro-climate modelling for urban flows. The advent of supercomputers and time resolve PIV have led us to new understanding of turbulence (mainly of turbulence structure), and with that new challenges and opportunities to impact society will emerge. One challenge is clearly the amount of data generated that is in the order of Terabytes (e.g. DNS of thermal rough turbulent boundary layers at high Reynolds numbers or in tomography PIV at high Reynolds numbers in Turbulent Boundary Layers). Moreover, the problem of turbulence is not only present in our daily lives, but is one of multiple scales in nature, ranging from micro to scales of the order of kms in the case of atmospheric flows.

Not only we still have the challenge of spectrum of scales, but we also have the challenge of how one integrates such multiple scales in a way we can make accurate prediction of large-scale motions while resolving with high fidelity the dissipative scales.

A case in point is in simulations of atmospheric turbulence from meso-scale to LES in micro-scale turbulence boundary layers using Weather Research Forecast (WRF). Existing models are unable to handle proper parameterization to account for large-scale motion and dissipative scales at the wall; this is imperative in wind hazard applications of urban flows and in our design of the cities of the 21st century (mega cities). In applications of military missions or in emergency response situations it is imperative to predict large-scale events while provide highly resolution simulations of velocity field and particle dispersion.

In 2015, and following the Cargése congress, we seek to extend the legacy of Prof. Lumley's symposium to address key pressing problems still facing the field and to project where the field is going in the next 25 years.

Objectives and Goals of the event.

First, the symposium sought to bring awareness and basic knowledge on the state-of-the-art fluid dynamics research including: modeling, experiments, and simulations.

Second, the symposium provided a cross-disciplinary environment for identifying the current issues and challenges of turbulence for the next quarter century.

Third, the symposium fostered collaborations and students exchange between the USA, Canada, Europe (incl. UK) and Australia.

The goal of symposium was to promote intense discussions to elucidate the grand challenges associated with whither turbulence and big data in the 21^{st} century.

2 Discussion/ Contents of Talks/ Highlights of Presentations and Discussions

Brief outline of the presentations and key discussions points.

Broader Questions:

- What new problems should the community be solving and how we will manage/reduce highly data intensive from numerical and experimental research;
- How to make these data accessible for a broader community in a secure but straightforward manner.

Fundamental Research Questions: There were several key fundamental questions we addressed during the five-day event in Corsica, France, e.g.

- How fundamental knowledge from High Performance Computing Simulations and laboratory experiments can be interrogated to uncover new science for high Reynolds number flows?
- How do we fuse these extensive data and their high fidelity from experiments and simulations for the turbulence community to elucidate new flow physics leading to an enhance ability for societal needs (e.g., energy, emergency response, under water maneuvering and stealth, turbulence noise generation and propagation, military missions in complex terrains)?
- How do we integrate large scale with micro scale flows in micro-climate situations (e.g., urban flows, weather predictions, and wind hazard, wind energy applications)?
- What are the promising avenues to employ advance flow control strategies (flow loop control tools) in aerospace, energy security, and environment sectors?

The organizing committee and participants also addressed the long-standing problem of modeling inflow boundary conditions for developing boundary layers.

<u>In terms of turbulence and wall-bounded flows, the following pressing questions were addressed:</u>

Figure 1: Picture of the participants to the congress, Cargése, Corsica, April 2015

- Increase basic understanding of turbulent boundary layers based on results on scaling variables and dynamic parameters that govern the downstream development of boundary layers under various conditions including the near the wall region.
- Fidelity between simulations and experiments with same external boundary conditions will enable us to further increase our fundamental understanding of the multiscale approach and the interaction between the inner/outer regions of the flow at a large range of Reynolds numbers for under water applications.

Information where the completed proceedings can be found. This will appear in a forthcoming publication in Springer Verlag format (see details hereafter).

3 Summary/Conclusions/Follow-up Meetings

The outcome from the proposed meeting will be a hard-cover volume similar in content to those produced by IUTAM-sponsored meetings. It will contain all papers with verbatim transcriptions of the discussion sessions. The papers will be limited to about 15 pages each. A searchable PDF version will also be produced. The book production will require administrative assistance which is requested as part of the proposal. The volume will be published through Springer-Verlag. The volume will be produced at the beginning of 2016.

Forward of the volume 'Whither turbulence and big data'

It is often said that advances in most fields of endeavour result from "standing on the shoulders of giants", and this meeting is no exception. In 1989 John Lumley, who needs no introduction to readers and researchers interested in turbulence, brought together leading thinkers and doers in turbulence to discuss the then current controversies in the subject as well as to consider the role of public policy (and therefore funding) decisions that help to steer the field in either a direct way or through decisions which have unintended consequences. The meeting was international in scope and attendance and there resulted from this meeting a volume entitled "Whither turbulence? Turbulence at the crossroads." The present volume considers the broad question of "Whither Turbulence" in the context of the ubiquitous network of computers and networks, to which John Lumley was invited and indeed enthusiastically supported: "I am honored...you have my blessing, for what it is worth". This simple statement is a testament to his kind demeanor. Unfortunately, John could not attend due to illness and sadly he passed away in late May 2015.

In the intervening years or so between Lumley's volume and the present one, much has happened and new giants have emerged in this, the oft-said "last unsolved problem in classical physics". While it is unfair to point to anyone in particular, a significant disrupter to and leader in our field is Professor W. K. "Bill" George who was also Lumley's student. From George there have emerged many academic children and now grandchildren, each of whom continue to provide leadership and impact on the field. Given his 5-decade long career, the meeting, details of which are provided within these pages, was dedicated to Bill on the occasion of his 70^{th} birthday.

In 25 years, the world of research in turbulence has changed to where computation and simulation has grown to become the third leg of the scientific stool. In fact, with the web/internet, commodity computing, high performance computing and significant advances in experimental tools, especially particle image velocimetry, it could be said that what was a dream in 1989, say active control of turbulence, is now becoming a reality because the three legs of the stool (theory, simulation and experiment) have each advanced, and Bill has been leading the charge on at least two of those.

However, it remains to be seen what state we will be in 2040, say. The meeting in Cargese began 50 years after Gordon Moore predicted the future of the semiconductor: a doubling of computer processing speeds every two years. A look at Bill Reynolds' paper in the Lumley volume (figure 1, pg. 342) suggests similar growth such that petaflops are now reachable (as at 2008), with exascale computing on the near horizon (expected by 2020). One can imagine even further ubiquitous computational infrastructure, new even more exciting methods, algorithms and most importantly ideas. But a significant issue now is data and this will continue to grow. In 1989, again with reference to Reynolds paper, computer memory sizes were of order gigabytes, while in 2015, terabyte drives are ubiquitous and cheap. An example of drivers for increased data storage and bandwidth is the square kilometer array (radio telescope) that will produce about 30 exabytes of data per month, which will require a doubling of the current internet traffic bandwidth, worldwide! One can imagine while the turbulence community will continue to push the Reynolds number envelope, it will be in combination with other physicochemical processes (e.g. high Schmidt number turbulent mass transfer) over the full spectrum of scales (nano to full scale, including planetary-scale).

Young ERCOFTAC Workshop on Thermoacoustic Instabilities

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12 – 18 April 2015, Montestigliano, Italy

Abstract

A specialized workshop for young ressearchers on thermoacoustic instabilities has taken place in the spring of 2015 in Montestigliano, as part of the ongoing workshop series under the auspices of the Young ERCOFTAC initiative. This workshop, as part of the series, is intended to bring together 10-15 doctoral students and postdoctoral researchers and expose them to relevant and interesting issues in thermoacoustics. The speaker for the 2015 workshop has been Prof. Aimee Morgans from the Department of Aeronautics of Imperial College London. This report gives a brief introduction to the underlying idea of the workshop series, a motivation for the study and importance of thermoacoustic systems and analyses, and a representative exposé of the students? work during the workshop.

1 The Young ERCOFTAC Workshop Series

Starting in 2007 with an initiative by ERCOFTAC to reach out to and foster interactions with young researchers in the fluids, turbulence and combustion communities, a workshop series for mainly doctoral students and but also postdoctoral researchers has been organized in Montestigliano, Italy. The workshops have attracted a great number of graduate students over the years and have resulted in impressive scientific accomplishments as well as the establishment of an associated research community and student network.

The establishment of this workshop series has also been based on the observation that multi- and interdisciplinary skills become increasingly important in many engineering fields, while a standard curriculum of engineering education often fails short in training graduate students adequately in advanced and modern techniques. Doctoral research, i.e., on-the-job training, is often expected to close this gap, but it is difficult and time-consuming to gain expertise by working through advanced literature. What is often needed is a pedagogical exposure to advanced concepts, combined with a hands-on demonstration by working through small-scale yet meaningful examples.

The Young ERCOFTAC workshop series in Montestigliano aims at accomplishing this task by introducing 15-20 graduate students to modern topics in fluid dynamics. While working alongside peers, they are closely supervised by a specialist in the chosen field. The direct involvement in a time-limited project and the immediate access to guidance and expertise is meant to yield a more long-lasting result than a passive lecture series. The workshop typically takes place in beginning to mid April in Montestigliano, a small and remote azienda agricola located about 20 km southwest of Siena. The estate has been an old farm and olive press which has been converted into a cluster of attractive country houses and mansions. It features a quiet and rural surrounding that is ideal for work in a secluded, yet pleasant environment. The remote nature of the accommodation requires the active participation of each and every student in the daily activities, such as the preparation of the communal meals. These activities further contribute to the quick and lasting bonding of the participants that often lasts beyond the duration of the workshop.

The format of the scientific program is laid out to introduce the students (which often have very different backgrounds and are a various stages of their scientific career) to the topic and to set the stage for group work in the days ahead. After the plenary invited lectures and presentations, the organizing committee and the invited speaker will divide the workshop participants into groups of three to four students according to their skill level, experience and scientific maturity. Each group will be presented with a limited yet interesting topic which covers a particular aspect of the invited lecture. The scope of the projects will be limited to typical laptop problems. In the choice of topics, a maximal spread and range will be attempted to illustrate the diversity and applicability of the learned technique. Although each student group will concentrate on one aspect of the technique, they all benefit from an exposure to the other projects during the final presentation of the results; in this manner, the students will, at the end, be proficient in one particular aspect, but knowledgeable in other related details.

The workshop series in Montestigliano has been initiated in 2007 as an attempt to generate interest of young researchers in the core disciplines of fluid mechanics, turbulence and combustion. The topic of the first workshop was Flow control, with the lecture given jointly by Profs. F. Gallaire (EPFL Lausanne) and Peter Schmid (Ecole Polytechnique Paris). A second workshop followed in 2008 on the topic of Model reduction, with the same speakers. In 2010 a third workshop was held on Advanced stability and sensitivity analysis. In 2011 the fourth workshop covered the topic of Derivative-free optimization with Prof. T. Bewley (UC San Diego) and Dr. P. Belitz as principal speakers. This was followed by workshops in 2012 on Fast methods in scientific computing presented by Prof. G. Martinsson (U Colorado

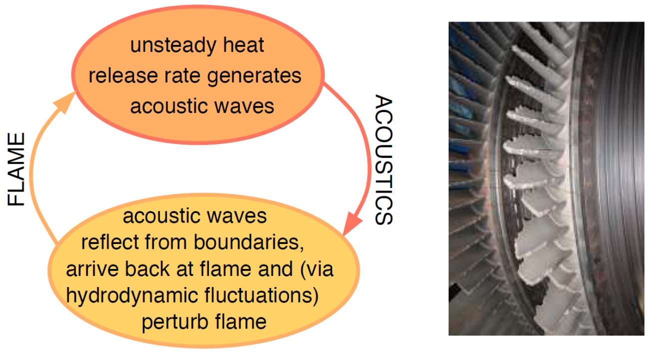

Figure 1: Left: combustion instability mechanism. Right: turbine blade damage caused by combustion instability

Boulder) and in 2014 on Radial basis function methods for scientific computing with Prof. G. Wright (Boise State University). The most recent workshop in 2015 had Thermoacoustic instabilities as the central topic, with Dr. A. Morgans (Imperial College London) as the main lecturer.

Over these years, the workshop series has established itself as a visible component of ERCOFTAC, reaching out to young scientists in the early stages of their careers by generating interest in the issues and topics of flow physics, by providing specialized training opportunities and by encouraging the formation of collegial networks and connections. With this most basic and fundamental level of activity, it is hoped to encourage, educate and foster the next generation of scientists and engineers in the field of fluid dynamics, turbulence and combustion.

2 Topic of 2015 workshop: Thermoacoustic instabilities

Combustion of fossil fuels currently account for 80% of worldwide energy production and meet almost all of the world's aviation power needs. Perhaps surprisingly, the IPCC predict that over the next 20 years, the share of fossil and bio-derived fuels in the overall energy mix will grow, despite anticipated increases in the use of renewable and nuclear energy. Indeed, gas turbines are viewed as a long-term ingredient essential to the overall energy mix, their fast start-up time making them an ideal companion to inconsistent renewable sources, such as wind turbines. A side effect of gas turbine operation is emissions, including NOx gases, which deteriorate air quality. There is a clear need to operate gas turbines as cleanly as possible, in order to harness their benefits while minimising their impact. Recognising this, the aircraft industries in Europe have signed up to an ACARE (Advisory Council for Aeronautic Research) agreement, which commits to reducing NOx emissions by 80%, CO2 emissions by 50% and perceived noise by 50% by 2020, compared to 2000 levels.

Combusting flows are inherent to the operation of all gas turbines. They are complex and multi-physics, with both time and length scales varying over many orders of magnitude, providing a major challenge for the science and engineering communities. According to gas turbine industrialists, one challenge stands above all others as having persisted despite research efforts over many years: combustion instability (or thermoacoustic instability). The flow mechanisms causing this are often complex, but are always underpinned by a two-way coupling between acoustic waves and unsteady heat release [1, 2], shown diagrammatically in Figure (1). It has the potential to affect all combustion devices, with gas turbines and rocket engines having been particularly susceptible. Gas turbines operate under lean premixed conditions in order to achieve ultra-low NOx emissions. However, these conditions show a real propensity to combustion instability. Achieving ultra-low NOx emissions without incurring damaging combustion instability (see Figure (1)) is therefore a real and immediate environmental problem.

One of the main hurdles to understanding, predicting and preventing combustion instability in gas turbines is the lack of analysis tools available. It is extremely difficult to perform experiments and simulations of thermoacoustic instability which are sufficiently representative of gas turbines combustors to be useful in the design process. Full-scale, high pressure and temperature annular test rigs are extremely expensive with limited measurement access, while full CFD simulations incorporating acoustic waves, turbulent hydrodynamics, combustion chemistry and heat transfer, all over long instability timescales, are prohibitively time consuming. It is for this reason that attention has turned to low order thermoacoustic network models [7, 4]. These describe the combustor as a network of connected simple geometry modules, and exploit the fact that one of the two phenomena key to the combustion instability mechanism, the acoustic waves, are very well modelled using simple analytical approaches. Their first important property is that they behave linearly with respect to the mean flow. Thus a steady flow simulation can be efficiently obtained, and flow fluctuations considered as superimposed on this. The acoustic wave behaviour is then well-captured using a linearwavemodelling approach [3]. At the lowfrequencies of interest, longitudinal combustors need only have plane waves modelled, while in annular-shaped combustors both plane waves and circumferential (azimuthal) waves need to be modelled. The change in behaviour of acoustic waves from one component to another is tracked using the flow conservation equations, while at system boundaries, acoustic impedances or pressure reflection coefficients can be employed. The effect of the acoustic waves on the unsteady heat release of the flame is achieved via a flame model [5]. The flame model should be linear at low amplitudes, but non-linear at higher amplitudes: flame non-linearity is now established as being the dominant effect which causes saturation into a limit cycle [6].

The scientific aim of this workshop was to explore low order modelling of combustion instabilities in simple combustors. The acoustic wave behaviour was modelled using linear plane-wave methods, while the flame response was captured via a variety of models, some analytical, some based on simulation/experimental data, some linear, some non-linear. Matlab and Simulink calculations of the combustor eigenmodes and oscillation time-histories were be obtained. These were used as the basis for more advanced investigations, including feedback control [2], whereby a loudspeaker actuator signal was made to depend upon combustor pressure measurements in order to inhibit instability, and sensitivity-based methods for systematically investigating changes in combustor stability in response to combustor parameter changes.

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Workshop on ‘A Systems Approach to Turbulence, with Scalar Transport, Buoyancy Effects and Confinement’ co-organised by Henri Bénard pilot centre and SIG 35

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May 4-5, 2015, Institut Jean-Le-Rond d’Alembert, Paris, France

Motivations and Objectives

This workshop is in line with the previous one, labelled **W2014-2**, co-organized by Pierre Sagaut and Claude Cambon in the same place, similar conditions, last year.

As a continuation, a part of the meeting was devoted to an ‘EDQNM festival’ with related topics, but other approaches, often very different or far beyond the multipoint closures, were addressed as well, with opening towards long-time perspective studies, dealing with internal intermittency, analogies with statistical physics, topology, mathematical challenges, and a special emphasis on engineering models: from fundamentals to applications. About new insight on passive and active scalar, transport of passive scalar by an isotropic velocity field has been extensively studied. However, what happens when the velocity flow is rendered anisotropic by various effects, as mean shear and mean stratification (see [14]), is not well known. In that case, triadic closures, with quantitative comparisons to high resolution DNS’s, are particularly well suited for a systems approach to such anisotropic turbulence. In addition, it is informative to compare the passive scalar and the active one, such as the density, temperature or concentration fluctuation with a feedback to fluctuating velocity via buoyancy effects. The case of near-wall turbulence, also discussed during the workshop, enters more explicitly in the themes of SIG 35 (e.g. [15, 17].)

The following list of themes are addressed:

- Extension of spectral theory towards anisotropic shear flows, with passive and active (buoyant here) scalar field. Application to practical (simpler) models for engineering and environment,

- Contribution of spectral appoach to turbulence confined by solid boundaries.

- Connections with analyses in terms of multipoint pdf’s, and with dynamical, statistical and structural approaches of the perceived fluctuating velocity gradient, density gradient.

The workshop gathered about 30 participants, with three doctoral students. It is labeled **W2015-3**, and ERCOFTAC sholarships are acknowledged.

Contents of The Talks

Claude Cambon (LMFA, CHB, SIG 35, Lyon) introduced the workshop and gave an overview of the programme.

Vincent Mons (IJLRA, Paris) presented ‘A new spectral model for shear-driven flows’ [12]. A fully nonlinear spectral model is derived for predicting homogeneous turbulence dynamics in the presence of arbitrary mean velocity gradients. The governing equations for the Fourier transform of the two-point second-order correlation tensor, are first closed by an anisotropic Eddy-Damped Quasi-Normal Markovian (EDQNM) procedure. Truncation at the first relevant order of spectral angular dependence allows to derive from these equations in vector $\mathbf{k}$ our final model-equations in terms of the wavenumber modulus k only. Analytical spherical integration results in a dramatic decrease in computational cost. Besides, the model remains consistent with the irreducible decomposition in terms of directional anisotropy and polarization anisotropy,with a spherically averaged anisotropic spectral tensor for each contribution, improving [4]. Restriction of anisotropy to spherically averaged descriptors, however, entails a loss of information, and realizability conditions are considered to quantify the upper boundary of anisotropy that can be investigated with the proposed model. Numerical exploitation confirms both versatility and low cost of the model. Several flow configurations are considered to assess the validity of the present model. A satisfactory agreement with experiments of grid-generated turbulence subjected to successive plane strains is observed, which confirms the capability of the model to account for production of anisotropy by mean flow gradients. The nonlinear transfer terms of the model are further tested by considering the return to isotropy (RTI) of different turbulent flows. Different RTI rates for directional anisotropy and polarization anisotropy allow to correctly predict the apparent delayed RTI shown after axisymmetric expansion. The last test case deals with homogeneous turbulence subjected to a constant pure plane shear. The subtle interplay between linear and nonlinear effects is reproduced, yielding the eventual exponential growth of turbulent kinetic energy.

Antoine Briard (IJLRA, Paris) presented ‘Passive scalar and cospectrum in homogeneous isotropic turbulence’ ([1, 2]). The passive scalar dynamics in a freely decaying turbulent flow is studied. The classical framework of homogeneous turbulence without forcing is considered. Firstly, both low and high Reynolds number regimes are investigated for very small and very large Prandtl numbers in isotropic turbulence. The long time behaviours of integrated quantities such as the scalar variance or the scalar dissipation rate are analyzed by considering that the decay follows power laws. The Comte-Bellot and Corrsin (CBC) dimensional analysis for the temporal decay exponents is extended to the case of a passive scalar when the permanence of large eddies is broken. Secondly, using numerical simulations based on eddy-damped quasi-normal markovian (EDQNM) model, the time evolution of integrated quantities is accurately determined for a wide range of Reynolds and Prandtl numbers. These simulations show that, whatever the Reynolds and the Prandtl numbers are, the decay follows an algebraic law with an exponent very close to the value predicted by the CBC theory. The possibility of a new spectral range at small scales for the scalar spectrum for very low Prandtl numbers was discussed as well. Secondly, the anisotropic EDQNM closure [2] extended from [12] is briefly presented to investigate the effects of both mean velocity and scalar gradients on the passive scalar field. Some comparisons are presented, along with new decay laws for the cospectrum in isotropic turbulence with a mean scalar gradient.

Benoît-Joseph Gréa (CEA, Paris-south) presented 'Challenging mix models on transients to self-similarity of unstably stratified homogeneous turbulence' [10]. The spatio-temporal development of the turbulent mixing layer induced by the Rayleigh-Taylor instability was the object of several studies; the understanding of its spatial growth rate vs. elapsed time remains ellusive, in spite of many computations, experiments and empirical models. Very relevant to statistics and dynamics of the 'homogenized' turbulent mixing layer, or unstably stratified homogeneous turbulence, was recently developed a generalized EDQNM model, which compared very well with very high resolution DNS [3]. The present work aims at expanding the set of buoyancy-driven unstable reference flows — a critical ingredient in the development of turbulence models, — by considering the abovementioned 'Unstably Stratified Homogeneous Turbulence' (USHT) in both its self-similar and transient regimes. The previously established accuracy of an anisotropic Eddy-Damped Quasi-Normal Markovian Model (EDQNM) on USHT has allowed us to (i) build a data set of well defined transient flows from Homogeneous Isotropic Turbulence (HIT) to late-time self-similar USHT, and (ii) on this basis, calibrate, validate, and compare three common RANS mixing models (two-equation, Reynolds stress, and two-fluid). The model calibrations were performed on the self-similar flows constrained by predefined long range correlations (Saffman or Batchelor type). Then, with fixed constants, validations were carried out over the various transients defined by the initial Froude number and mixing intensity. Significant differences between the models are observed, but none of them can accurately capture all of the transient regimes at once. Closer inspection of the various model responses hints at possible routes for their improvement.

Fabien S. Godeferd (LMFA, Lyon) presented 'Stratified turbulence, role of the Ozmidov scale and advances towards mixing'. Recently, an analysis of rotating turbulence based on high resolution DNS was carried out in order to identify the role of a Zeman's scale for delineating, scale-by-scale, both directional anisotropy and polarization anisotropy [7]. This approach is applied to stably-stratified turbulence, and confirms the role of the Ozmidov wavenumber $k_O = \sqrt{N^3/\varepsilon}$ (N stratification frequency, ε dissipation rate) as a threshold for restoring isotropy for the smallest scales [8]. New results are found for the angle-dependent (both ring-to-ring and shell-to-shell distribution) spectra of toroidal, poloidal and potential energies. In addition, promising analyses are in progress to show the analogies and differences between the Thorpe's scale and the Ozmidov one, in collaboration with Louis Gostiaux (LMFA), with future applications to actual mixing in non-homogeneous oceanic turbulent flows.

Laurent Nottale (LUTH, CNRS, Observatoire de Paris-Meudon) presented (with Thierry Lehner) 'Lagrangian intermittency and quantum mechanics analogy'. It has been recently suggested by L. de Montera to apply the theory of scale relativity, expressed in velocity-space, to turbulence. We use here this framework to address the question of intermittency, in particular as regards the large tails experimentally observed in the acceleration PDF's [13]. A new component of acceleration is identified, which becomes divergent on the local minima of the velocity probability distribution and creates $1/a^4$ tails in the acceleration PDF (in the K41 regime). Then we take into account the transition to the small (dissipative) time-scales, which involves two kinds of corrections to this $1/a^4$ law, at small and large accelerations. Finally we compare the corrected PDF to experimental Lagrangian data and we find an excellent agreement with the observed one, including its very large tails.

Christophe Josserand (IJLRA, Paris) presented 'Wave turbulence in vibrating plate: can one hear a Kolmogorov spectrum?' [9]. In this talk, he presented how wave turbulence can manifest in vibrating plates. Indeed, because of the dispersivity of the linear waves for an elastic plate, the usual weak wave turbulence can apply giving rise to the existence of turbulent spectra, the so called Kolmogorov-Zakharov. Interestingly, the experiments exhibit slightly different spectra. Different explanations can be developed for this discrepancy, some coming from the experimental conditions (always different than the theoretical framework), or from the model limitations and others from the dissipation in plates. We have shown, using both experiments and numerical simulations that the specific dissipation in the plates, not concentrated at small scales, provide the consistent explanation of the main differences between experiments and theory.

Marc Massot (Ecole Centrale de Paris) presented 'Eulerian models for DNS and LES relying on kinetic-based moments methods'. A very large review of disperse multi-phase flows was offered, from theory (both probabilistic, with pdf, and with moments), modelling, and numerical approach with dedicated schemes [18, 5].

Remi Zamanski (IMFT Toulouse) presented 'Turbulent thermal convection induced by heated particles'. The heating of a dilute suspension by an external source (for instance by radiation) leads to local temperature fluctuations in the fluid due to the non-uniformity of the dispersed phase. In presence of a gravity field, the fluid is set in motion by the resulting buoyancy forces.

When the particle density is not the same as the fluid's one, the fluid motions alter the spatial distribution of the particles and possibly lead to a strengthening of its non-uniformities. Direct numerical simulations in the Boussinesq limit, show this feedback loop. Various regime are identify according to the particle inertia. For very small particle inertia, the macroscopic behavior of the system is the result of thermal plumes generated independently of each other, while above a critical inertia clusters of particles are observed and their dynamics control the flow. Concerning the energy density in the spectral space, it is observed that the turbulent energy and temperature spectra present power law with exponent varying continuously with the Stokes number.

John Christos Vassilicos (Imperial College, London) presented 'The streamwise turbulence intensity in the inertial layer of a pipe channel flow' [17]. The spectral model of Perry et al. (*J. Fluid Mech.* **165**, 1986, pp. 163-199) predicts that the integral length scale varies very slowly with distance to the wall in the intermediate layer. The only way for the integral length scale's variation to be more realistic while keeping with the Townsend / Perry attached eddy spectrum is to add a new wavenumber range to the model at wavenumbers smaller than that spectrum. This necessary addition can also account for the high-Reynolds-number outer peak of the turbulent kinetic energy in the intermediate layer. An analytic expression is obtained for this outer peak in agreement with extremely high-Reynolds-number data by Hultmark et al. (*Phys. Rev. Lett.* **108**, 2012, 094501; *J. Fluid Mech.* **728**, 2013, pp. 376-395). Townsend's (The Structure of Turbulent Shear Flows, 1976, Cambridge University Press) production / dissipation balance and the finding of Dallas et al. (*Phys. Rev. E* **80**, 2009, 046306) that, in the intermediate layer, the eddy turnover time scales with skin friction velocity and distance to the wall implies that the logarithmic derivative of the mean flow has an outer peak at the same location as the turbulent kinetic energy. This is seen in the abovementioned data of Hultmark et al. (2012,2013). The same approach also predicts that the logarithmic derivative of the mean flow has a logarithmic decay at distances to the wall larger than the position of the outer peak. This qualitative prediction is also supported by the aforementioned data.

Stephane Zaleski (IJLRA Paris) presented, with Yue Stanley Ying, 'Statistical analysis of a two-phase atomizing shear layer' [11].

Current simulations of atomization using Volume of Fluid or Level Set method show impressive complex structures in three dimension and often match theory and experiment quantitatively and qualitatively.

However, doubts are rampant about the fully resolved character of these simulations and for good reason.

The talk describes these simulations, their successes and failures, and discuss which features are fully resolved and which are not. Perspectives for future improvements are given.

Laurent Jacquin (ONERA, DAFE, Meudon) presented, with Romain Courtier, 'Dynamics of streamwise vortices in an axisymmetric mixing layer under excitation'. This study involves the best techniques for measuring turbulence, from hot wire to the most recent versions of time-resolved PIV. The contribution of the latest techniques to the analysis and to the interpretation of turbulent fields has been illustrated on the case of axisymmetric jet and mixing layer. Following [6], the new Ph.D. work of Romain Courtier yields effects of forcing and identification of structures under a very large range of Reynolds number. It appears that, even if the flow structure without forcing is very different at low and large Reynolds number, the high-Reynolds-number structure becomes very similar to the low-Reynolds-number one, when the axisymmetric mode ($m = 0$) is selectively forced.

Round Table and General Discussions

A final round table took place. It was particularly inspired by a recent essay of Philippe Spalart, on 'philosophies and fallacies in turbulence modeling' [16], first mentioned in the talk by Benoît-Joseph Gréa, and was particularly animated by Antoine Llor, Laurent Jacquin and Pierre Sagaut, among other ones.

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ERCOFTAC workshop on Direct and Large-Eddy Simulation DLES10

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Department of Mechanical and Manufacturing Engineering

27^{th} - 30^{th} May 2015, Limassol, Cyprus

www.dles10.org

1 Introduction

The bi-annual series of Workshops on Direct and Large Eddy Simulation (DLES) started in 1994 focusing on modern techniques to simulate turbulent flows based on the partial or full resolution of the instantaneous turbulent flow structure. With the growing capabilities of modern computers, this approach has been gaining more and more interest over the years and will undoubtedly be further enhanced and applied in the future.

The Ercoftac Workshop *"Direct and Large-Eddy Simulation 10"* DLES10, was hosted in Limassol, Cyprus. The workshop was organized locally by the Department of Mechanical & Manufacturing Engineering of the University of Cyprus, from the 27^{th} to the 29^{th} of May 2015.

The goal of the workshop was to establish a state-of-the-art on DNS, LES and related techniques for the computation and modelling of turbulent and transitional flows. This gathering of specialists in the field was a unique opportunity for discussions about recent advances in the prediction, understanding and control of turbulent flows both in academic and industrial applications.

2 Topics and Scientific Program

The featured topics for the 10th edition of DLES in Cyprus covered a broad range of topics including,

- LES Fundamentals & modeling
- Quality of LES
- Numerical techniques
- Heat & Mass transfer
- Biological flows
- Multiphase flows
- Industrial applications
- Environmental and geophysical applications
- Reacting flows and combustion

Based on the submitted contributions, the scientific program was divided in those nine thematic areas organized in two parallel sessions of oral presentations covering the three days of the workshop. A total of 85 persons participated including 37 PhD students.

Figure 1: Picture of the participants to the workshop

3 Highlights of Presentations and Discussions

Nearly all aspects of the current state of the art for LES & DNS of turbulent flows have been covered from the contributors. After a careful review process, a total of 76 contributions were accepted for oral presentation. Those covered a wide variety of problems ranging from flows in biological systems and the environment, to external aerodynamics, domestic and centralized energy production, combustion and propulsion as well as aaplications of industrial interest.

Several contributions focused on fundaments studies dealing with physical scaling and proper invariants, stochastic models, uncertainty quantification and coherent structures. Following the advances on increased computational power and efficiency, a large portion of the contributions was devoted to LES & DNS of challenging applications, mainly in the areas of combustion and turbomachinery, including flame modeling, combustion processes and aeroacoustics.

4 Keynote lectures

During the workshop, the invited speakers delivered the following keynote lectures:

- "LES quality & benchmarking", by Professor Maria Vittoria Salvetti, (University of Pisa) who discussed the increasing interest on the assessment of the quality and reliability of LES results. Nonlinear interactions were demonstrated by interesting, counterintuitive results for cases where increased numerical resolution can lead to deterioration of the accuracy.

- “LES modeling: a scale by scale picture“ by Assoc. Professor Elisabetta De Angelis (University of Bologna) focusing on the scale modeling for LES. Starting from the physical insight on the energy transfer phenomena in turbulent flows, it was shown how modeling of the subgrid stresses can be improved in LES simulations. Moreover, it was highlighted how such a scale-by-scale analysis approach could be applied to other cases such as thermally driven flows by analyzing how thermal energy is produced, transferred and dissipated between different regions and flow-scales.

- “DNS & LES of biological flows“, by Professor Elias Balaras, (The George Washington University) who presented interesting methodologies and numerical methods applied for biological flows. Characteristic examples included applications from biology, physiology and animal locomotion, characterized by complicated multi-physics, multi-scale phenomena. The role of turbulence as a common characteristic in pathologic situations for blood flow in the heart, large arteries and bio-prosthetic devices was discussed.

- “Application of combustion LES within industry“ by Dr. Ruud L.G.M. Eggels, (Rolls-Royce Deutschland Ltd & Co KG) for the role of CFD on the design process of aero engines. Modeling efforts for the spray, combustion and emissions processes were presented. The advantages of using LES for flows with strong intermittencies were clearly identified. The need for further developments on modelling the mechanisms of spray break-up and soot prediction was demonstrated.

- “DNS & LES of transitional and two-phase flows“ by Professor Dominique ThÃľvenin, (University of Magdeburg) who discussed the connection between DNS, LES and POD for a variety of transition-related applications. Three main issues were presented in detail: the efficient implementation of -reacting or not- disperse particles or droplets in DNS, the impact of the disperse phase on the turbulence properties and transition and the possibility of quantifying transition to turbulence using a POD analysis.

- “DNS & LES of Atmospheric boundary layers“ by Professor Maarten Van Reeuwijk, (Imperial College London) who clearly demonstrated the non-linear interactions and the substantial diurnal and seasonal variability of the involved processes within the Atmospheric boundary layers. The state-of the art in the simulation of Direct and Large-eddy Simulation of atmospheric boundary layers was given with emphasis on turbulent entrainment and stratification effects.

- “Large-scale compressible flow DNS computa-tions“ by Professor Richard D. Sandberg (University of Southampton) who presented challenging DNS investigations of compressible flows in realistic configurations for problems related to turbomachinery and aeroacoustics. Impressive results were presented for the significance of various noise sources for a pipe-jet configuration, the flow through a linear high-pressure turbine cascade and the sensitivity of low-pressure turbines to inflow disturbances.

5 Follow-up Meetings

The next meeting on Direct and Large-Eddy Simulations, DLES11 (`www.dles11.org`) will be hosted at the University of Pisa, Italy, 27^{th} - 30^{th} May 2017, organized by Prof. Maria Vittoria Salvetti.

6 Book of proceedings

Continuing the DLES series of proceedings, the book of Proceedings for DLES10 will be published as a book by Springer in 2016, providing a comprehensive coverage of the state of the art on the physical and numerical aspects of turbulent flow simulation.

7 Organizing Committee

The organizing committee of DLES events consists of Vincenzo Armenio (Trieste, Italy), Jochen FrÃűhlich (Dresden, Germany), Bernard J. Geurts (Twente, Netherlands) and Hans Kuerten (Eindhoven, Netherlands).

Acknowledgments

The European Research Community On Flow, Turbulence And Combustion was the main sponsor of the event. Apart from ERCOFTAC, the local organizers of DLES10 would also like to acknowledge the contribution to the financial support of the event by The University of Cyprus, J.M. Burgerscentrum (JMBC) and the Cypriot Tourism Organisation.

The organizers also gratefully acknowledge all members of the Scientific Committee of DLES10 for their efforts to complete the review process of the submitted contributions.

10^{th} SPHERIC Workshop

R. Vacondio

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15-18 June 2015, Parma, Italy

http://www.spheric2015.unipr.it/

Introduction

The SPHERIC workshops are the only worldwide events which exclusively focus on the Smoothed Particle Hydrodynamics (SPH) methodology and related simulation approaches. SPH has recently gained enhanced attention in the area of scientific computing. Exemplary applications refer to the development of galaxies in astrophysics, environmental engineering, applied solid mechanics, marine and coastal engineering, nuclear power engineering, medical engineering or geotechnical problems.

The successful concept of SPHERIC is due to a methodological focus in an interdisciplinary application environment, integrating the know-how of physicists, mathematicians, IT experts and engineers from academia and industry. On behalf of the organizing team, it is a pleasure and honor to us to invite scientists to the 10th International SPHERIC Workshop at University of Parma, in Parma, Italy.

Dedicated to the aim of stimulating an enhanced direct exchange of ideas between the community of SPH researchers, there will be no parallel session during the Workshop.

1 Discussion/ Contents of Talks/ Highlights of Presentations and Discussions

The workshop once again proved to be a very popular event with a record 84 abstracts submitted from which 57 were chosen to be presented during the event. 120 delegates attended this tenth consecutive workshop held from June 16^{th} to June 18^{th} 2010, preceded by a training day June 15^{th}. The workshop began with a training day attended by 36 participants. 59 Students attended the workshop. They took advantage of a reduced fees ($330euro$ instead of $550euro$ for regular fee) thanks also to the ERCOFTAC funding. Trayning day: After an introduction to the SPH method by Prof. Stefano Sibilla (University of Pavia, Italy) taking both beginners and experienced practitioners through the basics of SPH, Prof. Antonio Souto-Iglesias (Technical University of Madrid, Spain) gave a stimulating lecture on the comparison between SPH and MPS meshless methods. In the afternoon participants have being introduced to the open-source code DualSPHysics, under the guidance of A.J.C. Crespo, J.M. Dominguez (University of Vigo, Spain), B.D. Rogers, G. Fourtakas (University of Manchester,UK).

Three days workshop: Over the next three days, the 15 workshop sessions on various topics gave an excellent overview of the varied SPH activity occurring around the world. To assess the progresses of the SPH methods over the years the same two keynote speakers of the first edition of the workshop were invited. Prof. J.J. Monaghan (Monash University) presented the “Evolution of SPH” whereas Prof. R.A. Dalrymple demonstrates how the method is being successfully applied to simulate Breaking Water Waves. At the end of the second day, the banquet took place at the "Fondazione Magnani Rocca" where a presentation was made by new Chair of SPHERIC Benedict D. Rogers (The University of Manchester, Italy) of the Steering Committee to thank David Le Touzé (ECN, France) for his outstanding work as Chair of SPHERIC during the last five years. During the Banquet the Joe Monaghan Prize has been awarded to Dr. Andrea Colagrossi for the paper "Colagrossi, A., Antuono, M., Le Touzé, D. (2009) Theoretical considerations on the free-surface role in the smoothed-particle-hydrodynamics model, Physical Review E 79:056701" which make outstanding advances in SPHERIC Grand Challenges of convergence and boundary conditions.

2 Summary/ Conclusions/ Follow-up Meetings

During the closing ceremony, the Libersky student prize was awarded to Philip Kunz of the University of Stuttgart. Dr. X. Hu announced that the XI SPHERIC workshop will be organized by the Technische Universität München (TUM) in Munich from 13^{th} to the 16^{th} of June 2016.

Figure 1: First day workshop coffee break at Casa della Musica

Figure 2: Andrea Colagrossi receiving the Monaghan Prize for for the paper "Colagrossi, A., Antuono, M., Le Touzé, D. (2009) Theoretical considerations on the free-surface role in the smoothed-particle-hydrodynamics model, Physical Review E 79:056701"

Figure 3: General discussion on Incompressibility during the first day workshop

Figure 4: Welcome cocktail at the "Circolo di Lettura" at the end of the first day workshop

Figure 5: Discussion at the end of a session during the third day workshop

Figure 6: Banquet at the “Fondazione Magnani Rocca“ on the second day workshop.

11^{th} Workshop on Synthetic Turbulence Models
Synthetic Flow Structure - Clustering and Modelling

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29^{th} and 30^{th} June 2015, LMFA, Ecole Centrale de Lyon, Eculy, France
`http://www.sig42.group.shef.ac.uk/SIG42-11.htm`

Introduction

The workshop was the 11th of the ERCOFTAC Special Interest Group on Synthetic Turbulence Models (SIG42). It took place at Ecole Centrale de Lyon, Ecully, France. It was co-organised with the SIG 35 dedicated to Multipoint Turbulent Structure and Modelling.

The workshop particular theme was 'Synthetic flow structure - clustering and modelling'

About 20 participants attended from different European countries (France, Germany, Poland, Spain, United Kingdom) and beyond the European Community (Saudi Arabia and USA) and 10 different institutions. It was an opportunity for the KS community to strengthen the links between the different institutions involved in the SIG. Abstracts from the main contributions are reported below. An Ercoftac Book Series that will publish more detailed contributions is in preparation (to appear early 2016)

Abstracts of Talks

The streamwise turbulence intensity in the inertial layer of a pipe/channel flow

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The spectral model of Perry et al. [1] predicts that the integral length scale varies very slowly as a function of the distance to the wall in the intermediate layer. The only way for the integral length scale's variation to be more realistic while keeping with the Townsend-Perry attached eddy spectrum is to add a new wavenumber range to the model at wavenumbers smaller than those of that spectrum. This necessary addition can also account for the high-Reynolds-number outer peak observed in the turbulent kinetic energy in the intermediate layer. An analytic expression is obtained for this outer peak in agreement with extremely high-Reynolds-number data [2, 3]. Townsend's (The Structure of Turbulent Shear Flows, 1976, Cambridge University Press) production/dissipation balance and the finding of Dallas et al. [4] that, in the intermediate layer, the eddy turnover time scales with skin friction velocity and distance to the wall implies that the logarithmic derivative of the mean flow has an outer peak at the same location as the turbulent kinetic energy. This is seen in the data of Hultmark et al. The same approach also predicts that the logarithmic derivative of the mean flow has a logarithmic decay at distances to the wall larger than the position of the outer peak. This qualitative prediction is also supported by the aforementioned data.

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Convective didactic thermoelectric devices

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Design and operation of thermoelectric coolers and heaters that may be used in detailled laboratory experiments of buoyancy driven turbulence, as well as in the general fluid mechanics of convection is important, there seems to be a lack of comparison between numerical models of turbulent flows (Including Kinematic Simulation and DNS) and non-homogeneous experiments. We present the results of a university-industrial collaboration that developed a Fluid Dynamic Didactic Apparatus able to model steady and transient thermoelectric driven convective models based on the control of thermal boundary conditions and also optimized to perform flow measurements inside a closed enclosure. The Thermoelectric Convection Didactic Device (TCDD) presented here is basically designed for a range of didactic uses, but a wide range of innovative research options are available, both in the small 4x4 device shown in figure 1 and in larger and higher power equipments. We present here both the thermoelectric and the fluid flow description of the TCDD. The coupling of heat transfer and electric conduction within the semiconductor thermal assemblies is important and takes into account the local thermoelectric effects, including Joule and Seebeck heating, Thomson effect, Peltier effect and Fourier's heat conduction.

Figure 1: Set up of the TCDD.

Acknowledgment

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Sweeping Errors In Kinematic Simulations

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The effectiveness of KS [1, 2] in pair diffusion studies has been questioned in recent times [3, 4, 5]. Most scientists in the field believe that locality is effective in real turbulence but not in KS owing to the sweeping of the small inertial scales by the large energy containing eddies in KS which, it is claimed, distorts the scaling away from locality scaling.

However, through a novel analytical derivation based upon the pairs of nearby particle trajectories, it is shown that KS yields physically reliable scalings provided that we work in the natural sweeping frame of reference in which the large scale energy spectra are set to zero, $E(k) = 0$, for $k < k_1$, and $E(k) = k^{-p}$, for $k_1 \leq k \leq k_\eta$, and $1 < p \leq 3$, in extended inertial subranges, $k_\eta/k_1 \gg 1$.

It is shown that the relative error in the turbulent pair diffusivity $e = |K_{KS}/K| \ll 1$, where K is the real diffusivity and K_{KS} is it equivalent calculated using KS, provided that the numerical time step Δt is much smaller than the timescale $\tau_s(\Delta)$ for sweeping to cut through local eddies, $\Delta t \ll \tau_s(\Delta)$ - this conditions is always met in any KS simulation.

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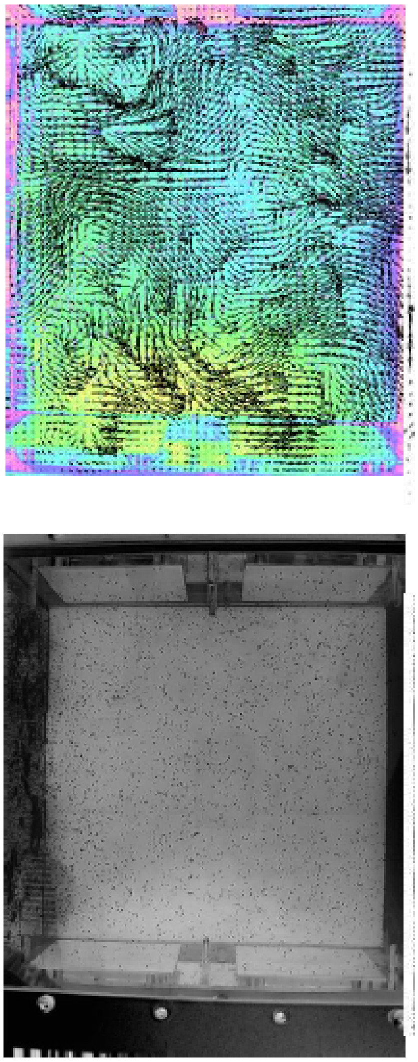

Figure 2: Set up of a Thermoelectric driven flow with PIV, and the resulting velocity/vorticity plot using program DigiFlow.

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A Lévy walk Model for Turbulent Diffusion

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We develop a Lévy walk model for anomalous diffusion which yields scaling laws of the form $\langle r^2(t)\rangle \sim t^\mu$ indicating a scale-free (self-similar) diffusional law. Whereas $\mu = 1$ describes Brownian motion, $\mu < 1$ subdiffusion, we especially focus on $\mu > 1$ of chaotic stochastic motions ("superdiffusion") which includes turbulent diffusion with Richardson's law $\mu \approx 3$ [1, 2]. We demonstrate by means of discrete self-similar Laplacians of the form of Weierstrass-Mandelbrot functions that by application of the *fractional continuum limit* which we introduced earlier [3], stochastic distributions of self-similar motions can be obtained which include turbulent diffusion. The approach opens a wide field of applications in turbulent diffusion, finance and stochastic motions characterized by statistically self-similar erratic motions.

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Effect of Gravity on Clustering Patterns and Inertial Particles Attractors

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Clustering could be defined as the propensity of an initially uniformly distributed cloud of particles to accumulate in some regions of the physical space. This is an important phenomenon to understand in order to explore, identify and possibly monitor some natural or handmade mixing processes such as those causing rain formation sediments transportation, fuel mixing and combustion.

In this contribution we study the clustering of inertial particles using a periodic kinematic simulation. The systematic Lagrangian tracking of particles makes it possible to identify the particles' clustering patterns for different values of particle's inertia and drift velocity. The different cases are characterised by different pairs of Stokes number St and drift parameter γ. For the present study $0 \leq St \leq 1$ and $0 \leq \gamma \leq 2$. The main focus is to identify and then quantify the clustering attractor - when it exists - that is the set of points in the physical space where the particles settle when time goes to infinity. Depending on gravity or drift effect and inertia values, the Lagrangian attractor can have different dimensions varying from the initial three-dimensional space to two-dimensional layers and one-dimensional attractors that can be shifted from an horizontal to a vertical position.

The particles initially uniformly distributed in the flow field are allowed to evolve until an asymptotic clustering pattern - also referred to as Lagrangian attractor - is achieved.

The shape of this cluster varies from clear one-dimensional structures to three-dimension distributed structures or two-dimensional layer-like structures (Fig. 3).

The main focus of this study is to evaluate the dimension of these attractors in a synthetic stationary field and to quantify them. The is done by using a nearest-neighbour distance analysis.

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Vortices in Synthetic Multicomponent Flows

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A compressible multiphase model together with its numerical solution were presented to expose the role of the baroclinic source of vorticity generation. The numerical procedures, accounting for pressure non-equilibrium and resolving interfaces separating compressible fluids, were designed to take advantage of the numerical diffusion generated in the computational simulation of multicomponent flows with shock waves. Several examples of shock-bubble interaction problem were investigated. The interaction of a shock wave with a cylinder (2D bubble) was examined for incident shock Mach numbers of 1.2 to 3 and for various Atwood number ratio of constituents. In all cases the bubble interface evolution, vorticity generation due to the misalignment of the pressure and the density gradients and mixing with an ambient fluid were monitored. The simulations reveal the complex phenomenological transition in which compression and distortion of the bubble and the formation of a vortex pair occur.

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Comparison of two Techniques to Analyse Turbulence in the Inertial Range

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Understanding the phenomenon of turbulence is a problem yet to be solved in detail. Increasing the knowledge in this field will enable us to enhance the standard of technology in many fields. To learn more about this complex matter we use a water channel to measure the velocity of a fully develop ed turbulent flow at various positions. In particular within the channel free flow and its boundary-layer. The channel has a 48.6 cm^2 cross

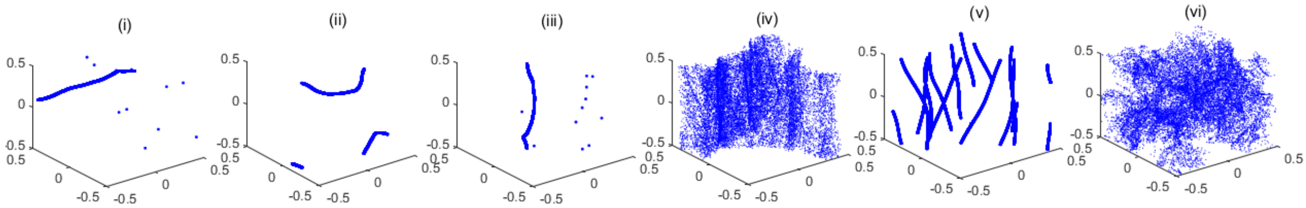

Figure 3: Different Lagrangian attractors

section and a 16 m length. It is capable to generate a flow speed of up to 20 cm.s^{1}. Measurements are done by a Laser-Doppler-Anemometer, which has a sampling rate of up to 1.5 kHz. Two different techniques are applied to the recorded data and results get compared. One technique is the so-called Four-Quadrand method which divides the data in four categories. Categories are low velocity with low degree of turbulence, high velocity with high degree of turbulence and the two possible mixed versions. This analysis works well with quite small data sets and gives a good first impression of the turbulence. The other method is the Markovian analysis, it holds the complete information about the turbulent cascade process. The cascade process is analysed in the so-called inertial range, bounded by integral length scale L and Taylor micro length scale λ. The turbulence's dynamics are captured by velocity increments defined as $u_{incr}(r) = u(r + \Delta r) - u(r)$ which can be expressed as Markov chain, at length above Markov length ($\sim \lambda$). By this approach the whole stochastic information in terms of conditional probability densities $p(u|u')$, and their change within the inertial range can be expressed. With those approaches and their comparisons a deeper understanding of free stream turbulence and turbulent boundary layers is to be achieved.

The 'N S f' Approach to Geophysics and Astrophysics

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Very rich dynamical, statistical and structural aspects of a turbulent flow can be investigated in the presence of 'distorting' linear effects induced by the three constant parameters N (stratification frequency), S (shear rate) and f (Coriolis frequency). The linear effects are studied individually and then possibly combined, e.g. via spectral linear theory (so-called 'rapid distortion'), and their interplay with basic nonlinearity is investigated by DNS, and by statistical triadic closures (generalized EDQNM, possibly matching wave turbulence theory) in some cases. Application to geophysics is very promising, with for instance the baroclinic context recovered for a large range of the Richardson number N^2/S^2, in which the baroclinic parameter Sf/N^2 is related to tilted mean isopycnes (Pieri *et al.* 2013, 2014). The 'shearing box approximation' allows applications to astrophysical objects, such as stratified accretion discs, even magnetized (N S f B parameters, Salhi *et al.* 2012, 2013, 2014), with extended use of sheared pseudo-spectral DNS (Rogallo 1981, Lesur 2007). In addition to new insights on turbulence subjected to rotating shear (S, f) and rotating stably stratified turbulence (N, f), the study of unstably stratified turbulence yields more recently a new success story: generalized EDQNM is quantitatively compared with very high resolution DNS, and allows us to revisit the homogenized mixing zone that results from the Rayleigh - Taylor instability from moderate to huge Reynolds numbers (Burlot *et al.* 2013, 2014).

Turbulence Under Internal Solitary Waves

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Internal solitary waves (ISWs) are $\mathcal{O}$(1km) long internal waves that are ubiquitous in the shelf regions of the coastal ocean and lakes. The interaction of ISWs and the bottom boundary layer and the resulting turbulence and particulate resuspension are of particular importance to shelf energetics, ecology, water-quality, acoustics and optics. It has regularly been hypothesized that the turbulence under ISWs results from a transition founded in the global instability of the separated near-bed vortex wake occurring in the lee (front) of a wave of depression (elevation).

This talk begins with a presentation of the relevant motivation and a review past, theoretical, numerical and laboratory work on ISW-bottom boundary layer (BBL) interaction. The latest progress on ongoing well-resolved massively parallel spectral multidomain-based Large Eddy Simulations (LES) of the turbulent under a mode-1 ISW of depression at Reynolds numbers typical of the laboratory is then shown. The computational cost of the LES of the ISW-driven BBL at even such relatively modest Reynolds numbers is linked to the non-negligible challenges that originate from the disparate scales involved: the long wave with its significant pycnocline depression vs. the considerably smaller scales of turbulence within the BBL. To this end, the major driver of computational cost is the need to sufficiently resolve the 2-D vortices of the globally unstable separated BBL and, thereby, capture the subsequent turbulent transition and ultimate fully developed turbulence.

A presentation of the most recent analysis of LES results focuses on the 3-D near-bed coherent structures, the bottom shear stress field and near-bottom turbulence spectra in the along-wave direction. Differences, in terms of the transition process and the potential for self-sustained turbulence, between the case of an ISW propagating into quiescent waters vs. that of a wave encountering a model barotropic current are highlighted. The perplexing disagreement with recent laboratory experiments of the no-current case are also discussed. Finally, while exploring connections with oceanic observations, the need for reliable and faster-turnaround LES modeling at coarser resolutions and higher Reynolds numbers values (closer to their oceanic counterparts) is addressed.

Stratified Turbulence and Mixing

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Stably stratified homogeneous turbulence is known to exhibit quasi-horizontal structures organized in vertically sheared layers. The thickness of these layers seems to scale according to a unit value of a related Froude number. In the ocean, the Thorpe Scale analysis is commonly used to determine the characteristic size of overturns. This contribution discussed the statistics of Thorpe's displacements both in in situ measurements and high resolution DNS.

Finite Size Particle Transport by Turbulent Channel Flow

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Particle transport by turbulent wall flow is a crucial issue in many environmental problems such as erosion, particle deposition and sand saltation. Despite great technological advances in measurement techniques as well as in numerical simulations, the understanding of the transport mechanism close to the wall is still incomplete. Many numerical studies have been devoted to this issue. By direct numerical simulations (DNS) of a turbulent channel flow coupled with Lagrangian tracking of pointwise particles, Zamansky et al. (2011) found that contrary to what is observed in homogeneous isotropic turbulence, close to the wall pointwise particles cluster in regions of high streamwise rms acceleration. The aim of the present study is to explore if this is still the case when size effects are taken into account in the DNS. Therefore, a pseudo-spectral DNS code is coupled with an immersed boundary technique (Uhlmann 2005). Finite-size particles with different Stokes numbers and density ratios are tracked at each time step. The velocity and acceleration statistics are analyzed. Particular attention is given to acceleration PDF of the solid phase, the fluid phase and the fluid in the vicinity of particles. The results are compared to the pointwise model and to other experimental or numerical studies on this topic.

Towards Particle Dispersion Modelling in Wall-Bounded Turbulence

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IMP Gdansk, Polish Academy of Sciences, Poland

Modelling particle dispersion in wall-bounded turbulence involves challenging problems. The particle velocity differs from that of the surrounding fluid owing to particle inertia or gravity which affects the fluid velocity fluctuations along the particle trajectory. The underlying phenomena also include particle-fluid, particle-surface and particle-particle interactions. These issues are not only important from a physical point of view but also have implications in many practical applications. The presentation developed a comprehensive insight into our understanding of particle deposition and discussed still open modelling issues.

Multiscale-forced Turbulent Flows: Fundamentals and Applications co-organised by SIG 44 and 42

W. Brevis[1,3], S. Laizet[2] and F. C. G. A. Nicolleau[1,4]

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7^{th} and 8^{th} September 2015, Sheffield,UK

1 Introduction

The workshop was co-organised by ERCOFTAC Special Interest Groups SIG44 and SIG42. It took place in the Department of Civil and Structural Engineering at the University of Sheffield, UK.

About 30 participants attended from different European countries (Germany, Italy, Netherlands, Spain, United Kingdom) and beyond the European Community (Canada, Japan and USA) and 11 different institutions. It was an opportunity for the different groups working on theory and applications of multiscale-forced flows to strengthen their links and introduce their work. Details of the programme can be found at *https://sites.google.com/a/sheffield.ac.uk/seefm/events* . Abstracts from the main contributors are reported below.

2 Abstracts of Talks

The space-scale unfolding (SSU) mechanism in multiscale-forced turbulence

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The stirring of a passive scalar by grid-generated turbulence in the presence of a mean scalar gradient is studied by Direct Numerical Simulations (DNS) for six different grids: one fractal square grid with three fractal iterations, one fractal square grid with four fractal iterations, one fractal I grid and three different regular grids. Our results can be summarised as follows. (i) For all these grids, the turbulence intensity averaged over time and over a plane parallel to the grid takes its peak value when the streamwise position of this plane is between $0.75M_{eff}$ and $1.5M_{eff}$ where M_{eff} is the effective mesh size introduced by Hurst & Vassilicos (2007). (ii) Downstream of the location of this peak, the turbulence intensity averaged in this way is greatly enhanced by the fractal grids relative to the regular grids even though the fractal grids have comparable or even lower blockage ratios. The novelty of this result lies in the fact that it concerns turbulence intensities averaged over lateral planes (as well as time). (iii) The pressure drop is about the same across grids of same blockage ratio whether fractal or not, but the pressure recovery is longer for the fractal grids. (iv) Even so, the fractal grids enhance turbulent scalar fluxes by up to an order of magnitude in the region downstream of the aforementioned peak and they also greatly enhance the streamwise growth of the fluctuating scalar variance in that region. (v) We demonstrate on a simple planar model problem that the cause of this phenomenon lies in the fractality of the grids. (vi) The turbulence scalar flux coefficient is constant far enough downstream of all the present grids and is significantly dependent on the nature and details of the turbulence-generating grid.

Reynolds number dependence of decaying multi-scale grid-generated turbulence

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Imperial College London, UK

Heat transfer enhancement due to static turbulence promoters is a relevant topic in power generation and process, automotive and aerospace engineering applications. Within this context we experimentally measure the convective heat transfer coefficient around the circumference of a circular cylinder in crossflow which is heated under uniform heat flux (UHF) conditions. The cylinder is placed in a wind tunnel at several downstream distances, x, from three different perturbing grids: a regular bi-planar grid (RG60), a fractal square grid (FSG17) and a single square grid (SSG). The flow downstream of the grids is first characterized without the cylinder in place via hot-wire anemometry in terms of mean velocity, turbulence intensity, Tu, and turbulence time scales. For both FSG17 and SSG a protracted turbulence production region exists and this is followed by a turbulence decay region where Tu is considerably higher than RG60, despite RG60 having a greater blockage ratio.

For the same inlet velocity, U_∞, at large distances from the grid in the turbulence decay region, the enhancement in the circumferentially averaged Nusselt number, Nu_g, with respect to its value under laminar free-stream conditions, Nu_{lam}, is always higher for FSG17 and SSG. Fractal and single square grids can be used to efficiently augment heat transfer since they are able to create protracted regions of high turbulence intensity, while maintaining a low blockage ratio and therefore a low pressure drop. The geometrical design of this type of grids can be optimized according to the specific needs: the ratio t_0/L_0 indicatively sets the value of the maximum heat transfer enhancement whereas the wake-interaction length scale,

$x_* = L_0^2/t_0$ sets the position where this peak occurs, where L_0 is the distance between the largest bars of the grids and t_0 is their thickness.

For both FSG17 and SSG clear differences exist between the angular heat transfer profiles measured in the production and in the decay region of turbulence, in positions where turbulence intensity is almost the same. Work investigating these differences is currently under way.

Investigation of a flow field generated by a fractal grid based on experimental data and CFD simulations

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Fractal grids generate turbulence by directly exciting many length-scales of different sizes simultaneously, rather than using the nonlinear cascade mechanism to obtain multiscale excitation, as it is the case for classical grids. These scales influence each other and show very different properties compared to all previously documented turbulent flows [1, 2, 3, 4].

In this work we present experimental wind tunnel and computational fluid dynamics (CFD) studies of the turbulent flow generated by a fractal grid under the same conditions. We did an extensive statistical study and a direct comparison between the experimentally and numerically acquired time series in order to investigate and compare one-point- and two-point-statistics. In addition we present an application of a stochastic method, so-called Langevin approach, to the experimentally acquired velocity increment time series to examine three-point-statistics in terms of Kramers-Moyal coefficients. These analyses will provide an enhanced insight on the turbulence generated by fractal grids and the suitability of CFD models (DDES: Delayed Detached Eddy Simulation with a Spalart-Allmaras background turbulence model [5]) to characterize this turbulence.

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Reynolds number dependence of decaying multi-scale grid-generated turbulence

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Three facets of the Reynolds number dependence of multi-scale grid-generated turbulence are investigated: (i) the inlet Reynolds number dependence of the decay of turbulent kinetic energy; (ii) the local Reynolds number dependence of spectra in the non-equilibrium region compared to spectra in the far-field; and (iii) relative turbulence levels and local Reynolds numbers for regular grids and a multi-scale grid at the same inlet Reynolds number. A square-fractal-element grid, featuring a 12×8 array of three iteration square fractal elements mounted to a background mesh, is compared to two regular grids with the same blockage. In the far-field of the square-fractal-element grid, the decay of the turbulent kinetic energy follows a power-law with an exponent of $n = -1.07 \pm 0.05$, independent of inlet Reynolds number. With respect to the spectra, it is found that if a spectrum with $< uv > \neq 0$ is compared to a spectrum at the same Re_λ with $< uv >= 0$, the spectrum with Reynolds shear stress has a scaling range that more closely matches $k^{-5/3}$. If two spectra are compared with the same Re_λ and $< uv >= 0$, even if one of these spectra is taken from the inhomogeneous, non-equilibrium region of a different grid, then they are approximately collapsed at all wavenumbers in the dissipative and scaling ranges. Finally, when the three grids are compared at the same inlet Reynolds number, both regular grids produce higher Re_λ sufficiently far from the grid (in both non-dimensional and physical units). Dye injected as a plume in the centre of the largest opening of each grid shows that the plume has spread over a greater area for the two regular grids at a downstream location 6 times the length of the largest element of a particular grid.

Flow field topology of free and impinging jets with fractal turbulence generators: a tomographic PIV study

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In a recent work (Cafiero G, Discetti S, Astarita T (2014) Heat transfer enhancement of impinging jets with fractal-generated turbulence. International Journal of Heat and Mass Transfer 75:173- 183), the authors proposed the use of fractal grids to increase the turbulence level of jets with the final aim of enhancing their mixing and heat transfer capabilities when impinging on a wall. The driving idea was the possibility to obtain high turbulence intensity at the desired location through proper selection of the fractal geometrical parameter. While the heat transfer measurements provided outstanding results at short nozzle-to-plate distance measurements provided outstanding results at short nozzle-to-plate distance (up to 60% enhancement of the heat transfer rate in correspondence of the stagnation point with respect to a jet without turbulence promoter), the spatial distribution of the convective heat transfer coefficient opened new interrogatives, which needed to be addressed by flow field investigations.

Owing to the complex turbulent interaction between the wakes of the grid bars and the outer jet shear layer, in this work we propose a full volumetric flow field investigation of free and impinging jets with a square space-filling fractal grid placed at the nozzle exit. The instantaneous flow field measurement highlight the presence of streamwise vortices, generated by the curvature changes of the inner and outer cross-shaped shear layers. In agreement with the behavior of jets with streamwise vortices generators (such as tabbed or chevron jets), such structures enhance the jet entrainment. Furthermore they have deeper streamwise penetration than the vortices generated by the Kelvin-Helmholtz instability of the outer shear layer, so they are able to survive and reach the wall before being dissipated. Additionally, if compared to the widely discussed fractal grids in wind tunnel experiments, the position of the maximum of the turbulent intensity is actually anticipated. This is to be addressed to the blockage effect of the outer shear layer that pushes the wakes of the largest bars of the grid to merge along the streamline direction.

Real-time turbulent flow simulation using GPU-based lattice Boltzmann method

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A novel lattice Boltzmann method (LBM)-based 3D computational fluid dynamics (CFD) technique has been implemented on the graphics processing unit (GPU) for the purpose of simulating turbulent flows in real-time. We study the time evolution of the turbulent air flow and temperature inside a test chamber and around wall mounted obstacles. The predicted results from LBM are compared with traditional CFD-based large eddy simulations (LES). Good agreement between LBM results and LES method are observed with significantly faster computational times. Efficient use of visualisation techniques allows the results of the simulation to be seen concurrently in real-time. The developed solver is validated against mechanically and thermally driven 3D cavities and flow around obstacles.

Analytical roughness models for turbulent flow over rough surface and generalizations to multiscale surfaces

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We conduct a series of Large-Eddy-Simulations (LES) to examine the mean flow behavior within the roughness layer of turbulent boundary layer flow over rough surfaces. We consider several configurations consisting of arrays of rectangular-prism roughness elements with various spacings, aspect ratios and height distributions. The results provide clear evidence for exponential behavior of the mean flow with respect to the wall normal distance. Once established, the generic velocity profile shape is used to formulate a fully analytical model for the effective drag exerted by turbulent flow on a surface covered with arrays of rectangular-prism roughness elements. The approach is based on the integral method by von-Karman Pohlhausen in which a shape function is assumed for the mean velocity profile and its parameters are determined based on momentum conservation and fundamental constraints. In order to determine a required attenuation parameter, wake interactions among surface roughness elements are accounted for by using the concept of flow sheltering. The model transitions smoothly between “k” and “d” type roughness conditions depending on the surface coverage density and the detailed geometry of roughness elements. Comparisons between model predictions and experimental/numerical data from the existing literature as well as LES data from this study are presented. It is shown that the analytical model provides good predictions of mean velocity and drag forces for the cases considered, thus raising the hope that analytical roughness modeling based on surface geometry is possible, at least for cases when the location of flow separation over surface elements can be easily predicted as in the case of wall-attached rectangular-prism roughness elements. The approach is then generalized to the case of multiscale, fractal surfaces with finite and infinite number of roughness element generations. The infinite case relies on the concept of Renormalized Numerical Simulation.

The coupling between inner and outer scales in a zero pressure boundary layer evaluated using a Holder exponent framework

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There has been significant research effort in the last decade attempting to understand the manner by which large scales modulate the behaviour of small scales in a boundary-layer. This work makes use of an existing dataset, obtained in the High Reynolds Number Boundary Layer Wind Tunnel at the University of Melbourne (Ganapathisubramani et al. 2012. Journal of Fluid Mechanics 712, 61-91). We introduce the idea of considering the modulation in terms of the pointwise Holder exponents of the velocity time series and discuss the connections between this approach and the turbulent multifractal spectrum, structure functions and models for turbulence with intermittency. The advantage of this formulation is that the measure of the modulation is continuous in time, permitting the adoption of forms of analysis such as cross-correlation and phase differences (derived from the Hilbert transform of the data). We show how the sign of the maximum absolute cross-correlation between the large scale velocity and small scale intermittency changes with height from the wall, being significantly negative below $y^+ \approx 500$ and significantly positive above $y^+ \approx 3000$. This change is explained in terms of the removal of a negative peak in the phase difference histogram as one moves further from the wall. Close to the wall, it is noted that these phase difference histograms are invariant to conditioning on the sign of the large scale fluctuating velocity or the sign of the small scale fluctuating Holder exponent. However, joint conditioning on these variables results in clear differences between the phase difference histograms as a function of the velocity-intermittency quadrants. Consequently, the behaviour of these quadrants is studied as a function of distance from the wall. Away from the wall, the importance of quadrant 2 (slow large scale velocity decreases. This quadrant has a clearly expressed bimodality for the phase differences. Quadrant 3 (slow large scale velocity with great small-scale velocity variation) becomes of increasing importance far from the wall. Hence, a refined model for the small scale modulation of the flow by large scales should incorporate information on the changing dependence between the two scales in the flow as a function of distance from the wall. The quadrant-based approach provides a means for formulating this dependence.

Generation of High Re number isotropic homogeneous turbulence in a wind tunnel by multi fans with simple input signals

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We try to generate high Reynolds number isotropic homogeneous turbulence in a multi-fan type wind tunnel. Total 99 fans are equipped and a flow with disturbances is generated by complicating the input signals for the fans. In the previous study, a signal which 40 sinusoidal waves with different frequencies ($f = 0.024-0.96Hz$) are superposed is applied to the fans with random phases. The generated flow is quasi isotropic homogeneous turbulence with $Re_\lambda \approx 650$. This time, we try to generate such a flow using a signal with only 1 or 2 frequency components to understand the transition process of turbulence. Sinusoidal waves with frequencies of $f = 0.34Hz$ and/or $f = 0.75Hz$ are tested. The results show that, in the 1 frequency cases, the input and its harmonic frequency components remain in flow even in the downstream region. On the other hand, in the 2 frequency case, such peaks almost disappear and the spectral shape for velocity fluctuation becomes relatively smooth. Turbulence characteristics such as turbulence Reynolds number, intensity, homogeneity, and isotropy in the 2 frequency case are almost the same as those in the 40 frequency case, although development of turbulence is much slower.

Multiscale trailing edges on lifting wings

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Serrations have been studied on trailing edges with the main purpose of reducing noise, with most studies focusing on serrated extension plates. A more recent approach has been the use of cut-in geometry for trailing edges, i.e. serrations that are directly cut into the wing's trailing edge and therefore exhibit both bluntness and sharpness along the spanwise evolution of the pattern. The partly blunt result has the structural advantage to avoid extension plates. Acoustic benefits were reported, but the exhibited bluntness induced vortex shedding which mitigates the possible acoustic improvement and generates coherent structures developing in the wake. The use of fractal patterns has proven to reduce this induced vortex shedding as well as presenting improved aerodynamic performances. Better understanding is still needed on the effect of multi scale patterns on the vortex shedding and span-wise coherence close to the trailing edge (e.g. source of noise, or base drag on the blunt parts) and further downstream where it could impinge on a secondary blade or a fixed object.

The work presented here focuses on the use of sinusoidal shapes, first single tone then multiscale patterns obtained by adding sinusoidal iterations orthogonally to the previous ones. The points of interest are the mean properties of the wakes as well as both vortex shedding and span-wise correlation. It is observed that using sinusoidal cut-in serrations creates a strong span-wisely inhomogeneous wake. Compared to a straight blunt wing the sinusoidal patterns offer up to 52% reduction in vortex shedding energy, defined as the total energy in the shedding band in the PSD. The main drawback is the increase of coherence at low frequencies. The multiscale shapes are found to further reduce vortex shedding intensity and associated correlation while reducing spanwise correlation at low frequencies. Indeed, by integrating the spectral span-wise correlation over frequencies lower than the shedding band, up 57% reduction is observed close to the trailing edge, compared to the single tone case.

Challenges of modelling multi-scale flows in Wind Engineering applications

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Owing to the rapidly increasing computer power and decreasing cost, along with the recently developed new technology, Computational Fluid Dynamics (CFD) is becoming increasingly attractive in modelling environmental flows. However, some challenges remain to be tackled. One among these is modelling multi-scale physical/chemical processes in the urban atmospheric boundary layer. The time scale of transport/dispersion/reaction of gas and particulate matter (PM) pollutant in urban environments varies from microseconds (10^{-6} s) to days (10^5 s). It is not feasible to resolve all of these scales in the foreseeable future. One option perhaps is to segment the full spectrum of these scales (such as the inertial sublayer of turbulence) and resolve one or more segments, whereas the other scales are to be modelled or to be synthetically generated using a sort of stochastic procedure [1].

In the first part of the talk, we used four case studies to demonstrate the importance of modelling muti-scale flows using our recently designed Numerical Environmental Wind Tunnel Of Newtonian fluid (NEWTON[2]-basically a comprehensive tool which uses CFD to primarily model physical wind tunnel scale, i.e. $O(1\ m)$ problems, but not limited to, such as considering the effects of weather-scale wind variation). The case studies are: a) the effect of unsteadiness of weather scale variation of wind on point/line source dispersion in the DAPPLE site – central London; b) effects of freestream turbulence on heaving/pitching response of a long-span bridge; c) locally generated large-scale motions by tall buildings ($\approx O(100\ m)$) which could have a significant impact on the European cities with low rise buildings; d) flows over a large geometry ($> 10\ km$) in which the small scales ($\approx 1\ m$) are of crucial interest as well as large scales, such as a long span bridge sitting in a valley. In the second part of the talk, we tried to identify some key issues: a) whether a generic slope/or separation of the spectrum exists at scales of $O(hour)$; b) how to assess and reduce the modelling uncertainties due to the coupling of the weather scales and street scale motions. At the end of talk, we suggested one potential solution to these – add correlated fluctuations at the nest interface.

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Multiscale turbulence manipulation for enhanced heat and mass transfer

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An immersed boundary method was adopted to solve flow through a cylindrical pipe in which an orifice with complex perimeter was mounted. It was shown that laminar mixing can be increased seven-fold when adopting a fractal-derived perimeter, compared to a circular orifice with the same blockage. The upstream modulation of flow for process intensification was further exploited for turbulent pre-mixed combustion. We showed both experimentally and numerically that passage of the flow through an appropriate grid can be used to double the turbulence intensity and corresponding flame velocity. This was illustrated using Beltrami deflection patterns at the inflow as well as a fully resolved immersed boundary representation of complex orifices.

Flow field characteristics and energy injection in a tank stirred by regular and fractal blades impeller

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A flat-blade turbine and two fractal modifications were experimentally compared in an unbaffled octagonal stirred tank ($T = 0.45m$), producing a highly turbulent regime. Shaft torque was monitored in order to assess the differences in power injection of the different impellers. Fractal blade impellers showed a decrease of power number Np of over 12%. Angle-locked PIV measurements in the impeller discharge region and spectral analysis of the radial velocity component revealed that the tip vortices produced by the regular blades are more coherent and have higher kinetic energy, being advected by a stronger radial jet compared to their fractal counterparts. This implies that the reduction in torque can be attributed to the differences in the vortex formation mechanism. PIV measurements in the bulk of the flow show an increase of over 20% of turbulence intensity for the fractal blades suggesting higher mixing efficiency.

Mixing enhancement behind multi-scale bar arrays

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It has been previously observed that fractal generated turbulence is beneficial to mixing performance. This is the motivation for our research whose objective is to explore the origins of this mixing enhancement, believed to be intrinsically linked to the multi-scale nature of fractal generated turbulence. Flows behind several different multi-scale bar arrays, having almost identical blockage ratio, are extensively studied (velocity field and concentration field are measured), in addition to single-scale arrays for comparison. Since the chosen arrangements can be viewed as the simplest examples of multi-scale obstacles one can think of, it is believed that the results will be symptomatic for a broad range of multi-scale flows.

The interest is focused in areas around wakes' intersection points, as these are highlighted by an earlier hypothesis explaining the nature of mixing behind multiscale obstacles, namely the Space Scale Unfolding (SSU) mechanism. The triple decomposition is used throughout the study to distinguish between stochastic fluctuations of the fields and coherent structures associated with wakes of different sizes. This enables analysis conditioned on phases of different wakes, which means the phenomena occurring at the intersection points can be tracked both in physical and phase space. Some kind of phase locking between wakes, that occurs downstream of the intersection point, has been identified. Velocity structures depending on phases of different shedding have been revealed as well. As for the concentration measurements, it has been observed that dye spread is considerably faster behind a multi-scale array compared to a single-scale one. The next objective is to perform a simultaneous measurement of concentration and velocity fields which would allow a further insight and help collapsing the observed phenomena into a single theory.

Drag and wakes of isolated 3D groups of obstacles in turbulent flow

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The interaction between isolated groups of obstacles and turbulent boundary layers is often encountered in nature: wind farms, tall buildings and patches of forest in atmospheric boundary layers, turbines in tidal channels, offshore structures and patches of vegetation in marine boundary layers. The main aim of this research is to characterize the properties of the wake and the drag forces on a 3-dimensional group of obstacles immersed in a boundary, focusing on the influence of the density of the obstacles within the patch. Particle image velocimetry (PIV) measurements and drag measurements on different patches have been carried out, focusing on how the wake of the patch changes with the density of the obstacles.The flow behind a porous patch of canopies is not affected by the free end as much as a solid case, behaving similarly to a high AR solid body. The free end effects only affect the upper third of the height, where entrainment from the free-stream flow starts to develop. The entrainment is less intense compared to the solid case, and this allows the wake to develop for a longer distance downstream of the patch. All these phenomena result in a higher drag coefficient for porous patches, with respect to a solid case, whose drag coefficient is comparable with the one of a patch with $\Phi = 0.05(C_{20})$. Bleeding along different directions due to the porosity of the patch leads to different effects on the wake, which are enhanced or diminished with respect to the patch density.

Drag and wakes of isolated 3D groups of obstacles in turbulent flow

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The wake developed behind arrays of cubes is examined via Acoustic Doppler Velocimetry (ADV) and Particle Image Velocimetry (PIV). A single pattern is utilised, based on different iterations of the Sierpinski carpet fractal, and in each case the flow behind single and multiple carpets is investigated. In each case wall-normal profiles of the mean and rms velocities, and Reynolds stresses are presented. The point-wise measurements reveal that the obstacles have an unexpected effect on the slope of the energy spectra immediately downstream of the arrays. In particular spectral short-circuiting is observed, whereby the injection of energy at wavelengths associated with the obstacle arrays results in a 'bump' in the energy spectra which is immediately followed by a -7/3 decay. It is shown that for the case of the wake behind a single Sierpinski carpet this lengthscale is comparable to the horizontal lengthscale of the smallest obstacles present. However deviation from this behaviour occurs in the case of the flow behind multiple Sierpinski carpet arrays, and the wavelength of the energy injection is no longer simply related to any of the obstacles.

Self-affine fractal bed roughness design

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Many natural and man-made surfaces exhibit self-affine fractal properties such as the wind-driven ocean surface (Belcher and Vassilicos, 1997), the topography of the ocean floor (Bell, 1975) and even the surface of the planet Mars (Nikora and Goring, 2004). The talk provides an overview of the design and manufacture of rough surfaces that possess self-affine fractal features and thus resemble real-life surfaces. Two types of roughness design are considered, termed one-dimensional and twodimensional. In the one-dimensional case, the rough surface is a function of streamwise position only, while for the 2D case the rough surface varies in both the streamwise and transverse directions. Self-affine roughness patterns are generated using the method of spectral synthesis (e.g., Saupe, 1988; Anderson and Meneveau, 2011) and a detailed account of the steps involved to implement this method are given for both the one- and two-dimensional cases. Bed roughness based on continuous self-affine fractal patterns has to date received little attention and marks a departure from more traditional approaches that typically adopt discrete roughness elements, such as cubes and spheres. In addition, through control of statistical properties of the surface, in particular the scaling exponent of the power spectrum, the method of spectral synthesis affords a robust technique for regulating and systematically varying the roughness.

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A systematic study of the effect of fractal geometric parameters on the heat transfer features of circular impinging jets

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Cooling of turbine blades, electronic components and outer walls of combustors, paper and film drying, annealing and tempering of glass are just a few examples of applications in which the high local heat transfer of impinging jets is exploited. Several solutions have been proposed over the last decades to increase the heat transfer rate of impinging jets (acoustic excitation, application of swirl, introduction of perforated plates between the nozzle and the target plate or installing mesh screens within the nozzle). In all cases the heat transfer enhancement is obtained by exciting/altering the structure and organization of large scale turbulence, which is widely recognized to be the main agent in heat and mass transfer mechanism of impinging jets. Tampering with the large coherent turbulent structures is the key to achieve a significant heat transfer enhancement.

In a recent work (Cafiero G, Discetti S, Astarita T 2014 Heat transfer enhancement of impinging jets with fractal-generated turbulence) we demonstrated the effectiveness of fractal turbulence promoters to enhance the heat transfer of circular jets impinging onto a normal wall. The effect of introducing a square fractal grid in correspondence of the nozzle exit section $0.5d$ and $1d$ (being the nozzle exit section diameter) is such that the heat transfer rate increases up to 63% in the stagnation region with respect to the well-known circular jet under the same power input. However, a systematic analysis of the effect of the singular geometric parameters of the fractal grid (such thickness ratio and length ratio) onto the spatial distribution of the Nusselt number has not been proposed yet.

In this work we propose the analysis of the heat transfer enhancement produced by a class of turbulence promoters (square fractal grids, semi-fractal grid, cross grids) located in correspondence of the nozzle exit section of a circular jet. A scaling of the stagnation point Nusselt number with the geometric parameters is presented. Moreover the upward shift of the turbulence intensity profile due to the blockage effect induced by the growing shear layer on the wake developing behind the fractal grid is discussed in terms of heat transfer enhancement.

Fractal experiments to test turbulent flow theories

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In the first part of the talk, Direct Numerical Simulations of unsteady spatially periodic turbulence with time-dependent rms velocity $u'(t)$ and integral lengthscale $L(t)$ show that not only the instantaneous energy dissipation rate but also the instantaneous energy flux at intermediate wavenumbers scales as $U_0L_0u'(t)/L(t)^2$ where U_0 and L_0 are velocity and length scales characterizing initial or overall unsteady turbulence conditions. These high Reynolds number scalings are qualitatively different from the well-known $u'(t)^3/L(t)$ cornerstone scalings of equilibrium turbulence where the energy flux and dissipation are exactly balanced at all times.

In the second part of the talk, we present a combined Direct Numerical Simulation and Hot Wire Anemometry study of an axisymmetric turbulent wake. The data lead to a revised theory of axisymmetric turbulent wakes which relies on the mean streamwise momentum and turbulent kinetic energy equations, self-similarity of the mean flow, turbulent kinetic energy, Reynolds shear stress and turbulent dissipation profiles, non-equilibrium dissipation scalings and an assumption of constant anisotropy. This theory is supported by the present data up to a distance of 100 times the wake generator's size which is as far as these data extend.

DNS of the interaction of a wall-mounted cube with a turbulent boundary layer

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The fundamental study of turbulent boundary layers has been a topic of great interest in the last decades, due to the complexity of the flow and its importance in many engineering applications. For this numerical study we are interested in the influence of a wall-mounted cube placed in a fully turbulent boundary layer. The present investigation starts with a DNS of a fully turbulent zero-pressure gradient boundary layer with Reynolds numbers up to 2000 based on the momentum thickness. Afterwards, a wall-mounted cube is included in the computational domain using an immersed boundary method. The cube, located at a streamwise position corresponding to Re=750, has dimensions comparable to the boundary layer thickness.

A highly complex flow is generated downstream of the cube with unstable recirculation regions on the top, sides and rear of the cube. As a result, sharp peaks are produced in the noise signature of the flow. Comparisons between the flow with and without the cube confirm the presence of several peaks for the velocity and pressure signals close to the cube. Far away from the cube and outside the boundary layer, we observe a well-defined low-frequency peak corresponding to a Strouhal number of around 0.05.

On the Large Scale Dynamics in the Wake of a Fractal Obstacle

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In a water flume at the University of Sheffield (UK), three-dimensional Particle Tracking Velocimetry is used to capture the turbulent wake of two full-width and wall-mounted obstacles: The first obstacle is a uniformly spaced array of square cylinders of same length-scale; the second is a three-iteration pre-fractal based on a the deterministic Sierpinski Carpet. Both obstacles emerged from the water surface and had the same porosity.

It is found that whilst the largest length scales of the pre-fractal dominated the vorticity field in the wake, the smaller length-scale within the obstacle caused intense vortical structures within the near field of the wake. To further investigate the spatio-temporal behaviour of the wake a simple and integrated use of the Proper Orthogonal Decomposition (POD) and Dynamic Mode Decomposition (DMD) is introduced. POD is used to rank the spatial structures relatable to the total variance (i.e. vorticity) while DMD is used to identify their dominant oscillation frequencies and spatial characteristics. From the POD it is clear that the largest length-scale creates spatially dominant structures, whilst the DMD extracted a set of oscillatory frequencies relatable to each of the pre-fractal length-scales.

Alignments and small scale statistics in the production region of grid turbulence

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Direct Numerical Simulation (DNS) of turbulent flow generated by a single square grid is investigated using an unstructured finite volume method. The maximum value of the Taylor length-based Reynolds number throughout the computed flow field is about 40. The main focus of this study is on the production region which lies in the lee of the grid where turbulence builds up. Statistics of vorticity and of eigenvalues (λ_i, where $i = 1, 2, 3$) and eigenvectors (e_i, where $i = 1, 2, 3$) of the fluctuating strain rate tensor (S_{ij}) are analyzed. It is observed that the PDFs of all the eigenvalues in the production region are highly non-gaussian. The PDFs of the compressive (λ_3) and intermediate (λ_2) eigenvalues are strongly skewed to negative and positive values respectively. The energy spectrum of the streamwise fluctuating velocity has a well-defined power law with an exponent around -2 or $-5/3$ over more than one decade depending on the position in the production region. It is also observed that the most extensive eigenvector (e_1) and the intermediate eigenvector (e_2) align significantly with vorticity vector in the production region, which in turn increases average enstrophy production.

3 Follow up meeting

There is a plan to publish the contributions as a special theme.

A follow up meeting is also planned for next year (2016) at Imperial College London, UK.

Details will be announced soon. Please contact the organisers if you are interested.

Workshop on "New Challenges in Internal Wave Dynamics", co-organised by Henri Benard Pilot Centre and SIG 35

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Oct 14-16, 2015, Centre Blaise Pascal, ENS Lyon, France

Abstract

The workshop "NewWave: new challenges in internal wave dynamics" was held from Oct 14 to Oct 16 in ENS Lyon. The aim of the meeting was to bring together researchers from different scientific communities interested in internal wave dynamics. The meeting included introductory lectures, long review talks, short talks and poster presentations. We summarise here the main results that have been presented during the workshop.

1 Motivation and Objectives

Owing to density stratification and rotation, the ocean and the atmosphere support internal waves. Either through direct turbulent mixing following wave breaking, or through other non-linear effects, internal gravity waves play a key role in momentum and energy budgets. Yet the scale separation between wave dynamics and the large scale circulations makes their numerical and theoretical study very challenging. Indeed, current resolutions of general circulation models can not resolve internal waves, whose effect must therefore be parameterised.

On the one hand, physical properties of internal wave dynamics are often addressed in idealised numerical or laboratory experiments that isolate the salient features of the dynamics. On the other hand, parameterisations in realistic settings have to address different issues related to the full complexity of the dynamics and of its numerical implementation. Finally, *in situ* observations offer both new problems for idealised studies and proxies to be compared with numerical models, with the inherent difficulty that such measurements are sparse in time and space.

Our goal in this interdisciplinary workshop was to familiarise physicists and atmosphere/ocean scientists with ongoing research outside of their field, and fertilise new work between those groups. The half-day sessions were organised as follows :

- Internal waves : physical properties (2 sessions)
- Internal waves in the ocean (2 sessions)
- Internal waves in the atmosphere (1 session)

This three day workshop gathered around 70 participants, with introductory lectures allowing for a thorough discussion and understanding, long review talks, as well as short research talks and poster sessions for informal scientific discussions.

2 Summary of the Lectures

G.K. Vallis (Exeter) gave an opening talk on the process that give rise to stratification in the ocean and the atmosphere, focusing on the large-scale structure of the two fluid systems [1, 2, 3]. Using phenomenological analytical models and numerical experiments of intermediate complexity models for the large scale dynamics, he presented a recent shift of paradigm concerning the role of internal waves on the large scale stratification and meridional overturning circulation. In this new paradigm, wave-induced mixing play a weaker role as previously expected. More precisely, the upper cell of the meridional overturning circulation may be understood as mostly wind driven, independently from small scale mixing. Although the role of internal wave mixing on the lower cell of the meridional overturning circulation remains to be addressed, it seems fair to say that there is neither a "missing mixing problem" nor a "missing energy problem" in our current understanding of the oceanic circulation.

A.C. Naviera Garabato (Southampton) reviewed recent evidence from a major UK-US observational programme (the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean, DIMES) pointing to a significant role of internal waves in the zonal and meridional circulations of the Southern Ocean. The meridional overturning circulation and stratification of the global ocean are shaped critically by processes in the Southern Ocean. This influence is exerted via a set of special dynamics that couple the eastward flow of the Antarctic Circumpolar Current with the meridional overturning circulation across the Southern Ocean. Efforts to unravel the dynamics of this coupling have to date emphasised the large-scale circulation's control by wind, buoyancy forcing, and by mesoscale eddies.He showed that the impingement of mesoscale flows onto rough seafloor topography generates internal waves that contribute significantly to dissipating the regional eddy field, arresting Antarctic Circumpolar jets, and mixing and upwelling water masses across density surfaces.

J. Vanneste (Edinburgh) discussed some of the properties of near-inertial waves. Those waves are highly energetic and play a significant role in the slow dynamics of the ocean at large and mesoscales. Indeed, wind forcing generates a spectrum of inertia-gravity waves that is sharply peaked near the local inertial (or Coriolis) frequency. Using an asymptotic model originally derived by Young and Ben Jelloul [4], he studied the interactions of near inertial waves with the mesoscale flow to explain their observed vertical propagation and their concentration in anticyclones [5]. He then introduced a new coupled model which captures the two-way interaction between near inertial waves and mesoscale flow. The model is derived using generalised Lagrangian mean theory and preserves energy and an action [6]. Using these conservation laws, he showed how near-inertial waves act as an energy sink for the mesoscale flow through a process of " stimulated wave generation".

U. Achatz (Berlin) discussed some challenges and steps towards possible solutions concerning atmospheric gravity waves modelling. A major source of uncertainty in current climate-chemistry models are internal gravity waves represented by oversimplified parameterisations, e.g. [7]. One focus were on the theory and numerically stable modelling of the two-way interaction between subgrid-scale waves, either internal gravity waves or geostrophic modes, and the resolved flow, e.g. [8, 9, 10]. Another were on the spontaneous emission of gravity waves from large-scale flow, with a special eye on the reproducibility of this process in the laboratory [11]. mathematically consistent way, and where these will be tested by implementation into a state-of-the-art numerical-weather-prediction and climate model, and by reference to data from dedicated measurement campaigns and laboratory experiments.

T. Dauxois (Lyon) discussed three fascinating physical properties of internal gravity wave, with illustrations from laboratory experiments: internal wave reflection [12], mean flow generation [13, 14, 15], and parametric subharmonic instabilities [16, 17]. He showed recent theoretical advances for all these problems, using instability theory and multiple scale analysis. He pointed out to a mysterious cancellation of non-linear terms that remains yet poorly understood.

3 Summary of The Talks

The oral and poster presentations covered important issues concerning internal wave observation in the atmosphere (through balloons and SAR imagery) and in the the ocean (through *in situ* measurements or altimetry), the parameterization of their effects in general circulation models, the study of mechanism coupling those waves with "balanced" motion (vortex, jets), their role in several routes to energy dissipation and in global energy or momentum budgets. Substantial advances have also been achieved in laboratory experiments, either for homogeneous rotating fluids, for purely stratified fluids, or for both. Recent theoretical progress have been obtained either through asymptotic analysis, or statistical mechanics approaches. Those aspects were also addressed in several oral presentations.

Many features of the atmospheric motion involve internal wave dynamics. **R. Plougonven (Paris)** reviewed analytical results on spontaneous gravity wave emission from atmospheric "balanced motion" (jets and fronts), and numerical evidence that the background flow plays a key role in determining the characteristics of the waves that are emitted [18]. The confrontation of these results to gravity waves in real atmospheric flows reveals some additional surprises, emphasising for instance the role of moisture in the generation of waves from fronts [19]. **V. Jewtoukoff (Paris)** showed observation of gravity waves in the southern hemisphere derived from balloon, allowing for a new evaluation of the ability of a widely used operational model (ECMWF analyses) to accurately describe the atmospheric gravity wave field [20]. **J. Magalhaes (Porto)** presented observation from synthetic aperture radar (SAR) imagery revealing the presence of atmospheric gravity waves above the red sea and discussed possible generation mechanisms.

By contrast with the atmosphere, much of the ocean interior remains poorly observed. New technics of observations bring new problems to be addressed, both for the interpretation of the measurements and for the understanding of the physical mechanism at stake. **D. Bourgault (Rimouski)** presented a variety of field observations of nonlinear internal waves collected in the Saguenay Fjord (Canada) with the goal to identify and discuss some challenges we are facing in terms of measuring and understanding the behaviour of internal waves in natural environments. **J. Da Silva (Porto)** gave a comprehensive view of the generation mechanisms and evolution of internal waves on the upstream side of a large sill of the Mascarene Ridge [21]. **A. Ponte (Brest)** presented recent efforts to develop methodologies that achieve the distinction between the sea level signatures of low-mode internal waves and mesoscale eddies, which will be a major challenge to interpret altimetry measurements collected by SWOT in 2020. These methodologies rely on a combination between observations of sea level and sea surface temperature and on the fundamental difference of dynamics between these two processes. High resolution numerical simulations of the propagation of an idealised internal tide through a turbulent eddy field provide testbeds for these methodologies [22].

Several new physical mechanism responsible for internal wave emission and dissipation have been proposed. **N. Grisouard (Toronto)** presented an analytical study of internal gravity waves reflection on density fronts within the oceanic mixed layer [14]. He showed the existence of critical reflections of such inertial waves off the sea surface, after which incident wave energy cannot escape. This is analogous to the classical critical reflection of internal gravity waves in a quiescent medium off a sloping bottom. An important consequence of this result is an irreversible energy exchanges between internal gravity waves and geostrophically-balanced frontal flows. He showed that a tidal wave passing over an irregular bottom is for a substantial part trapped to this irregularity, and only partly converted into freely propagating internal tides. **P. Diamessis** presented large eddy simuations on the surface reflection of the internal wave field emitted by a localized submerged stratified turbulent source. **D. Whitt (Cambridge)** proposed a resonant generation mechanism for wind-forced near-inertial motions in a geostrophic flow. This provides a sink of geostrophic kinetic energy which preferentially damps flows with anticyclonic vorticity and thus could contribute toward shaping the positively skewed vorticity distribution observed in the upper ocean [23]. **O. Richet (Plaiseau)** presented a numerical study on the enhanced energy dissipation observed at the critical latitude 28.8°, presumably due to parametric subharmonic instability, and addressed the role of a mean flow on the location of this critical latitude. **C. de Lavergne (Paris)** compared deep water mass transformation by internal wave-driven mixing and geothermal heating. Using parameterisations of lee wave and internal tide energy dissipation combined with two different models for the mixing efficiency, he showed that near-field mixing by breaking internal tides and lee waves cannot ount for the full strength of the abyssal overturning and argued this abyssal overturning can be explained by taking into account geothermal heating [24].

The interaction between bottom topography and large scale fluid motion is an important source of internal waves in the ocean and the atmosphere. **C. Staquet (Grenoble)** proposed a resonant-interaction mechanism to explain the growth of inertial oscillation eventually leading to momentum deposit and mixing when lee waves are generated by barotropic currents above bottom topography, as for instance in the Southern Ocean. This mechanism contrasts with previous explanations based on a dissipative process. **L. Maas (Nioz)** presented experimental and theoretical results on tidal wave above topographic features: tidal wave passing over an irregular bottom is for a substantial part trapped to this irregularity, and only partly converted into freely propagating internal tides. **R. Chassagne (Paris)** studied the fate of topographically-trapped internal tides by considering the case of Rockall bank (N-E Atlantic ocean), with a combination of numerical simulations and observations. **Y. Dossman (Lyon)** reported results from laboratory experiments with a topographic ridge towed through a stratified fluid. Full field density measurements provide the depth-dependence of energy loss to turbulent mixing, allowing separation of the local mixing in the turbulent wake and remote mixing by wave radiation. Remote mixing is significant only for a narrow band of forcing parameters where the flow speed is resonant with internal waves; in all other parameter regimes local mixing close to the topography is dominant. The results suggest that mixing by local nonlinear mechanisms close to abyssal ocean topography may be much greater than the remote mixing by lee waves. Another peculiar property of orographically generated internal waves is the possible formation of rotors, horizontal vortex rolls located beneath the wave crests which are very turbulent. **D. Etling (Hannover)** presented observational and experimental studies on the emergence of such coherent structures [25].

The breaking of internal waves occurs on scales too small to be resolved explicitly in ocean climate models. **A. Melet (Toulouse)** presented parameterizations of internal-wave driven mixing for ocean models. Classical parameterisation for the local effect of internal tides and lee waves on vertical mixing rely on prescribed vertical (bottom intensified) profile of turbulent diffusivity whose amplitude depends on the local amptitude of bottom topography fluctuations, mean flow, stratification and mixing efficiency [26, 27]. Climate simulations of 1000 years are used to assess the sensitivity of the ocean state to these parameterizations. She especially focused on the sensitivity of the thermohaline circulation, ocean ventilation, temperature field and of steric sea level to parameterizations of local and remote internal-tide dissipation and of lee-wave driven mixing [28]. **A. Koch-Larrouy (Toulouse)** presented a local study on the effect of changing the prescribed vertical profile for the vertical diffusivity in Indonesian archipelago, with enhanced diffusivity below the thermocline [29]. This parameterization changes significantly properties of water mass transformations, with strong climatic impact, e.g. [30], and its main hypothesis are consistent with *in situ* observation from the INDOMIX campaign [31].

Independently from applications, peculiar physical properties of inertial-gravity waves are still an active subject of theoretical, experimental and numerical investigations, with important questions concerning their propagation, their dissipation, and their interactions through non-linear effects, leading to large scale flow motion or direct wave cascades. **N. Mordant (Grenoble)** reviewed weak turbulence theory and his previous experimental studies on wave turbulence, e.g. [32]. He then presented his research program on the study internal gravity wave turbulence. **C. Brouzet (Lyon)** showed recent experimental observation of a direct cascade of internal waves through triadic resonances within an internal wave attractor, which eventually leads to small scale turbulent mixing. **M. Mercier (Toulouse)** presented an experimental study of the wave pattern observed in the wake of an object towed at the surface of a two-layer fluid, and discuss a transition from Kelvin to Mach angle when the Froude number is varied. **P.-P. Cortet (Orsay)** presented theoretical and experimental results on the far-field decay of the (inertial) wave amplitude in the presence of multipolar sources in rotating flows [33]. **N. Shmakova (Grenoble)** presented experimental and theoretical results on the geometric focusing of internal waves, including the description of non-linear effects which eventually leads to overturning and turbulent motion. **S. Le Dizes (Marseille)** presented an exact viscous solution of the linear wave field generated by a librating disk (harmonic oscillation of the rotation rate) in a stably stratified rotating fluid, which includes the description of a zonal mean flow, using asymptotic analysis [34].

Most often, internal gravity waves co-exists with turbulence motion. **K. Winters (San Diego)** showed three-dimensional numerical simulation of the near-boundary flow induced by a low-mode internal tide impinging on a sloping boundary, considering a ‘deep-ocean’ case relevant to continental slopes where the topography is supercritical, i.e. steeper than the inclination angle of energy propagation for internal tides, and compared those results with observations. He also reviewed classical results on mixing efficiency and indirect estimates of vertical turbulent diffusivities inferred from *in situ* measurements. **A. Delache (Lyon)** presented analysis of direct numerical results on turbulent mixing in a freely evolving confined stratified fluid. He clarified the range of validity of the Dillon’s relation, which is widely used in oceanic context, and which relates the Ozmidov length scale (below which isotropic turbulent motion occurs) to the Thorpe scales (characterising overturning). **A. Renaud (Lyon)** presented a statistical mechanics approach that predicts energy partition between inertia-gravity waves and vortices in a freely evolving shallow water flow [35].

4 Conclusion

The aim of the meeting was to identify open questions that may be addressed by the different scientific communities interested by internal wave dynamics. Several issues have emerged at the end of the meeting:

- A clear and complete understanding of wave-topography interaction is still lacking. In particular, what is the effect of topography on wave scattering, wave dissipation and wave emission ? What are the consequences in term of energy and momentum budget ?
- Wave-mean flow interactions remains an active subject of research, in particular when studying the interplay between geostrophic motion and internal gravity waves. This will become even more important with new observations from altimetry and high

resolution numerical models that begin to simulate inertia gravity waves.

- Can the empirical parameterization used in oceanic climate modelled be derived from physical principle in limiting cases (i.e. what sets the prescribed vertical profile) ?
- Can we observe internal wave turbulence in the laboratory and natural flows ?

We hope that those points will be be addressed in the coming years with a combination of theory, experiments, simulations and observations.

Acknowledgment

We warmly thank all the sponsors of the conference: ERCFOTAC, CHB Lyon, CNRS (InPhyniTy), FST Lyon, Lab-Phys ENS-Lyon, CBP Lyon, ANR-JCJC STRATIMIX. Abstracts for oral or poster presentations as well as supplementary materials are available on the conference website http://newwave.sciencesconf.org.

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Report of the Ercoftac Greek Pilot Centre 2010-2015

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[1] *National Technical University of Athens*
[2] *University of Western Macedonia*

1 Introduction

The ERCOFTAC Greek Pilot Centre was founded in 2000, and is coordinated by Prof. M. Founti since 2013. This report describes the research activities undertaken in the last five years by six laboratories from four Greek Universities that have been involved with ERCOFTAC activities. The reported research covers a wide variety of scientific and engineering applications and highlights the diverse research interests of the Greek PC. A good part of the ongoing research in fluid flow in Greece has been presented at the "FLOW-2014: 9th Pan-Hellenic Conference on Fluid Flow Phenomena" that took place in Athens, 12-13 December 2015.

2 Members

2.1 Academic Members

A. National Technical University of Athens, School of Mechanical Engineering

   L1. *Laboratory of Heterogeneous mixtures and Combustion Systems*
   Director: Prof. Maria Founti
   Email: mfou@central.ntua.gr

   L2. *Parallel CFD and Optimization Unit- Laboratory of Thermal Turbomachines*
   Responsible: Prof. Kyriakos Giannakoglou
   Email: kgianna@central.ntua.gr

B. Aristotle University of Thessaloniki, Department of Mechanical
Engineering

   L3. *Laboratory of Applied Thermodynamics*
   Director: Prof. Zissis Samaras
   Email: zisis@auth.gr

   L4. *Laboratory of Heat Transfer and Environmental Engineering*
   Director: Prof. Nicolas Moussiopoulos
   Email: moussio@eng.auth.gr

C. University of Patras, Department of Mechanical and Aeronautics Engineering

   L3. *Laboratory of Applied Thermodynamics*
   Director: Assoc. Prof. Panagiotis Koutmos
   Email: koutmos@mech.upatras.gr

D. University of Western Macedonia, Department of Mechanical Engineering

   L3. *Laboratory of Thermodynamics and Combustion Engines*
   Director: Prof. Ananias Tomboulides
   Email: atompoulidis@uowm.gr

2.2 Industrial Members

There is no current membership from the Industry.

3 Research Activities of Greek PC members

3.1 National Technical University of Athens, School of Mechanical Engineering

L1. *Laboratory of Heterogeneous mixtures and Combustion Systems*
Contributed by: Prof. Maria Founti, Dr. Christos Keramiotis, Dr. Dionysis Kolaitis

HMCS - the laboratory of Heterogeneous Mixtures and Combustion Systems of NTUA (`http://hmcs.mech.ntua.gr//`) is an accredited laboratory of the School of Mechanical Engineering of the National Technical University of Athens, established in 2002. The main research activities of the HMCS laboratory focus on the experimental investigation and numerical modelling of the fundamental momentum-, heat- and mass-transfer phenomena and chemical kinetics, occurring in multiphase and reactive flows (e.g. technical combustion systems, industrial burners, fire in buildings, high-temperature behaviour of building elements, pollutant formation, dispersion and control, fuel cells, erosion, drying).

The HMCS personnel comprise five permanent faculty members; one professor (Director of the lab., Prof Maria Founti)and four post-doctoral permanent teaching staff, five postdoctoral research associates, four doctoral candidates, fifteen graduate students on an annual basis and three members of staff for administrative and technical support.

Teaching at under- and post- graduate level covers Combustion Theory and Applications, Transport Phenomena, Radiative Heat Transfer, Numerical Methods in Multi-phase-Multi-component-Reacting Systems and Energy Systems in Buildings and Industry. HMCS has an abiding research expertise on a variety of research areas covering:

Combustion technologies and thermo-chemical systems

- Investigation of multi-phase, multi-component, chemically reacting flows and systems.
- Combustion in ovens, burners, prototype combustion processes, physic-chemical processes (e.g. evaporation / burning droplets).

- Detailed chemical kinetic mechanism development, implementation and analysis of the heat release and pollutant formation processes.
- Thermo-kinetic modelling of fossil and alternative (bio-) fuels. Development of reactor networks for estimating environmental performance of industrial combustion equipment.
- Fuel reforming modelling. Application in high temperature fuel cells

Fire research

- Simulation tools for prevention and control of fire propagation in enclosed spaces (buildings, ships, aircraft, and tunnels) and building facades.
- Experimental and numerical investigation of combustion and two-phase flow phenomena in fires.
- Investigation of fundamental physical phenomena related to flames exiting a building.
- Study of material behaviour at high temperatures

Integrated evaluation of energy systems

- Evaluation of energy technologies with multi-criteria analysis methods and life cycle analysis. Overall methodology for supporting energy system selection.
- Modelling energy systems and performance optimization of production line processes.
- Integrated assessment of energy technologies by incorporating the overall environmental impact, the technical efficiency and economic viability.

Building and district energy saving and storage

- Improvement and evaluation of energy properties of building materials.
- Assessment of the impact of Phase Change Materials integration on energy storage and building efficiency.
- Experimental and numerical investigation of energy performance of buildings, districts and historic buildings.
- Evaluation of application of super-insulation materials (e.g. VIP, aerogel) on light structures.
- Improving energy efficiency of systems through management automation systems.

During the past years a number of numerical tools have been developed to support the combustion research, such as in-house CFD codes for two-phase, reactive flows using Eulerian-Lagrangian and multi-fluid approaches, combustion chemistry models for thermal process optimization (e.g. Diesel auto-ignition, cool flames), tabulated chemistry tools for combustion of primary reference fuels in novel fuel processing devices. These were supported by velocity - temperature - species quantification experimental campaigns in prototype configurations (e.g. stabilised cool flame vaporizers and semi-industrial pilot furnaces).

The *research infrastructure* of HMCS includes pilot scale units such as mills for ultra-fine pulverization of materials and fuel flexible boilers and furnaces. HMCS has a variety of prototype burner and reactor configurations (e.g. multi-fuel swirled-stabilized flame burners, cool-flame and C-POX reactors). HMCS has largely investigated a diverse range of off-gas burners particularly designed for low calorific value fuels, such as a model diffusion flame and porous burners. The flame/burner characterization is performed in terms of (a) velocity profiles using LDA/PDA and hot-wire anemometry, (b) gaseous and surface temperature measurements using fine thermocouples and infrared thermometry and (c) exhaust speciation realized by gas chromatography and continuous state-of-the-art analysers. The laboratory emphasizes on the application of the aforementioned diagnostic tools for experimental campaigns assisting in optimizing the in-house detailed kinetic schemes.

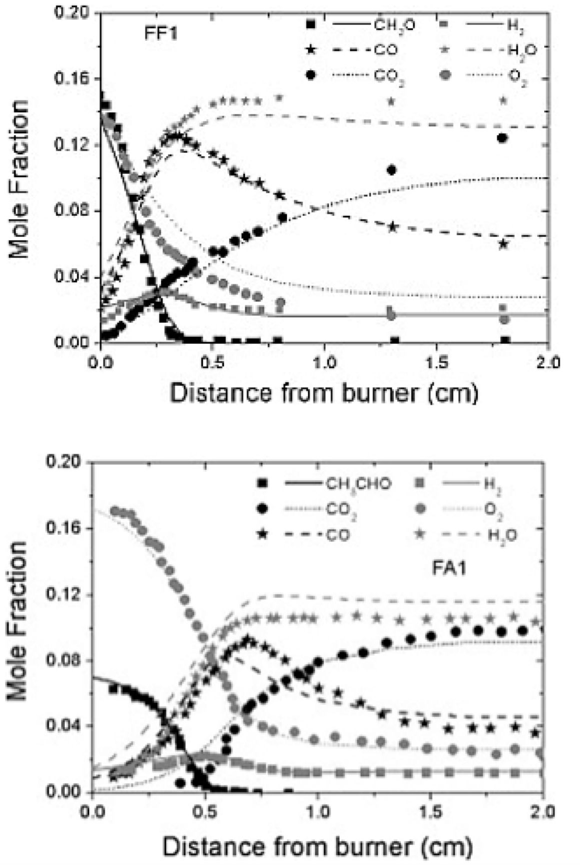

Figure 1: Mechanism performance against experimental major species profiles in formaldehyde (up) and acetaldehyde (down) flame [1]

CFD work within the ERCOFTAC framework is mainly directed towards the *numerical modelling of thermo-chemical systems*, supported by experiments conducted in fundamental experimental configurations. This reflects on the continuous effort for the development and validation of a comprehensive detailed chemical kinetic model for the pyrolysis, oxidation and combustion of conventional and alternative (e.g. *ethanol*) fuels.

Particular focus is given on describing the chemistry of gaseous species crucial for molecular growth processes, such as C_2, C_3 and benzene [1, 2, 3, 4]. Moreover, key oxygenated intermediates have been studied (see 2). In this respect, the model is utilized for the analysis of the gas phase chemistry of combustion pollutants (UHCs, PAHs, NO_x, SO_x, VOCs, dioxins) and soot, as well as for thermal and catalytic partial oxidation reforming of various conventional and alternative fuels. In addition, an ideal reactor network approach has been formulated for the analysis of practical thermo-chemical systems (e.g. fuel cells, gas turbines) and the holistic thermo-chemical optimization of fuel flexible CHP systems, predominantly for domestic scale applications [4, 5].

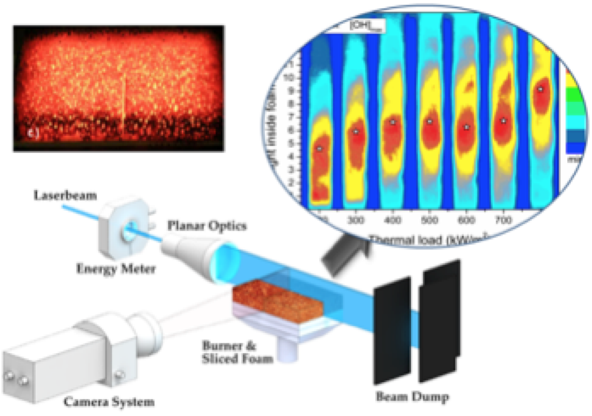

Figure 2: Flame visualization via OH-LIF measurements inside porous media for varying thermal loads [6]

The HMCS has developed and utilized intrusive and nonintrusive *combustion diagnostic* techniques in combustion systems of varying complexity. Configurations with moderate degree of complexity, such as plug flow reactors have been tested via gas chromatographic measurements so as to quantify in detail the gaseous products up to toluene, assisting in this respect the optimization of the performance of the in-house detailed kinetic mechanism [7]. Furthermore, potential drop-in fuels, which may originate from natural gas or coal feedstock through the Fischer-Tropsch process, have been tested in a premixed laboratory flame burner via temperature and emission measurements which were combined with an analytical methodology that allowed the systematic evaluation of combustion trends to fuel constituent compounds [8]. Finally, a fruitful combination of computational and experimental tools has been realized in applied research fields directly relevant to engine combustion [9, 10, 11].

A significant research effort has been placed in describing the combustion in porous media [6, 12, 13, 14]. Intrusive and nonintrusive tools are combined to characterize stable species as well as radical concentrations from a random foam porous burner. *OH - LIF* experiments were performed in order to parametrically examine the burner operating regimes, through flame the visualization inside porous media, and subsequently, the burner stability, emission characterization and fuel interchangeability with conventional as well as alternative fuels, has been thoroughly tested with respect to operating conditions.

HMCS is additionally active in fire research focusing on the experimental and numerical investigation of transient effects of Externally Venting Flames (EVF) in under-ventilated compartment fires [15, 16, 17]. In a compartment fire, Externally Venting Flames may significantly increase the risk of fire spreading to adjacent floors or buildings, especially today that there is an ever-increasing trend of using combustible materials in building facades. The main scope of the ongoing work is to investigate the fundamental physical phenomena governing the transient development of EVF, employing both experimental and numerical simulation methodologies.

A series of under-ventilated compartment-facade fire experiments, employing a 1/4 scale model of the ISO 9705 room, equipped with an extended facade (see 3), has been performed. An "expendable" fuel source, i.e. n-hexane liquid pool fire, is used to effectively simulate realistic building fire conditions. Experimental results provided a detailed insight regarding the transient nature of the EVF and the effect of varying the investigated parameters. Recording of the dynamic behaviour of the EVF is carried out using an extensive sensor network that allowed monitoring of important physical parameters, such as flame envelope geometry, gas and wall surface temperatures, facade heat flux, fuel mass loss and gas species concentrations. A dedicated image-processing tool has been developed, aiming to monitor the dynamically changing shape of the flame envelope (e.g. height, width, projection). The EVF geometry and duration were found to be mainly affected by the opening dimensions, whereas the fuel load has a significant impact on the heat flux to the facade.

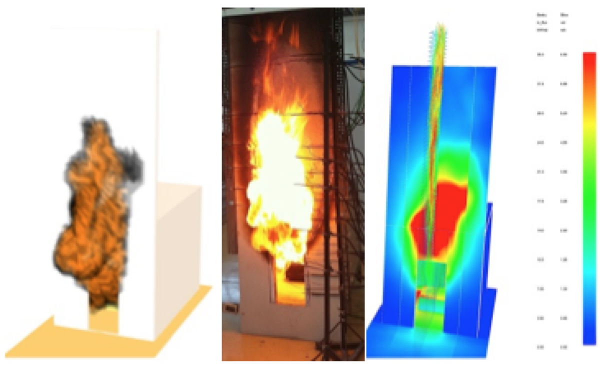

Figure 3: Schematic of the experimental facility and measurement setup (left) and predictions of flame envelope (middle), velocity vectors and heat flux on the facade (right)

The Fire Dynamics Simulator (FDS) CFD tool, which utilizes the Large Eddy Simulation approach, was used for the numerical simulation of the turbulent, multi - component and reactive flow field developing in the medium scale compartment-facade configuration. Numerical results of the temporal evolution of gas velocity, gas and wall temperatures, heat flux on the facade wall and flame shape were obtained at both the interior and the exterior of the compartment. Predictions were compared to respective experimental data; good qualitative, and occasionally quantitative, agreement was observed for all the considered test cases.

Current *research* of HMCS is financially supported mainly through EU - funded research projects. Indicatively:

- ECCO-MATE: Experimental and Computational Tools for Combustion Optimization in Marine and Automotive Engines (FP7-PEOPLE, 2013-2017)
- HELMETH: Integrated High–Temperature Electrolysis and Methanation for Effective Power to Gas Conversion (FCH JU, 2014-2017)
- AMANAC-CSA: Advanced Material And NAnotechnology Cluster (H2020, 2015-2016)
- ELISSA: Energy efficient lightweight-sustainable-safe-steel construction, (FP7-EeB, 2013- 016)
- DAPHNE: Development of adaptive ProductioN systems for Eco-efficient firing processes (FP7-FoF.NMP, 2012-2015)
- MESSIB: Multi-source Energy Storage System Integrated in Building (FP7-NMP-2007-LARGE, 2009-2015)
- GtoG: Gypsum to gypsum from cradle to cradle - a circular economy for the European gypsum industry with the demolition and recycling industry (Life+, 2013- 015)
- FIRE-FACTS: Basic and applied research in multi-scale compartment fires (GSRT, 2012-2015)
- FC-DISTRICT: New μ-CHP network technologies for energy efficient and sustainable districts (*FP7 - EeB*, 2010-2014)

The HMCS is also actively involved in the European Cooperation in Science and Technology (COST) network though actions CM0901: Detailed chemical kinetic models for cleaner combustion and its follow-up action CM1404: Chemistry of Smart Energy Carriers and Technologies (SMARTCATS).

L2. *Parallel CFD and Optimization Unit*
Contributed by: Prof. Kyriakos Giannakoglou

The Parallel CFD and Optimization Unit (PCOpt) of the Fluids Dept. of the School of Mech. Engineering of NTUA develops modern CFD-based optimization methods, for aero/hydrodynamic shape and topology optimization problems [18, 19, 20, 21, 22]. These include gradient-free (stochastic) and gradient-based methods coupled with the adjoint approach, based on CFD s/w. As such, either OpenFOAM or the in-house GPU-enabled RANS solver which may predict incompressible up to transonic flows, are used. The in-house code runs on modern NVIDIA GPUs by making use of the CUDA parallel computing architecture, with a speed-up of about x60 compared to the corresponding CPU code. Development and computations are performed on the PCOpt computational platform. This comprises three clusters with 44Teraflop computing power in total. The basic cluster consists of 58 Dell PowerEdge nodes with 528 cores and 1.4TB RAM in total (each node has either 2xQuad or 2xSix core Xeon CPUs and 8 to 48 GB RAM). The GPU cluster consists of 4 HP SL390s servers (with 12 NVIDIA Tesla M2050, in total) and 4 Dell PowerEdge C8220X nodes (with 8 K20/K40 NVIDIA GPUs, in total) and 56 GB GPU RAM. A third cluster with 32 nodes (80 cores, 105 GB RAM in total; some of them equipped with GTX 280, 285, 580 GPUs) is used by the BSc/MSc students.

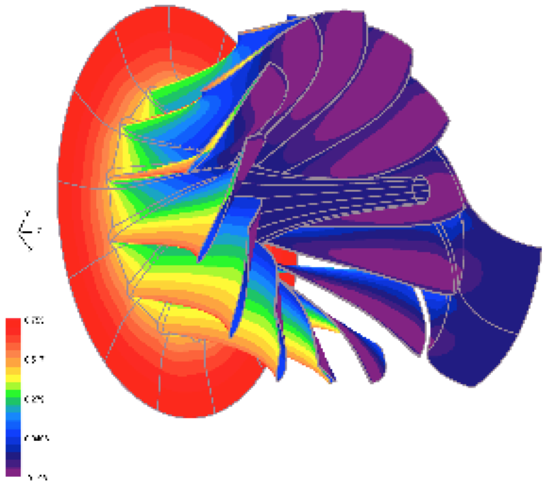

Figure 4: Two-objective design of a Francis runner at three operating points yielding desirable outlet velocity profile and blade loading. Computed pressure distribution on the optimal runner. Since this problem involves 372 design variables, the PCA-driven dimensionality reduction techniques of EASY were used to handle it with affordable computational cost. Industrial application by Andritz-Hydro [18]

Regarding *gradient-free optimization* (stochastic, population-based), current research focuses on the further development of the Cluster- and Grid-enabled optimization platform EASY (Evolutionary Algorithm SYstem, `http://velos0.ltt.mech.ntua.gr/EASY`), developed and brought to market by the PCOpt in 2000. EASY is based on multilevel, distributed, metamodel-assisted EAs and is appropriate for single- and multi-objective problems with computationally demanding evaluation (CFD) tools. To make EASY a viable tool for use in real-world applications with many design variables, techniques for dimensionality reduction (through a principal component analysis) are employed. EASY is used by several academic groups and companies in a variety of applications.

Regarding *gradient-based optimization*, emphasis is laid on the development of continuous (occasionally, discrete too) adjoint methods. This has led to new continuous adjoint formulations for the computation of first-, second- (required by any "exact" Newton method) and third-order (for solving design problems under uncertainties based on the method of moments) sensitivity derivatives. The developed adjoint methods run with both OpenFOAM and the in-house GPU-enabled RANS solver, for a variety of objective and constraint functions. Among other, three novel contributions can be reported: (a) new, exact continuous adjoint methods for RANS turbulence models; the most widely used one- and two-equation turbulence models are differentiated, avoiding thus the usual assumption of neglecting turbulence variations ("frozen turbulence" adjoint); the latter might become detrimental since it may produce wrongly signed sensitivity derivatives and mislead the search algorithm, (b) a new continuous adjoint method for RANS models based on wall functions, which can be used for low-CPU-cost industrial problems such as those encountered by the car industry and (c) a new continuous adjoint formulation which, for the first time, takes into account mesh sensitivities, with the minimal computational cost. Apart from shape and topology optimization, the optimization of active flow control systems (steady and pulsating jets) is also carried out using the developed methods. Regarding the computation of higher-order sensitivities, research focuses on the reduction of the design turnaround time, i.e. on keeping the cost of solving the additional PDE systems (resulting from the direct differentiation of the flow and adjoint equations) almost independent from the number of design variables. Recent activities are also directed towards the use of polynomial chaos for uncertainty quantification and the corresponding adjoint-based optimization.

Next to the above methods, various mesh displacement techniques (Laplacian models, models using linear and torsional springs, RBF models, volumetric NURBS, harmonic coordinates, etc) are available to support the optimization loop and avoid remeshing; some of the above tools are also used as morphing techniques, in order to get rid of the direct shape parameterization.

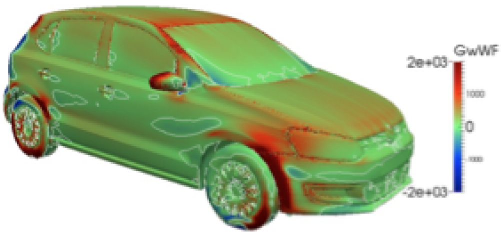

Figure 5: Sensitivity map of the VW Polo car targeting min. drag force, computed by the continuous adjoint method of PCOpt. To reduce drag, red areas should be displaced inwards and blue areas outwards. Research funded by Volkswagen AG

All the aforementioned methods have been used in internal/external aerodynamics (including turbomachinery and automotive) applications; two indicative applications are shown in 4 and 5. PCOpt has longstanding collaborations with European companies such as Volkswagen AG and other automotive industries, Andritz Hydro, Schlumberger, NUMECA. In addition, PCOpt participates/has participated in several EU-funded projects such as HISAC, ACFA2020, RBF4Aero, AQUAGEN, ABOUTFLOW, IODA, HYDROACTION.

A detailed description of the modern research activities of the PCOpt/NTUA can be found in the ERCOFTAC Bulletin (vol. 102, March 2015) dedicated to the activities of the ERCOFTAC Special Interest Group (SIG) 34 on Design-Optimization which is chaired by Prof. K. Giannakoglou.

3.2 Aristotle University of Thessaloniki, Department of Mechanical Engineering

L3. *Laboratory of Applied Thermodynamics*
Contributed by: Prof. Zissis Samaras, Assoc. Prof. Leonidas Ntziachristos, Assoc. Prof. Grigoris Koltsakis.

The Laboratory of Applied Thermodynamics (`http://lat.eng.auth.gr`) is part of the Energy Department of the School of Mechanical Engineering, in the Aristotle University of Thessaloniki, Greece. LATs educational and research activities cover the following fields:

- Applied Thermodynamics and Combustion
- Internal Combustion Engines and Emissions Control
- Emissions Inventories and Forecasts
- Energy Policy and Renewable Energy Sources

The main focus of LAT activities is on applied as well as basic research, regarding exhaust emissions control of Internal Combustion Engines [23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. LAT possesses state-of-the-art equipment and know-how on both testing and simulation methodologies in the field of engine emissions characterization and exhaust after treatment. LAT also provides R& D services in both these fields of automotive exhaust emissions and after treatment technology.

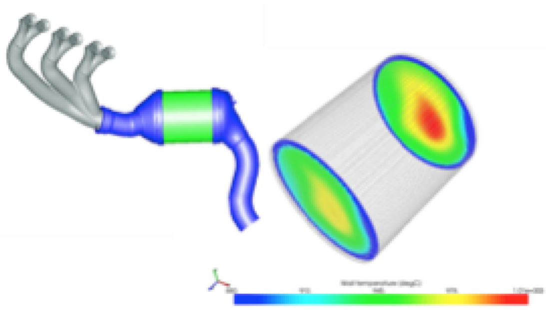

Figure 6: Simulation of reacting flow and thermal field in a 3-way catalyst under full-load operation using 3-d CFD/axisuite coupling

LAT is associate member of EARPA (European Automotive Research Partners Association), EGVIA (European Green Vehicle Initiative Association) and ERTICO-ITS (European Road Transport Telematics Implementation Co-ordination Organisation). LAT is also certified by QMS, as conforming to the requirements of ISO 9001:2008. The head count of LAT involves 1 professor, 2 assoc. professors, 1 emeritus professor, 6 post-doctoral researchers, 14 PhD candidates and also 3 technical and 2 administrative staff. Since 1990, LAT faculty staff has supervised more than 30 PhDs, has published more than 150 scientific papers and counts more than 3000 citations.

LAT facilities stretch over an area of 650 m^2 within the Aristotle University Campus. 400 m^2 are occupied by laboratory facilities, while the remaining

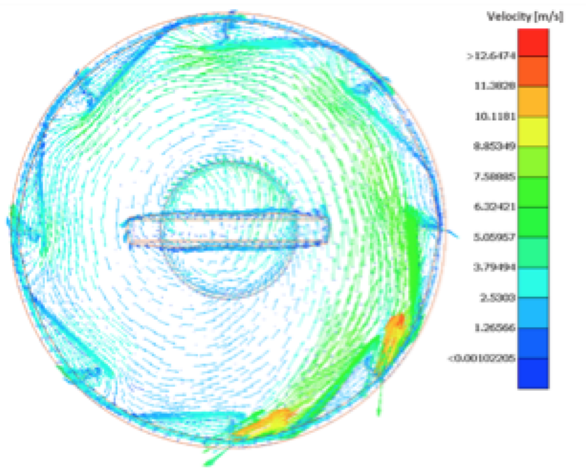

Figure 7: Gas velocity vectors in a Stoneridge soot sensor (visualization performed in μETA)

250 m^2 are office space. The main testing facilities in LAT include one chassis dyno for vehicle emissions testing, 3 fully equipped engine benches for emissions testing of gasoline and diesel engines, one fuel injector test rig and a mobile biomass gasification demonstration unit for electricity production. In addition LAT operates a complete synthetic gas bench test rig for detailed catalyst characterization. Its instrumentation consists of, among others, 15 gas analysers including a portable emission measurement system (PEMS), 18 particle measurement devices, a "clean roo" and two precision balances for PM filter weighing, a Thermogravimetric analyser, a 20kW fluidized bed reactor.

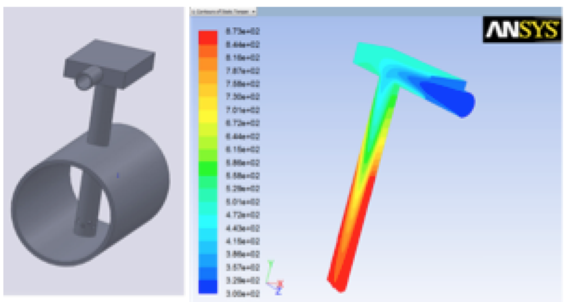

Figure 8: Pegasor dummy sensor geometry mounted on the exhaust (left) and temperature contour during operation (right)

LAT carries a 35-year long tradition in the field of characterization & control of automotive exhaust emissions. Valuable experience has been gained through close collaborations with the automotive and fuel and the supplier s industry. Currently, the focus research areas include:

- Diesel and gasoline-engine after-treatment technologies (including diesel particulate filters, oxidation catalysts, lean NOx traps, SCR systems, three-way catalytic converters, gasoline particle filters)
- Particulate matter and number measurement techniques
- Soot sensor prototyping
- Effect of fuel properties and fuel additives
- Renewable energy production from agro-industrial residues

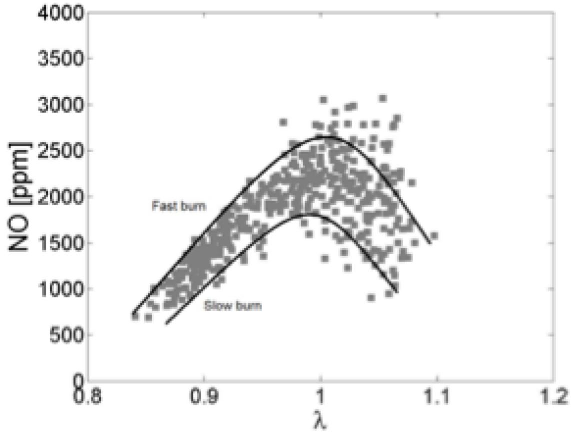

Figure 9: Impact of cycle-to-cycle variation on NO emissions from a spark-ignition engine

Mathematical modeling of complete exhaust systems is supported by the commercial software axisuite (Exothermia SA) originally developed at LAT.

The 3-D modeling work is supported by commercial software for 3-D Fluid Dynamics Calculations (Star-CD and CCM+ and ANSYS FLUENT) and advanced geometry meshing (BETA CAE ANSA & ÎijETA). Coupling of CFD codes with axisuite is also possible and is frequently used to study the effects of exhaust system design on emissions performance (6).

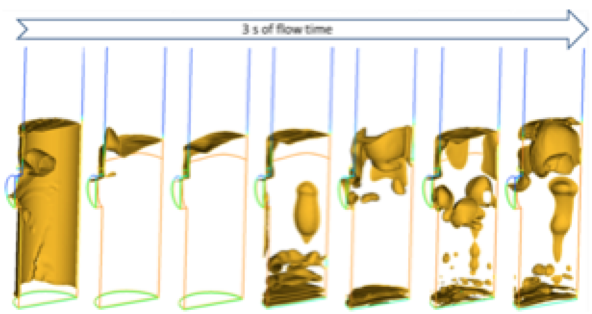

Figure 10: Iso-surface of 50% sand volume fraction in a bubbling fluidized bed reactor (visualization performed in μETA)

Other examples of LAT modeling activities include: a) Development of physical models of prototype soot sensors (7,8) b) Combustion modelling for the prediction of in-cylinder pollutant formation using detailed chemical mechanisms and accounting for the impact of cycle-to-cycle variability (9) c) 2D and 3D transient fluidization of biomass gasification in a fluidized bed reactor (10).

LAT has coordinated and participated in several projects providing experimental and modeling services. A sample of modeling-oriented projects includes:

- LESCCV - Large-Eddy Simulation and System simulation to predict Cyclic Combustion Variability in gasoline engines (EU funded)
- Validation of SCR Control Systems through modeling (funded by PSA Peugeot Citroen)
- Development and Evaluation of a particulate sensor for OBD (funded by Pegasor Oy)
- Developing a New Concept Rotary Engine (funded by Honda R& D Europe)
- Technical Support for the development of a Soot Sensor (Stoneridge Inc)
- HiCEPs – Highly Integrated Combustion Electric Propulsion System (EU funded)

LAT has founded Exothermia S.A. (2007) and EMISIA S.A. (2008), two spin-off companies specialized on software engineering for exhaust aftertreatment applications and emission inventorying, emission modelling and impact assessment studies of environmental policies, respectively.

L4. *Laboratory of Heat Transfer and Environmental Engineering*
Contributed by: : Prof. Nicolas Mousiopoulos, Dr. Fotios Barmpas, Dr.George Tsegas

The Laboratory of Heat Transfer and Environmental Engineering (LHTEE) belongs to the Energy Section of the Mechanical Engineering Department of Aristotle University Thessaloniki, Greece. Founded in 1990, LHTEE is responsible for eleven pre-graduate courses in the Mechanical Engineering Department, while also supervising several doctoral candidates in the frame of their post-graduate studies. Furthermore, it has a long record of research and consulting activities, both at national and international level, having successfully completed over 150 projects. The Laboratory staff includes 2 Professors, 7 permanent staff members and about 20 co-workers, mostly engineers on a contract basis. Most of the research funds of the Laboratory originate from competitive programmes of the European Commission or from industry. In the last ten years, the turnover of the Laboratory exceeded five million euro. Results of our research efforts are published in peer-reviewed journals and in the proceedings of national and international conferences. Since 2002, highlights of LHTEE's activities are presented every year in our Annual Report "Sustainability Dimension", available online through the Laboratory's official website at `http://aix.meng.auth.gr`.

LHTEE conducts research mostly in the fields of energy systems and environmental engineering. Emphasis is given on the rational use of raw materials and energy, air quality issues, the assessment of the environmental burden caused by various processes and the optimisation of environmental control and management practices. Scientific work spans over a wide range of areas, from air pollution modelling to the analysis of low energy buildings, and from recycling studies to Life Cycle Assessment (LCA) and Ecodesign. The multidisciplinary approach adopted by the Laboratory staff allows arriving at innovative solution concepts that may constitute useful steps towards sustainability.

One of the main areas of LHTEE's research work is the simulation of transport and chemical transformation of pollutants in the atmosphere with the use of advanced air quality models, with emphasis on the assessment of urban air quality. The Laboratory is also involved in Air Quality Management through the assessment of various measures for reducing air pollution levels, and the impact analysis of industrial activities and major public works on air quality. In addition, the Laboratory provides practical support to public authorities and the private sector within its area of activities through the development of integrated environmental assessment tools with the use of informatics technologies.

LHTEE holds a long experience in the development and application of case-specific, advanced numerical modelling techniques for environmental purposes. More specifically, as regards the prediction of environmental flows and the dispersion of air pollutants in urban areas, the emergence of increasingly powerful computers enabled the development of state-of-the-art formulations for resolving atmospheric turbulence in meteorological and air quality models. Extensive research is being carried out on transient, three-dimensional computational fluid dynamics approaches for the numerical simulation of the transport of air pollution from the main emission sources near the vicinity of urban structures in indoor environments, under external flow [33, 34, 35]. Towards this purpose, the implementation of both Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES) schemes is at the moment under investigation in order to better describe the highly turbulent atmospheric flows.

Emergency management and safety assessments are an important part in the design and operation of tunnels. With the help of detailed analyses of possible accident scenarios, effective safety equipment can be installed and in the case of a real event, adequate countermeasures can be taken. As the most immediate threat to human life during road tunnel fires results from the effects of smoke inhalation rather than from direct exposure to heat, a variety of models have been developed, in order to analyse the possible life threatening effect of a number of fire related parameters, such as the released thermal energy and the amount of smoke generated. For this purpose, LHTEE has been keen to study the rise, the deflection and the spread of fire gases during fire episodes for emergency management purposes with the employment of both Reynolds Averaged Navier Stokes (RANS) and Large Eddy Simulation (LES) numerical modelling techniques.

An active research area of the Laboratory involves the refinement and application of computationally efficient multi-scale coupling approaches for the calculation of air flow and pollutant dispersion over urban areas. Moreover, the Laboratory aims to incorporate novel modelling approaches for the description of local scale aerosol dynamics, to its existing arsenal of models. Focusing on ultrafine exhaust particles, the investigation of accurate exposure patterns in relation to urban street traffic enables the improved assessment of impacts to human health. Within the frame of COST Action ES1006 (`http://www.elizas.eu/`), the Laboratory played a leading role in the development of an integrated modelling tool for managing accidental or deliberate releases of hazardous agents in complex built environments. The Laboratory has also participated in the COST Action ES1004 (`http://eumetchem.info`), where online integrated air quality and meteorology modelling was investigated, focusing on the significance of two-way interactions between various atmospheric processes.

In the context of addressing the impacts of multi-scale interactions on environmental flows with focus on the lower parts of the Atmospheric Boundary Layer (ABL), over the past three years LHTEE has been active in the assessment of the efficiency of large scale wind farms and their optimisation in terms of increased energy production at a reduced cost. To this end, an integrated numerical tool has been under development for the quantification of the impacts of the “wake effec” within a wind farm, the effects of topography and the varying weather conditions on the efficiency of the wind farm. In addition, the application of this state-of-the-art numerical tool allows addressing the potential impacts of wind farm operation on local climate, mainly as a result of the pulling down of warmer near-surface air from higher altitudes. Given the EU strategy in favour of Renewable Energy Sources (RES), this tool will provide significant support to decision makers towards increasing the awareness of local communities for the potential benefits and costs, both socioeconomic and environmental, in an effort to promote large scale investments mainly for offshore wind farms.

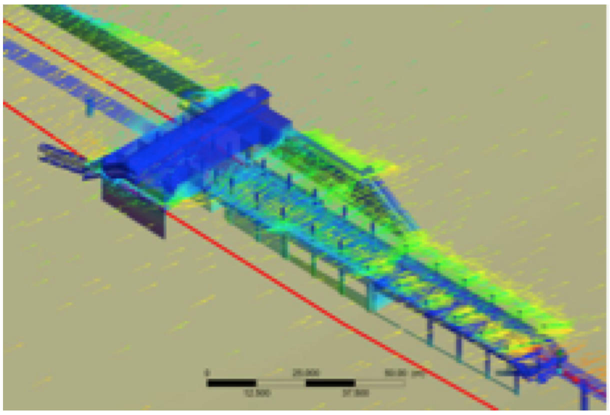

Figure 11: Simulated wind field over a metro station in Manila, Phillipines

The computational infrastructure of the Laboratory includes:

- A 20 CPU Intel Xeon E312xx with a total of 64 GB of available memory
- A 16 CPU Intel Xeon E7320 with 36 GB of available memory
- Access to bwUniCluster supercomputing facility at the German federated HPC competence centers of tier 3

Regarding specific modelling techniques, the Laboratory currently operates MIMO and MEMO for environmental flow problems, two models which were developed internally, MIMO belonging to the family of Computational Fluid Dynamics (CFD) tools. Both models are presently supplemented by simpler tools that are based on a statistical description of the urban area as distinct from the resolution of specific buildings and obstacles. Other models which are currently employed by LHTEE include MARS, which is used for the comprehensive simulation of the dispersion and chemical transformation of air pollutants, OFIS, which is a simplified model used for urban air quality assessment and OSPM an operation model for the dispersion of traffic emitted air pollution in streets. In addition, for industrial applications flow problems LHTEE also operates ANSYS 16.2.

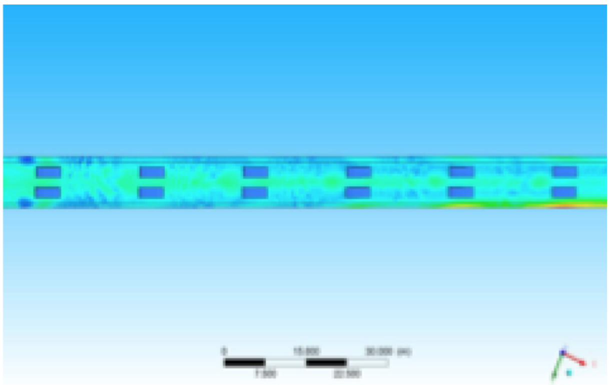

Figure 12: Simulated pressure distribution inside a road tunnel under the influence of the vehicles motion

Some indicative recent EU-funded research projects are listed below:

- ACCENT (Atmospheric Composition Change - The European Network of Excellence)
- AEROHEX (Advanced Exhaust Gas Recuperator Technology for Aero-Engine Applications)
- APPRAISAL (Air Pollution Policies foR Assessment of Integrated Strategies At regional and Local scales)
- A-TEAM (Advanced Training System for emergency management)
- ATREUS (Advanced Tools for Rational Energy Use towards Sustainability with emphasis on microclimatic issues in urban applications)
- Cyprus AQMS (Development of an operational web-based system for Air Quality Management in Cyprus)
- MEGAPOLI (Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation)
- PHOTOPAQ (Demonstration of Photocatalytic remediation Processes on Air Quality)
- PICADA (Photocatalytic Innovative Coverings Applications for Depollution Assessment)
- PM3 (Particulates Monitoring, Modelling and Management)
- RESPOZE-children (Respiratory effects of ozone exposure in Greek children)
- TRANSPHORM (Transport related Air Pollution and Health impacts - Integrated Methodologies for Assessing Particulate Matter)

3.3 University of Patras, Department of Mechanical and Aeronautics Engineering

L5. *Laboratory of Applied Thermodynamics*
Contributed by: Assoc. Prof. Thrassos Panidis, Assoc. Prof. Panagiotis Koutmos, Lecturer Dr. Konstantinos Perrakis.

(`http://www.lat.upatras.gr`) has more than 40 years involvement in teaching and research in the fields of turbulence and combustion. Besides ERCOFTAC, LAT is a member of the European Aeronautics Science Network Association (EASN) and the Environmentally Compatible Air Transport System (ECATS) International Association. It is also accredited under ISO/IEC 17025 to carry out reaction to fire tests according to ISO 5660.

The educational activities cover Thermodynamics, Transport Phenomena of momentum, heat and mass in single and multiphase systems, Combustion and Propulsion. The LAT personnel consists of (3) faculty members, (3) postdoctoral fellows, (7) doctoral researchers, several graduate students and machine and electronics technicians.

The Laboratory has participated in numerous research and training programs funded by European and National organizations and the Industry, in the fields of Energy, Aeronautics and the Environment. Research activities cover the areas of Heat Transfer, Fluid Mechanics, Two-Phase Flows, Spray Dynamics, Combustion and Fire Technology, with application in the fields of Aeronautics, Energy Systems and the Environment.

The Lab is equipped with suitable experimental facilities such as wind tunnels and spray test rigs, combustion rigs and physicochemical reactors. It has a long standing expertise in developing test rigs and manufacturing specialized devices with advanced technologies. The suite of tools that are available for performing measurements and monitoring tasks include H/W anemometry (TSI), high temperature T/Cs, LDA-PDA (Dantec), 3-D PIV (Lavision), OH^* and CH^* chemiluminescence imaging (FlowMaster-Lavision), high speed Schlieren and exhaust gas analysers and FTIR (Perkin Elmer). Computational capabilities include Fluent, OpenFoam, LaminarSMOKE, Chemkin, CANTERA.

Some selected recent research activities are described below:

Rectangular and round jets: The identification and control of the mechanisms that dominate the flow field and mixing of jets is of importance to several applications. Significant experimental and numerical work is performed on round and rectangular jets focusing on the influence of the initial and boundary conditions and the significance of vorticity on the development of the flow field in collaboration with Queen's University, CA [36, 37, 38].

Interaction of co-rotating vortex pair: The interaction of a co-rotating vortex pair was studied using a split wing configuration (2 NACA0030 wings at equally opposite angles) at Re^c=133000. A dipole, of opposite streamwise mean vorticity, characterises each vortex. The adverse streamwise pressure gradient due to rotation leads to a large streamwise velocity deficit characterizing the vortices. After shedding and formation, the two vortices are swept downstream spiralling around each other and forming a braid CA [39]. Measurements were obtained using *Multi-sensor hot wire anemometry* allowing direct measurements of the velocity gradients and vorticity components. Micro-manufacturing techniques are nowadays developed in collaboration with Saarland University, DE, for the construction of miniature hot wire probes CA [40].

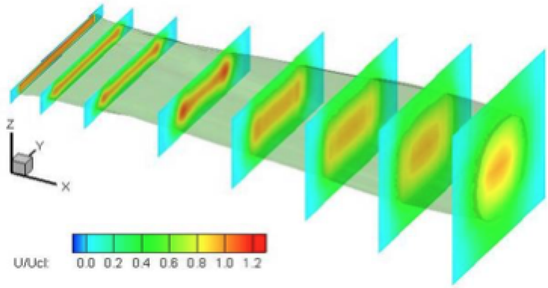

Figure 13: Development of a rectangular jet

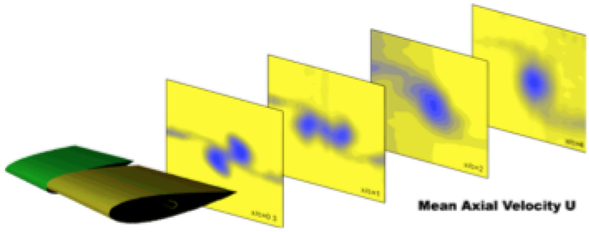

Figure 14: Merging of a co-rotating vortex pair

Flammability properties of aircraft materials and their contribution to hidden fires: The increasing use of composite materials in modern aircrafts introduces concerns about their behavior in case of a fire. Several materials used in aircraft cabins and hidden areas have been tested using TGA, DSC and Cone Calorimeter along with FTIR spectroscopy. A testing devise was developed able to characterize the material behaviour in hidden fires providing among others information on fire spreading and heat and toxic products release rates. Experiments are accompanied by numerical simulations [41, 42].

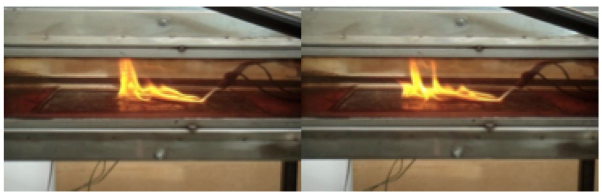

Figure 15: Fire spreading in Hidden Fire Apparatus

Biological flows: The hemodynamic field of an occluded artery with an "end to side" anastomosis is studied in order to provide insight on the development of the flow field and its impact on the long term effectiveness of bypass operations. PIV measurements highlight the development of flow patterns due to interaction of the arterial stenosis with a bypass graft in a pulsating flow [43].

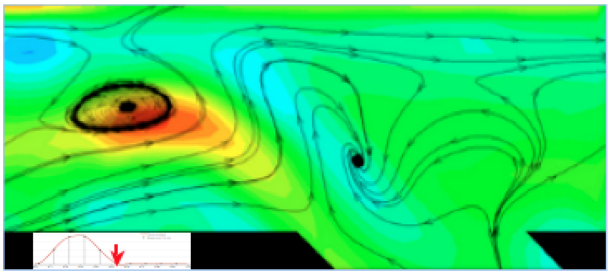

Figure 16: Vorticity and streamlines in the anastomosis region

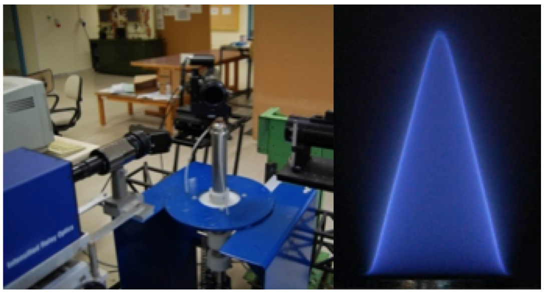

Figure 17: Bunsen burner and flame arrangement

Fundamental laminar flame speed studies: To aid in the design and optimization of energy production systems LAT has developed a versatile experimental Bunsen burner flame configuration along with a user friendly automated protocol for the determination of fundamental laminar flame combustion parameters. Laminar flame speed is one of the most important, observable, traditional, key scaling, target parameters, as its characterization offers fundamental information regarding reactivity, diffusivity and exothermicity of the fuel mixture. The exploitation of this experimental facility and methodology, offers an attractive and cost effective procedure for routine flame speed evaluations over a variety of practical fuel blends at laboratory and industrial level [44].

Studies of buoyant fires and plumes: The objective of these concerted efforts on buoyant flames and fires, in cooperation with local authorities, is to improve understanding of the mechanisms that control open or enclosed fires with the aim to achieve successful models to mitigate their effects. Measurements and simulations are used in a series of experiments related to water mist suppression of axisymmetric fires, identification of line fire base characteristics, control of onset of fire whirls and aerial water bombardment of ground fires [45].

Studies of large scale vortex dynamics in square cylinder reacting wakes: A challenge in bluff-body turbulent combustion modelling is the influence of large scale structures and the time-varying flow on flame characteristics such as stability, heat release and emissions. Turbulent flame stabilization by planar, counter- or con-current fuel injection across the span of a square cylinder in cross-flow is studied in a range of experiments and LES [46, 47].

Investigations of reacting swirl flows under fully premixed, stratified or vitiated conditions: Experiments

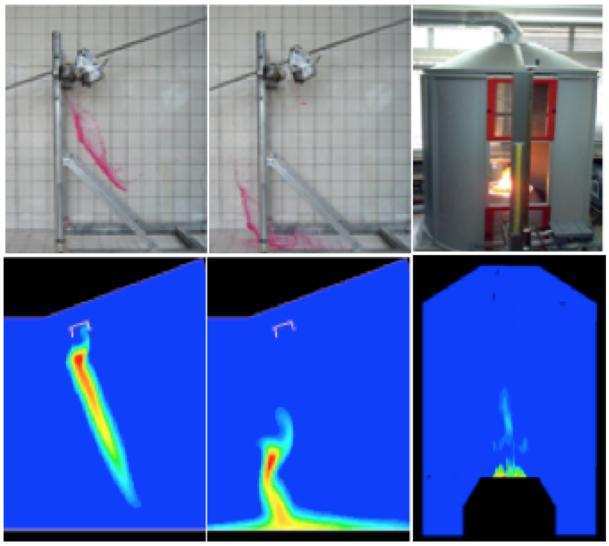

Figure 18: Water bombardment of ground fire (Exp, Sim) and, Axisymmetric fire plume (Exp, Sim)

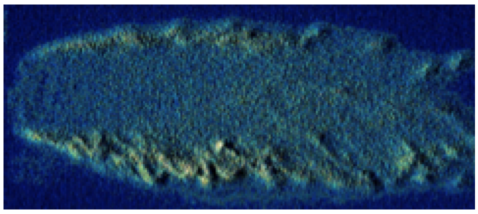

Figure 19: Chemiluminescence image of Kelvin-Helmholtz vortices in reacting wake

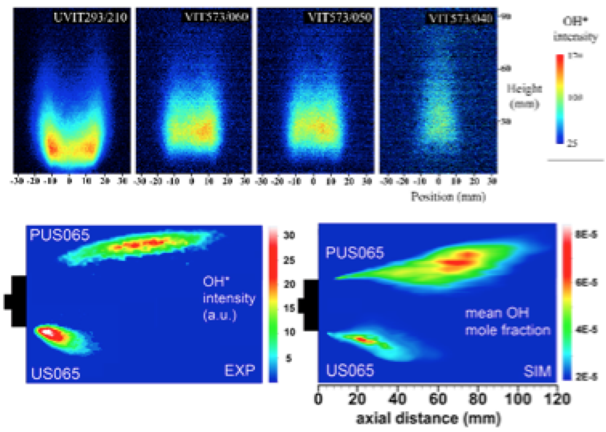

Figure 20: Effect of vitiation or stratification at ultra-lean flame operation

and LES of disk stabilized propane flames established through staged fuel-air premixing in an axisymmetric double cavity premixer arrangement are performed for a variety of lean or close to blow-off inlet mixture conditions. Measurements and LES of turbulent velocities, temperatures, OH^* and CH^* chemiluminescence, major species concentrations and overall efficiencies are assessed to elucidated the influence of variations in mixture stratification or vitiation on local and global flame performance [48, 49].

3.4 University of Western Macedonia, Department of Mechanical Engineering

L5. *Laboratory of Applied Thermodynamics*
Contributed by: Prof. Ananias Tomboulides, Prof. Antonios Tourlidakis, Dr. Dimitrios Kolokotronis.

The Laboratory of Thermodynamics and Combustion engines (LTCE) is a laboratory in a young department with fifteen faculty members. The Division for Energy Production and Transfer teach Applied Thermodynamics, Fluid Mechanics, Combustion Engines, Thermal Power Systems, Renewable Energy Sources and Turbomachinery. Also advanced courses on Power Generation, Combustion Phenomena, Computational Fluid Dynamics, and large-scale scientific computing applied to flow and combustion.

Research activities concentrate in CFD and Combustion with several research projects:

- EU projects for the computational study of flows with combustion and premixing, Cycle-to-cycle variations of combustion in internal combustion engines, etc [50, 51, 52].
- Project (General Secretariat for R& T and Public Power Corp.) for the optimization of thermo-electric energy production with emphasis in computational combustion and problems of turbine corrosion in two-phase flow.
- Project funded by the Region of W. Macedonia on modern analysis techniques in thermal power generation [53, 54].
- Projects related to combustion and turbine/ pump power in power generation stations.
- Projects related to the behaviour of bio-fuels sprays with applications in internal combustion engines
- Projects funded by industry, related to aerodynamic - turbulence generated sound by baffled silencers.

The infrastructure consists of the following:

Experimental facilities: Subsonic wind tunnel, hot wire anemometers, a portable gas analyzer, high accuracy scales and a bomb calorimeter. Instrumentation for optical measurements in fluid mechanics and combustion include an Nd-Yag laser with double pulse capabilities, a Dye Laser, an ICCD camera for PIV and PLIF measurements in reacting, non-reacting and multi-phase flows. There are also two laser power-meters to support the laser operation for the above measurements.

There is also a variable flow (with inverter fans) wind tunnel with anechoic termination which is being used for the measurement of sound insertion loss and air regenerating noise of several baffled silencers, manufactured according to ISO 7235. This setup is accompanied by microphone with an acquisition system, pressure transducers for the determination of the pressure loss induced by the silencers and flow meters.

Moreover, the laboratory has an optical engine - dynamometer test cell which is used for the investigation of combustion and mixing in real like internal combustion engines.

Figure 21: Optical Engine -Dynamometer Setup

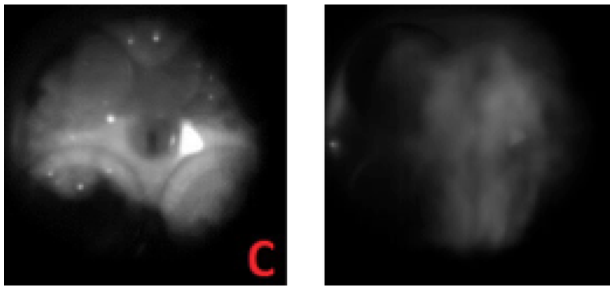

Figure 22: Flame (Left Side) and Spray (Right Side) Image inside the Cylinder of the Optical Engine

Additionally, the infrastructure includes a stack gas analyser for CO, CO2, HC, O2, NOx engine emissions measurements and a high frame rate camera (up to 100000 fps) for flame development and other fast time scale thermofluidic applications visualisation.

Computational Infrastructure: 64-processor (AMD 2218 2.6GHz), 32-processor Linux cluster with Intel 2.8GHz processors in a rack arrangement, used for parallel flow and combustion simulations. There are also networked PCs and workstations, in a 16-PC cluster system as well as additional 1- and 2-processor computers for pre/post-processing and simulations.

Software: The codes used are either in-house MPI-based parallel codes, based on spectral and spectral element methods (e.g. nek5000), or commercial (StarCD and Ansys-CFX).

Applications are mainly in computational combustion [55, 56, 57] and turbomachinery aerodynamics and international collaborations include ETHZ and Argonne National Laboratories as well as others.

Prof. Tomboulides has been appointed Chairman of ERCOFTAC since 2012; in the past he was the coordinator of ERCOFTAC SIG28 on combustion and the national representative of the COST Action P20 LES AID for the application of LES methods in complex industrial systems. He has been member of the organizing committee of the "Engineering Turbulence Modeling and Measurements (ETMM)" series of conferences since 2008.

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70th *Birthday Anniversary of Professor W.K. George*

William K George is a university professor holding both Swedish and American citizenships. Born in **Camp Shelby, Mississippi** in 1945, George graduated from Cambridge, Maryland High School as valedictorian. He attended the **Johns Hopkins University in Baltimore, Maryland on a Maryland State Senatorial scholarship** and received his BES degree from in 1967 in Engineering Physics. He continued at Johns Hopkins for doctoral work and received his Ph.D. Degree in Mechanics under the supervision of **John L. Lumley** in 1971. In 1968, he joined the faculty of the **Pennsylvania State University**, University Park, where he held positions in both Aerospace Engineering and the Applied Research Laboratory. In 1974, he left Pennsylvania State University and joined the Department of Mechanical and Aerospace Engineering at the **State University of New York at Buffalo**. He was promoted to Professor in 1980. George joined the Department of Applied Mechanics at the **Chalmers University of Technology, Gothenburg, Sweden** in September 2000 as Professor of Turbulence. Since retiring as Professor Emeritus from Chalmers in 2009, he has held positions with CNRS and Ecole Central de Lille in France, Imperial College of London, and Princeton University.

WKG has authored several hundred papers, mostly on turbulence and its applications. The number of citations of his work is measured in thousands, and his h-factor is near 40 (*Numbers compiled from Google Scholar. Note that the average number of citations for papers in the leading fluids journals is less than 2.*). He is known for his work on both theoretical and experimental turbulence. His contributions range from measurements in gas turbines and automotive components to fundamental studies of turbulent shear and wall bounded flows. Among his most significant contributions was the translation and editing in 1980-81 of WIND ATLAS FOR DENMARK, which provided a methodology for siting wind generators and has contributed much to the increasing popularity of this technology in Europe and around the world. He has supervised (or co-supervised) 30 PhD students and a large number of MSc students, all of whom hold responsible positions as professors, researchers, or engineers in leading establishments throughout the world. His academic descendents now extend through five generations and number more than 100.

Professor George has lectured extensively throughout the world and has presented numerous invited talks, including the 2006 AIAA Fluid Dynamics meeting, the 2003 American Physical Society/Division of Fluid Dynamics meeting, and the 2001 Australasian Fluid Mechanics meeting, among others.. Among his fellowships, honors and awards, the most recent are the 2008 Freeman Scholar Award from the ASME, the 2008 DCAMM scholar award from the Danish Center for Applied Mathematics and Mechanics, and the Ph.D. Supervisor of the Year award from Chalmers University in 2006. He was also a distinguished research fellow of the British Royal Engineering Academy and CNRS. Together with a former student and grandstudent, he received the Robert T. Knapp Award from the ASME Fluids Engineering Division 2002 for the best paper in 2001. He has been a Fellow of the American Physical Society since 1988. He is also a Fellow of the ASME and an Associate Fellow of the AIAA. From 2010 to 2012 he was named by the EU as Marie Curie Professor at Imperial College of London, and since has remained there as Senior Research Investigator. For the academic year 2013-2014 he was William R. Kenan Jr Professor of Distinguished Teaching at Princeton University.

George (Bill) has a wife, April Howard, and two children, Robert (deceased) and Tony. His hobbies have varied throughout his career. After moving to Buffalo in 1974 he became an avid skier and sailor. When a broken back in 1983 left him with a partially paralyzed leg and ended his beloved cross-country skiing, he took up down-hill skiing and dog-sledding. And while his children were small, for about a decade in the 1980's they managed a small farm with over 100 animals including cows, pigs, chickens and goats. He also holds an Amateur Extra ham radio license. After winning several local trophies for racing a Shark 24 sailboat in the late 1980's, he trained to become an off-shore sailor in the early 90's. In 1995, he and April (both licensed USCG captains) completed a transatlantic in their sailboat, a Vancouver 42 named WINGS. Since then they have sailed extensively throughout Northern Europe, often with PhD students aboard. Frequently they have lived aboard ship, including the first year when moving to Sweden and during visiting academic appointments, and most recently for three years at St. Katharines Dock in London. Since 2011 they have split their time between Europe and the 1929 home they inherited in Cambridge, Maryland, but have converted into a true Zero Energy Home powered entirely by the sun.

Luminita Danaila

In Memoriam of Jeroen Witteveen

It is with deep sorrow and sadness that we announce the passing **this summer** of our colleague Jeroen Witteveen, researcher at Centrum Wiskunde & Informatica (CWI) in Amsterdam, **and one of the coordinators of the ERCOFTAC "Uncertainty Quantification in Industrial Analysis & Design" SIG 45.**

Jeroen studied Aerospace Engineering at TU Delft and obtained both his Bachelors and Masters degrees with honours as well as his doctorate with honours, with a dissertation entitled Efficient and Robust Uncertainty Quantification for Computational Fluid Dynamics and Fluid-Structure Interaction, with which he participated also as a finalist to the ERCOFTAC Da Vinci competition. He then held two prestigious postdoctoral positions at TU Delft and Stanford University.

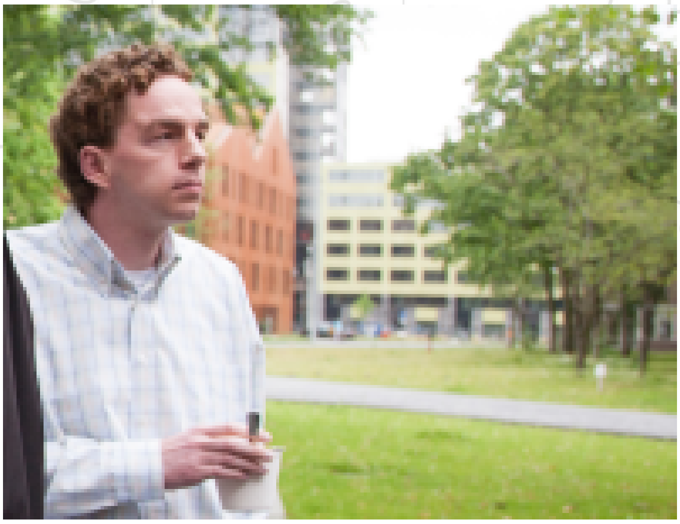
Jeroen began his promising career at CWI in 2013, taking a position as tenure track researcher in the Scientific Computing group. His research was characterised by a blend of modern, pioneering mathematics inspired by important social issues. Taken from his research statement on his personal website, Jeroens own words perhaps best outline his work: *One of the greatest challenges of this century is the transformation of our society into a sustainable energy economy. I am contributing to the necessary scientific progress and technological developments to reach this goal. To that end, my work focuses on the uncertainties in wind power generation from my background in computational fluid dynamics and uncertainty quantification.*

We will remember Jeroen as an amiable, **composed** and mild-mannered colleague. He was an extremely talented, passionate researcher with a strong commitment **to the field of Uncertainty Quantification in Computational Fluid Mechanics.** He was always open to cooperation and realised a range of successful collaborations, **both at his research center but also with external partners, including people from the SIG and within ERCOFTAC. He was very devoted to his duty in the group and actively participated to all of the workshops and meetings organized by the group since its creation.**

With his passing, Jeroen leaves a great void. We will miss him as a friendly, humorous colleague, but above all as a dedicated and inspired researcher.

We would like to pass on our heartfelt wishes to everyone who knew Jeroen as they come to terms with this sudden loss.

Bernard Geurts
and
Didier Lucor



ERCOFTAC Programme of Events in 2016

Organiser: Dr. Richard E. Seoud
richard.seoud-ieo@ercoftac.org

The below events, represent a set of two day courses, that bridges and builds on the available knowledge between Industry and Academia, where best practice and technology trends are the drivers. These courses are fundamental to how we disseminate FTAC knowledge in ERCOFTAC. The wide spectrum of topics engaged, indicates the deep level of capability and influence in the world of FTAC, which mirrors the level of commitments to our members and beyond. The list, is a season calendar update, that we aim to firm on all fronts by January 2016.

http://www.ercoftac.org/events/programmeof_events_v1/

1. Oil, Gas, and Petroleum - Best Practices and Technology Trends (II), Winter/Spring 2016
2. Lattice Boltzmann Methods for Industrial Apps: Overview, Guidance and Examples (I), Spring 2016
3. CFD for Dispersed Multiphase-Flows (VI), Summer 2016
4. High Order Methods for Industrial CFD, Autumn 2016
5. FSI , Acoustics and Big Data: Impact to Industrial Applications (II), Autumn 2016
6. Hybrid RANS-LES Methods for Industrial CFD: Overview, Guidance and Examples (VII), Autumn 2016
7. Best Practices in Combustion CFD, Flame Stabilization and Combustion Instabilities (II), Autumn 2016
8. Advanced Computing for Fluid Solver, Autumn 2016
9. Uncertainty Management and Quantification in Industrial Design and Analysis, Autumn 2016

11th International ERCOFTAC Symposium on
Engineering Turbulence Modelling and Measurements
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Major Themes

Modeling, simulation and analysis methods for turbulent flows with heat and mass transfer, combustion and multi-phase transport

Experimental techniques for flow, turbulence, combustion and environmental processes

Innovative applications of modeling, simulation and experiments to unresolved issues in energy, health and the environment

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Simone Hochgreb – Cambridge
Detlef Lohse – University of Twente
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Abstracts due: February 26, 2016
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ERCOFTAC Workshops and Summer Schools

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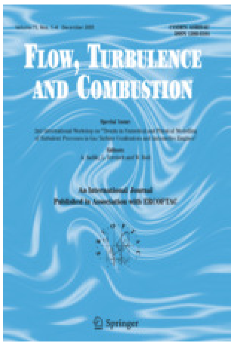
Title	Location	Date	Coordinators	Organiser
Modelling mixing and transport in Lakes, Estuaries and Harbours 2016 (MMTLEH16)	Trieste, Italy	?/02/2016	Armenio, V.	SIG 5
New Challenges in Turbulence Research IV	Les Houches, France	20-25/03/2016	Cambon, C. Godeferd, F.	SIG 35
New challenges in shear-driven and buoyancy-driven turbulent flows	Paris, France	5-6/05/2016	Cambon, C.	SIG 35
Gas Engine Combustion Fundamentals	Zurich, Switzerland	?/06/2016	Wright, Y.M. Boulouchos, K.	SIG 28
Uncertainty Quantification in CFD and Fluid Structure Interaction	Crete, Greece	5-10/06/2016	Sarkar, S.	SIG 45
13th International Workshop on Measurement and Computation of Turbulent Flames	Seoul, Korea	28-30/07/2016	Janicka, J. Barlow, R. S.	SIG 28
11th International ERCOFTAC Symposium on Engineering Turbulence Modelling and Measurements	Palermo, Italy	21-23/09/2016	Guerts, B. et al.	

ERCOFTAC Summer Schools, Courses – 2016

Title	Location	Date	Coordinators	Organiser
JMBC/ICISS Course on Combustion	Eindhoven, The Netherlands	25-26/01/2016	van Oijen, J.A. de Goey, L.P.H.	SIG 28
Summer School on Near-Wall Reactive Flow	Bensheim, Germany	6-10/06/2016	Dreizler, Aa Poinsot, T. Sadiki, A.	SIG 28



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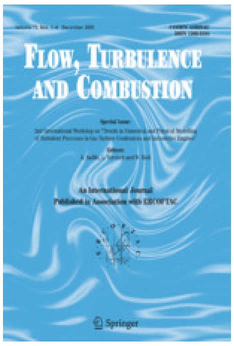

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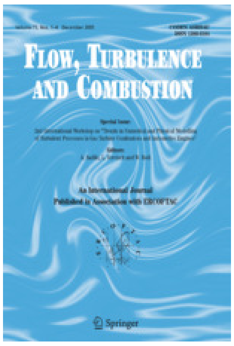

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Best Practice Guidelines for Computational Fluid Dynamics of Dispersed Multi-Phase Flows

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&
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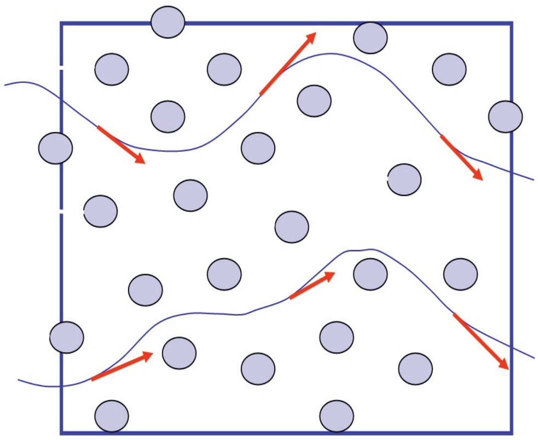

The simultaneous presence of several different phases in external or internal flows such as gas, liquid and solid is found in daily life, environment and numerous industrial processes. These types of flows are termed multiphase flows, which may exist in different forms depending on the phase distribution. Examples are gas-liquid transportation, crude oil recovery, circulating fluidized beds, sediment transport in rivers, pollutant transport in the atmosphere, cloud formation, fuel injection in engines, bubble column reactors and spray driers for food processing, to name only a few. As a result of the interaction between the different phases such flows are rather complicated and very difficult to describe theoretically. For the design and optimisation of such multiphase systems a detailed understanding of the interfacial transport phenomena is essential. For single-phase flows Computational Fluid Dynamics (CFD) has already a long history and it is nowadays standard in the development of air-planes and cars using different commercially available CFD-tools.

Due to the complex physics involved in multiphase flow the application of CFD in this area is rather young. These guidelines give a survey of the different methods being used for the numerical calculation of turbulent dispersed multiphase flows. The Best Practice Guideline (BPG) on Computational Dispersed Multiphase Flows is a follow-up of the previous ERCOFTAC BPG for Industrial CFD and should be used in combination with it. The potential users are researchers and engineers involved in projects requiring CFD of (wall-bounded) turbulent dispersed multiphase flows with bubbles, drops or particles.

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www.ercoftac.org

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