Research Statement – Dr. Paris A. Fokaides

1. Previous research

My previous research was primarily concerned with experimental fluid mechanics, with a particular focus on combustion diagnostics. I have been mostly interested in fundamental problems which typically find applications in energy contexts and particularly in the field of combustion in gas turbines. I entertained collaborations with researchers from numerical fluid mechanics, process and environ-mental engineering departments in the field of academia and industry and I greatly benefited from these interactions, both as a source of interesting problems and as a way to keep in touch with realistic applications. The three main areas of my research are briefly described below. I also provide some brief information regarding my collaboration with the Environmental Flow Mechanics Laboratory of the Civil and Environmental Engineering Department of the University of Cyprus.

a. Stability mechanism of lifted swirl non premixed flames

Partially premixed flames represent a class of hybrid flames established when a quantity of oxidizer is molecularly mixed with the fuel stream before entering the reaction zone, where additional oxidizer is available for complete combustion. This art of combustion can be used to exploit the advantages of both non-premixed and premixed flames regarding operational safety, lower pollutant emissions and flame stability. Lifted swirl flames are a representative application of partially premixed combustion, and are considered to be the break-through which should enable high-level reduction in NOx emissions.

I have studied the stabilization mechanism of a confined lifted swirl non-premixed flame by applying a novel Airblast nozzle. In terms of my research, I adapted 3D-Laser Doppler Anemometry, for the determination of 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 concerned the determination of the lift-off behavior by means of a gaseous (natural gas) as well as a liquid fuel (Jet A1) flames. Besides 3D Laser Doppler Anemometry the two phase flow combustion in terms of JetA1 fuel was visualized by means of planar Mie-Scattering measurements. At the time being the experimental measurements, which were performed during my PhD candidature at the University of Karlsruhe are processed by means of numerical CFD models in terms of the European Project "Towards Lean Combustion"(AST4-CT-2005-012326 - FP6).

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 are substantial evidences resulting from experimental studies, show-ing that the assumption of axisymmetry is true only for low Reynolds numbers (Re) and very low swirl numbers (S), typically (S)<0,6. The break of the axisymmetry is related to the phenomenon of the vortex breakdown of the flow, as it results due to the expansion of helical vortices, lying between the boundary of the reverse flow and the zero streamline. This kind of coherent structures 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 stood in the foreground of my research work. The main scope was to confirm the precessing character of high frequency in-stabilities determined at the nozzle vicinity, as well as to further investigate their nature and their overall impact on the 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 the 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. The comparison of the results provided by the two measurement techniques revealed a very good agreement and determined the conditions under which (LDA) is appropriate for the performance of (PSD) analysis. A satisfied 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. The determination of turbulent length scales as well as of energy density spectra by means of LDA-measurements is, however, linked with some challenges. These difficulties are based on the fact that the LDA measurement signal is not equally spaced in time but stochastic, and thus, a direct implementation of a Fast Fourier Transformation (FFT) in order to determine the energy density function EDS is not possible.

Over the recent years, several mathematical algorithms have been developed in order 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 utilized. The forecast reliability of the autocorrelation function ACF estimation was not found to be independent of the block duration, but rather depended on the number of pairs of measurement data per interval, and therefore it was optimized in case of higher data rate. The “Refined Sample and Hold”-method was proved to be reliable in terms of the estimation of the turbulent scales of the investigated flow.

d. Research as a member of Environmental Fluid Mechanics Laboratory, Department of Civil and Environmental Engineering at University of Cyprus

Since June 2008 I have been collaborating with Lecturer Dr. Marina Neophytou as a research fellow of the Environmental Fluid Mechanics Laboratory at the University of Cyprus. The laboratory hosts a wide range of experimental arrangements for investigating fluid flow phenomena in environmental and industrial applications, such as airflow and dispersion around and inside buildings, water flows and pollution in rivers and seas and air pollution. The research addresses both turbulent and laminar incompressible flows as well as particle dispersion; by combining theoretical, experimental and computational investigations the laboratory aims to understand the physical processes involved in these flows and to develop new mathematical models to simulate them.

2. Future Work

In my research so 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 work in this field. At the same time, I plan to further experimentally study the flow characteristics for other types of flow problems.

a. Biomass combustion

Based on my knowledge on 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 as well as 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 in order to reliably operate by means of alternative fuels. In order 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 should be to determine the flow field characteristics and to modify the swirler geometries in order to achieve optimum operation by means of efficiency and emissions for given commercial combustor geometries. I strongly believe that this direction is of a great importance for research in Cyprus at presence, because not only the renewables are promoted, but this option shall bring international gas turbine industries and the research field in Cyprus together. This approach may also provide some reliable solutions regarding the waste treatment by means of combustion.

b. Swirl induced instabilities

Another 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 in order 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 instable flow areas and shear layers and deliver a tool for analysing and determining the 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 in flow highly instable areas.

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