<u>Research Statement – Dr.-Ing. Paris A. Fokaides</u>

<u>Research work Review</u>

My previous research was primarily concerned with experimental thermofluid mechanics, with a particular focus on fundamental problems. Typically, this focus finds applications in energy contexts, particularly, in the field of combustion in gas turbines. The three main emphases of my research may be described as follows:

1. Experimental investigation of combustion stability mechanisms.
2. Experimental investigation of building materials' energy performance.
3. Environmental fluid mechanics and urban meteorology for the analysis of the urban heat island effect.

The first scientific field was mainly developed during my collaboration with the University of Karlsruhe (2002-2007), whereas the second and third have been the objectives of my collaboration with the Department of Civil and Environmental Engineering of the University of Cyprus since 2008.

The following presents these three scientific fields of my previous research work in the area of experimental thermofluid mechanics.

1. <u>Experimental investigation of combustion stability mechanisms</u>

My research interest in the field of experimental combustion may be categorised in the following subjects:

a. Stability mechanism of lifted swirl nonpremixed flames.
b. Swirl-induced, self-excited high-frequency instabilities.
c. Determining the integral time scales in turbulent flows by means of LDA- measurements.

<u>a. Stability mechanism of lifted swirl nonpremixed flames</u>

Partially premixed flames represent a class of hybrid flames that are established when a quantity of oxidiser is molecularly mixed with the fuel stream prior to entering the reaction zone where additional oxidiser is available to complete the combustion process. Lifted swirl flames are a representative application of partially premixed combustion and are considered to be the breakthrough that should enable high-level reduction in NO_x emissions.

I have studied the stabilization mechanism of a confined lifted swirl non-premixed flame by applying a novel air blast nozzle. In terms of my research, I adapted 3D-Laser Doppler Anemometry to determine all three mean velocity components, as well as the six Reynolds stress components. The determination of the temperature and mixture field resulted by employing in-flame measurement techniques. Another important aspect of my research work regarding the stability of lifted swirl flames was concerned with determining the lift-off behaviour by means of a gaseous (natural gas) as well as liquid fuel (Jet A1) flames. Besides 3D-Laser Doppler Anemometry, the two phase flow combustion, in terms of Jet A1 fuel, was visualised by means of planar Mie-Scattering measurements.

b. Swirl-induced, self-excited high-frequency instabilities

The basic assumption for models and studies conducted in the area of swirl flows is that the flow field is axisymmetric. However, there is substantial evidence resulting from experimental studies showing that the assumption of axisymmetry is true only for low Reynolds numbers (Re) and very low swirl numbers (S), typically (S)<0.6. This type of coherent structure known in the field of non-reactive and reactive swirl flows are interpreted as precessing vortex cores (PVC) due to their precessing motion about the symmetry axis.

The experimental and numerical investigation of swirl-induced, self-excited instabilities in the vicinity of an Airblast Atomiser was foremost in my research work. The main scope was to confirm the precessing character of high-frequency instabilities determined at the nozzle vicinity, as well as to further investigate their nature and overall impact on combustion. The frequency analysis, based on the autocorrelation of 3D-(LDA) measured data, has evidenced the existence of a high-frequency periodic instability. The nature of this investigated instability was determined on the basis of planar measurements of Mie-Scattering performed by employing a high-speed camera operating at 12 kHz. This technique provided further information on the topology of the identified instability, as well as on the response of the flame. A comparison of the results provided by these two measurement techniques revealed a very good agreement and determined the conditions under which (LDA) is appropriate to analyse (PSD) performance. A satisfactory agreement was also demonstrated by means of the performed numerical simulation using the 3D (RSM) Model.

c. Determination of integral time scales in turbulent flows by means of LDA- measurements

Laser-Doppler Anemometry is a technique that has evolved over the past few years as a powerful tool for measuring velocity fields in various research and industrial applications. Determining turbulent length scales and energy density spectra by means of LDA-measurements, however, is linked with some challenges. These difficulties are based on the fact that the LDA measurement signal is not equally spaced in time but is stochastic, and thus, a direct implementation of a Fast Fourier Transformation (FFT) to determine the energy density function EDS is not possible.

In recent years, several mathematical algorithms have been developed to enable the data resampling and thus the determination of the autocorrelation function out of LDA measurements. Within the scope of my work, the refined sample and hold method, as well as a modification of the standard slotting technique, known as ‘local scaling’ or ‘local normalization’, were utilised. The forecast reliability of the autocorrelation function ACF estimation was not found to be independent of the block duration, but rather dependent on the number of pairs of measurement data per interval; therefore it was optimised in the case of a higher data rate. The refined sample and hold method was proved to be reliable in the estimation of the investigated flow's turbulent scales.

2. Experimental investigation of building materials' energy performance

The efficient energy performance of buildings is a scientific field which steadily gains more importance due to the policies being implemented in the area of energy saving in buildings. Especially in the area of building materials, the development of advanced experimental and in-situ measurement methods for the identification of their energy performance is an area with important initiatives in recent years.

My research involvement in the experimental investigation of building shells' energy properties has mainly been concerned with the development of experimental methods for the determination of materials' main energy properties, such as thermal conductivity, thermal capacity, the coefficient of radiation emissivity, and the overall heat transfer coefficient. As far as the employed experimental techniques are concerned, the application of infrared (IR) thermography presents great research potential. I have been concerned with the application of IR thermography in the developing building materials for the identification of thermal conductivity and the overall heat transfer coefficient. In both cases, I have developed a complete methodology, based on necessary boundary conditions, where the measurement techniques, as well as the possible measurement errors and deviations, are analysed to define the complete characterisation of building materials. The evaluation of the proposed methodologies has been conducted by means of application of other relevant measurement techniques, such as with heat flux meters. The results were found to be in very good agreement under steady-state conditions, whereas the methodologies should be further developed for the case of non-steady conditions.

3. Environmental fluid mechanics and urban meteorology for the analysis of the urban heat island effect

The urban heat island effect is a very important environmental problem mainly occurring due to the increased thermal emission of dense city centres. The main heat sources are anthropogenic activities as well as thermal radiation emitted from buildings. In particular, as far as the building shells are concerned, the fact that the thermal emissivity of the vast majority of the applied building materials exists at 0.8 has a great impact on the problem's immediacy. This emissivity results in a decrease in the difference between the diurnal and the nocturnal ambient temperature, in addition to increasing the urban heat island intensity.

My research activity in this field includes the following initiatives:

a. Determining the optimum urban planning design parameters to further enable the natural ventilation of city centres.
b. Applying urban meteorological techniques to identify the urban heat island effect at the atmospheric mesoscale.

a. Identification of optimum urban planning design parameters

The atmosphere circulation in urban centres is influenced by the urban design and especially by building density, which in many cases does not allow for natural ventilation of city blocks, especially in the case of street canyons. This results in the deceleration of wind velocity within the urban centre couples with the augmenting of negative impacts of the urban heat island effect because neither heat nor pollutants may be removed from street canyons.

My research interest in this specific field is focused on the identification of optimum urban planning design parameters, regarding the building orientation and height-to-street width to optimise natural ventilation conditions. To this end, I have conducted a series of measurements in water channels by employing a 2D Particle Image Velocimetry measurement technique. The main scope of this work is the determination of atmosphere flow fields around buildings and the identification of the optimum design conditions under which the exchange velocity is maximised. A very important finding of this research work is the characteristics of the atmosphere recirculation zones within street canyons. Another result that may be elaborated upon for further analysis is the identification of the boundary layer characteristics developed above the urban canopy area, as well as a characterisation of friction velocity.

b. Urban meteorology for the determination of the atmosphere mesoscale behaviour

The direct impact of the buildings on the atmosphere flow behaviours and the urban boundary layer was found to be maintained at a height equal to five times the building's average height. Also, thermal emissions from city blocks related to thermal radiation may have an impact on atmospheric stability. Therefore, an investigation of the atmosphere within the urban boundary layer is a scientific field of great interest, currently.

My research involvement in the field of urban meteorology is mainly concerned with the determination of the meteorological magnitudes (e.g. temperature, humidity, pressure, wind speed and direction) for the identification of the urban heat island intensity, as well as the impact of the built environment in urban meteorology. I have evaluated radiosounding data for the determination of the atmosphere stability under several thermal urban conditions. An important finding of this research is related to the urban surface boundary layer and the fact that the parameters that have an influence on the urban flow field are mainly affected by the boundary layer surface roughness and not directly from the total thickness of the boundary layer.

2. Future Work

In my research thus far, I have found that the experimental investigation of flows is an interesting, important and promising field of research. In the next few years, I plan to continue to my work in this field. At the same time, I plan to further experimentally study the flow characteristics for other types of flow problems.

a. Swirl-induced instabilities

A field I would like to further investigate is the field of flow-induced instabilities within swirl flows. Having developed some Matlab-based tools to analyse the measurement signal of non-intrusive measurement methods, I would like to apply spectroscopic methods, such as LDA, HWA and PIV, for a series of swirl generators to deliver a universal model characterising swirl-induced instabilities. Within this scope, I would also like to further investigate the bimodal and multimodal probability density function of flow signal within unstable flow areas and shear layers; in addition, I would like to develop a tool for analysing and determining instability characteristics. Such a tool should be a great asset to well-known problems arising in the area of numerical modelling due to lack of data flow within highly unstable areas.

b. Experimental methods for the identification of materials energy performance

The aim of my future research activity in this field is to establish experimental techniques for the identification of the materials energy performance, especially of building elements with the use of IR thermographic applications. Furthermore, I would like to promote the creation and adoption of specific procedures in the context of European standards, in which the best practices, as well as the necessary boundary conditions, will be described for the optimum application of IR thermography in building materials. The character of this application concerns both experimental and in-situ measurements. One special case of these methodologies concerns cases of in-situ measurements where the boundary conditions are non-steady, whereas in this case, not only the techniques but also the evaluation of the boundary conditions shall be further evaluated and processed.

c. Biomass combustion

Based on my knowledge of combustion systems, I intend to focus on adopting well-known techniques of fossil fuel combustion in the area of renewables and thus in the field of biomass and hydrogen. The main problem arising in this case is to maintain the efficiency of the combustion as well as to modify the existing combustion units to reliably operate by means of alternative fuels. To achieve this, a detailed investigation of the flow field of the flame should be carried out. I have already developed, during my PhD Candidature, a series of gas turbine nozzles producing swirl and lifted flames (see European Patent: 06009563.5-, 2006, Fuel injection apparatus), which I would like to test by combusting gasified biomass and hydrogen. The main purpose of this research would be to determine flow-field characteristics and to modify swirler geometries to achieve optimum operation by means of efficiency and emissions for given commercial combustor geometries. I strongly believe that this research direction is of great importance for current research in Cyprus because not only are the renewables promoted, but also this option will bring international gas turbine industries and the research field together in Cyprus. This approach may also provide some reliable solutions regarding waste treatment by means of combustion.

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