REPORT OF THE ERCOFTAC GREEK PILOT CENTRE, 2010-2015

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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 & 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 & Aeronautics Engineering

L5. Laboratory of Applied Thermodynamics

Director: Assoc. Prof. Panagiotis Koutmos

Email: koutmos@mech.upatras.gr

D. University of Western Macedonia, Department of Mechanical Engineering

L6. 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 & 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 façades.
- 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 & district energy saving & 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.

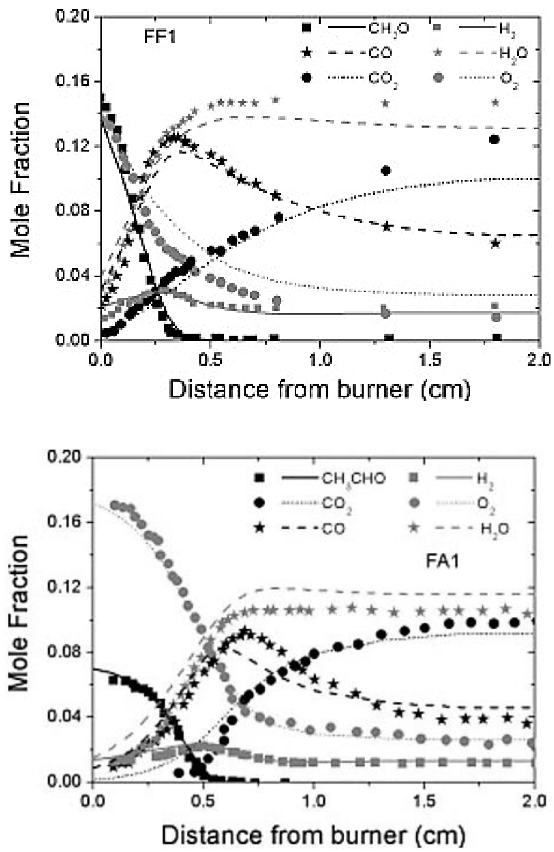

Figure 1: Mechanism performance against experimental major species profiles in formaldehyde (up) and acetaldehyde (down) flames [1]

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 [1-3]. Moreover, key oxygenated intermediates have been studied (see Figure). In this respect, the model is utilized for the analysis of the gas phase chemistry of combustion pollutants (UHCs, PAHs, NOx, SOx, 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].

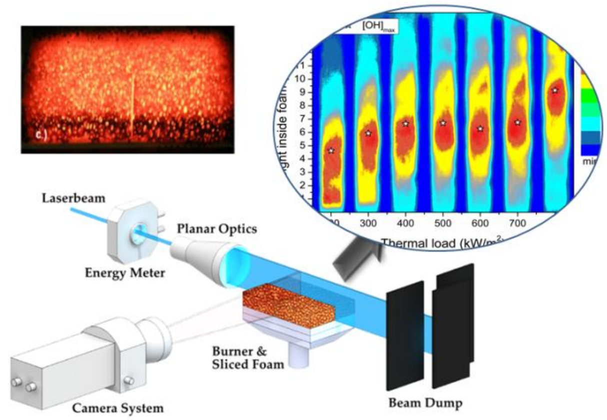

Figure 2: flame Visualization via OH-LIF measurements inside porous media for varying thermal loads [11]

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 [6]. 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 [7]. Finally, a fruitful combination of computational and experimental tools has been realized in applied research fields directly relevant to engine combustion [8-10].

A significant research effort has been placed in describing the combustion in porous media [11-14]. 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 [15-17]. 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-façade fire experiments, employing a ¼ scale model of the ISO 9705 room, equipped with an extended façade (Figure 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, façade 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 façade.

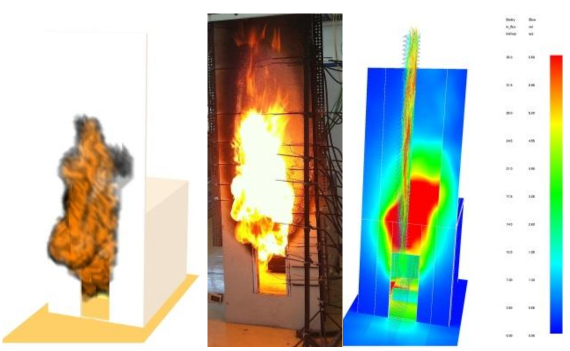

Figure 3: Schematic of the experimental facility and measurement setup (left) and predictions of flame envelope (middle), velocity vectors and heat flux on the façade (right).

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, 2013-2016)
- 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+, 2013-2015)
- 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 & Optimization Unit

Contributed by: Prof. Kyriakos Giannakoglou

The *Parallel CFD & 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 [18-22]. 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.

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.

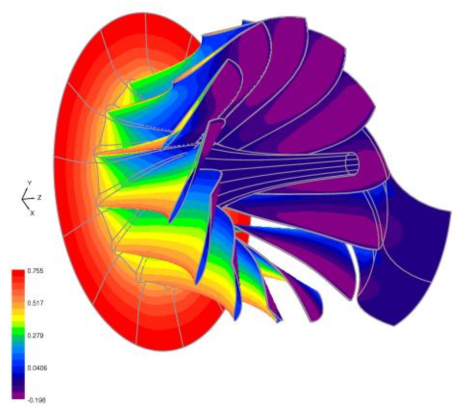

Figure 4: Two–objective design of a Francis runner at three operating points yielding desirable outlet velocity profile and blade loading. Computed pressure distribution on the optimal runner. Since this problem involves 372 design variables, the PCA-driven dimensionality reduction techniques of EASY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

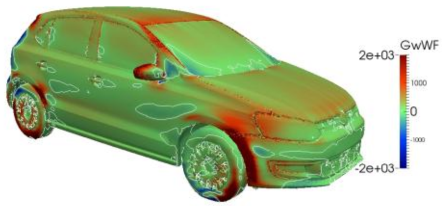

Figure 5: Sensitivity map of the VW Polo car targeting min. drag force, computed by the continuous adjoint method of PCOpt. To reduce drag, red areas should be displaced inwards and blue areas outwards. Research funded by Volkswagen AG.

All the aforementioned methods have been used in internal/external aerodynamics (including turbomachinery and automotive) applications; two indicative applications are shown in figures 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. LAT's 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. 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 aftertreatment. LAT also provides R&D services in both these fields of automotive exhaust emissions and aftertreatment technology.

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 650m^2 within the Aristotle University Campus. 400m^2 are occupied by laboratory facilities, while the remaining 250m^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 room" and two precision balances for PM filter weighing, a Thermogravimetric analyser, a 20kW fluidized bed reactor.

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

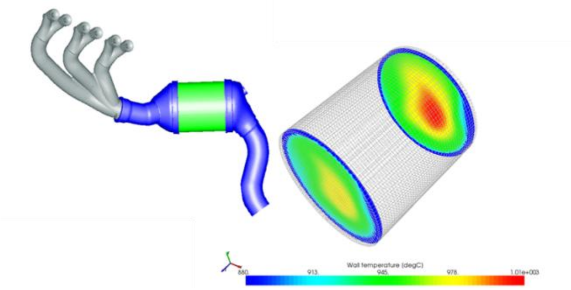

Figure 6: Simulation of reacting flow and thermal field in a 3-way catalyst under full-load operation using 3-d CFD/axisuite coupling

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 & μETA). Coupling of CFD codes with axisuite is also possible and is frequently used to study the effects of exhaust system design on emissions performance (Figure 6).

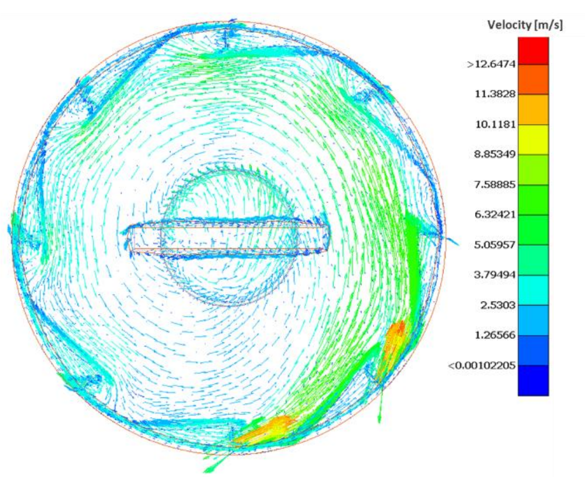

Figure 7: Gas velocity vectors in a Stoneridge soot sensor (visualization performed in μETA)

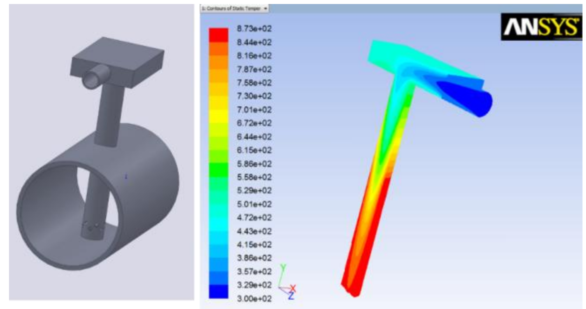

Figure 8: Pegasor dummy sensor geometry mounted on the exhaust (left) and temperature contour during operation (right)

Other examples of LAT modeling activities include:

a) Development of physical models of prototype soot sensors (Figures 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 (Figure 9)

c) 2D and 3D transient fluidization of biomass gasification in a fluidized bed reactor (Figure 10).

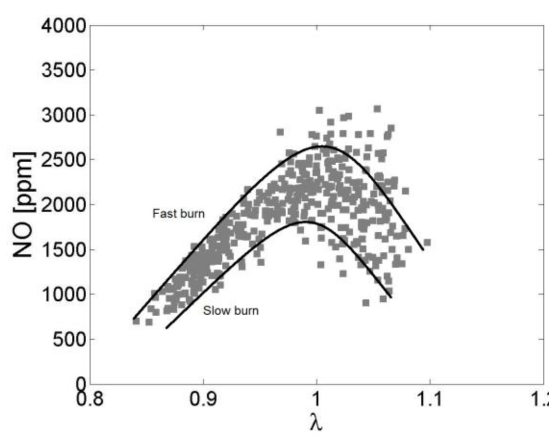

Figure 9: Impact of cycle-to-cycle variation on NO emissions from a spark-ignition engine.

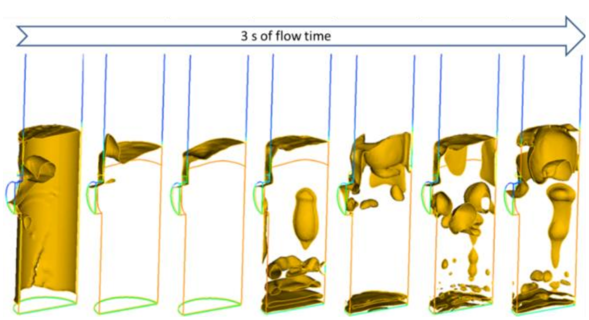

Figure 10: Iso-surface of 50% sand volume fraction in a bubbling fluidized bed reactor (visualization performed in μETA)

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 & 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 €. 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 Dimensions", 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 [23-25]. 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 effect" 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.

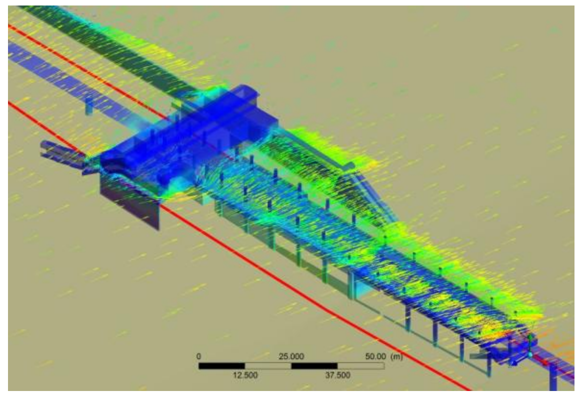

Figure 11: Simulated wind field over a metro station in Manila, Phillipines

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.

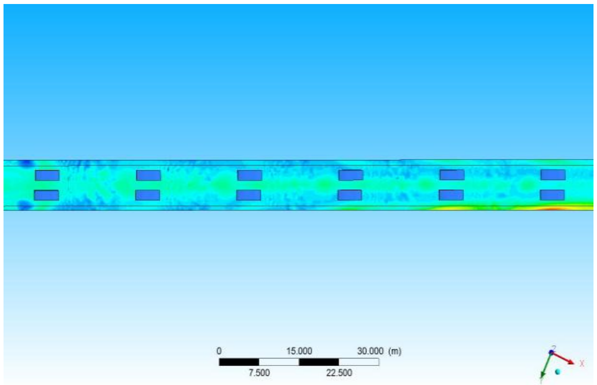

Figure 12: Simulated pressure distribution inside a road tunnel under the influence of the vehicles motion

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 & 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:

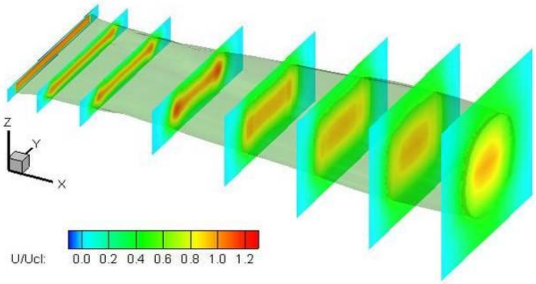

Figure 13: Development of a rectangular jet

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 [26-28].

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 [29]. 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 [30].

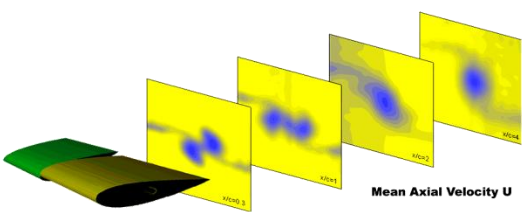

Figure 14: Merging of a co-rotating vortex pair

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 [31-32].

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 [33].

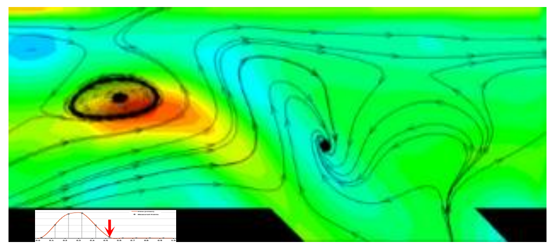

Figure 16: Vorticity and streamlines in the anastomosis region

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 [34].

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 [35].

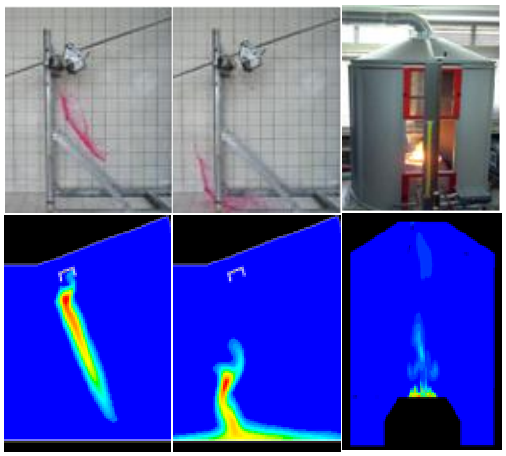

Figure 18: Water bombardment of ground fire (Exp, Sim) and, Axisymmetric fire plume (Exp, Sim)

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 [36, 37].

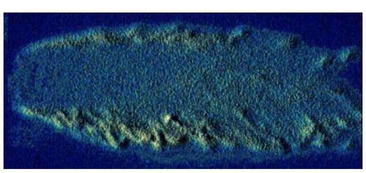

Figure 19: Chemiluminescence image of Kelvin-Helmholtz vortices in reacting wake

Investigations of reacting swirl flows under fully premixed, stratified or vitiated conditions: Experiments 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 [38, 39].

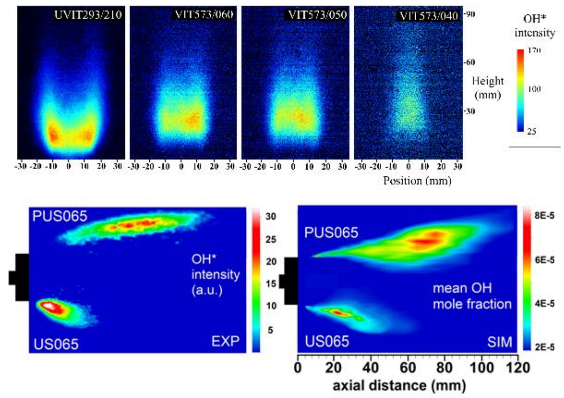

Figure 20: Effect of vitiation or stratification at ultra-lean flame operation.

3.4 University of Western Macedonia, Department of Mechanical Engineering

L6. Laboratory of Thermodynamics and Combustion Engines

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 [40-42]
- 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 [43-44].

- 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.

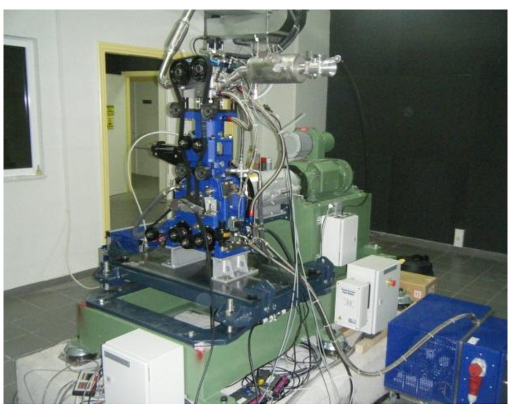

Figure 21: Optical Engine -Dynamometer Setup

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.

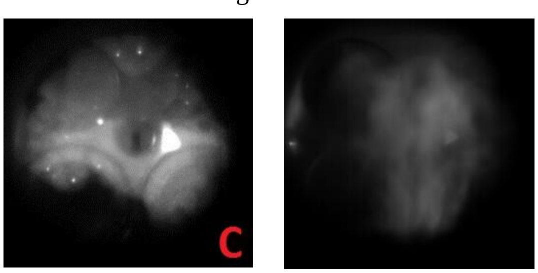

Figure 22: Flame (Left Side) and Spray (Right Side) Image inside the Cylinder of the Optical Engine

Additionally, the infrastructure includes a stack gas analyser for CO, CO_2, HC, O_2, NO_x 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 [45-47] 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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