von Karman Institute for Fluid Dynamics

E N V I R O N M E N T A L   A N D

A P P L I E D   F L U I D   D Y N A M I C S

Project Subjects for Graduation Theses 2010-2011

The ENVIRONMENTAL AND APPLIED FLUID DYNAMICS Department is engaged in a wide variety of research activities, closely related to problems of industry.
Graduation projects are proposed in the following areas :

1. SOLID PROPELLANT ROCKETS & BOOSTERS

The projects proposed in this section are related to fluid dynamics phenomena arising in solid boosters, which equip the first stages of launch systems such Ariane 5. Large solid rocket motors are composed of a submerged nozzle and segmented propellant grains separated by inhibitors called frontal thermal protection (PTF). During propellant combustion the PTF emerge in the gas cross flow inducing complex vortical structures and pressure oscillations. Under such a flow field, the PTF bends and oscillates at its structural frequency. Coupling may appear if both the vortex shedding frequency and the structural frequency synchronize. The research objective is to understand the basic principles of fluid/structure interactions, to perform experiments using non-intrusive techniques allowing both frequency and displacement measurements and to assess the potential of CFD codes to simulate fluid/structure coupling.

2. AEROACOUSTICS

Noise from cooling fans
Cooling fans are extensively used in many applications, ranging from engine cooling fans in automotive and rail transportation, to CPU-cooling fans in electronic devices and laptops. The aerodynamic noise emitted by these fans represents an important societal issue, which eventually affects the public acceptance of new devices introduced in our daily life. The advent of hybrid and full electric vehicles in particular, brings the fan noise to the foreground of the passenger's acoustic landscape. In that line, the VKI has developed an important theoretical, numerical and experimental aeroacoustics research pole aimed at a better understanding and modelling of the mechanisms through which aerodynamic noise is produced by low-speed fans. The measurements are done within an anechoic chamber, unsteady pressure measurements are performed in the near- and far-field using microphone arrays (acoustic beamforming). Particle Image Velocimetry and hot wire anemometry are used for flow field characterization. The modelling efforts are articulated around semi-analytical (Amiet's theory) and numerical strategies (Large Eddy Simulation).

Noise from airframe components
The annoyance caused by aircraft noise has become a major societal concern, and one of the top priorities of the 7th Framework Programme of the European Commission. Engine and airframe (high-lift devices and landing gears) noise are strong contributors to the acoustic footprint perceived by local communities. Important progress has been made over the past decades to reduce these source components, mostly through incremental changes in the aircraft design. But in order to fulfil the ambitious objectives defined in terms of EPNL reduction, more drastic changes in the aircraft design will be necessary, which rely on advanced simulation strategies and innovative noise control approaches. The VKI has developed a strong expertise in the modelling of turbulent flows on the one hand, and on the prediction of the related noise production and propagation on the other hand. Hybrid methods based on the aeroacoustical analogy are an important component of these research and

development activities. Two specific axes of research are pursued thereto: 1) based on a deterministic flow model (e.g. Large Eddy Simulation or Detached Eddy Simulation) coupled with an analytical or numerical (Linearized Euler Equations) propagation solver, and 2) based on a statistical description of the flow-field, coupled with analytical (Amiet's theory) or numerical acoustics (e.g. Finite Element Method) approach. An innovative combination of these techniques is meant to cover the whole frequency spectrum of the noise emitted by high-lift devices.

Compressible LES and LEE applied to aeroacoustics
VKI has a long experience in the Large Eddy Simulation for industrial flow. Present efforts is focused on wall resolved simulation allowing the determination of pressure fluctuations further used as sources terms in another solver. The sound determination at a distance from the studied object is obtained in different manners. Actual efforts are dealing with incompressible or compressible LES executed with an open source code (OpenFoam) on a cavity like geometry. The wave propagation is carried out by a Linearized Euler solver developed in the VKI CoolFluid framework. Different aspects of the subject may involve Code development in C++ or incompressible/compressible LES computation or advanced post-processing.

3. AERODYNAMICS OF GROUND VEHICLES

Drag characterisation
The drag characterization of ground vehicles relies on a good simulation of the ground effect in wind tunnel. In particular, it is important to suck the boundary layer and to use a moving belt or symmetric models. VKI has two different wind tunnels aimed at investigating the aerodynamics of ground vehicles. The objective of the project is to assess their performances and to investigate the ground effect on the drag based on the Amhed body.

Drag reduction
The drag of a ground vehicle consists of skin friction and pressure drag. For Ultra-streamlined vehicle, the drag is mainly produced by skin friction, separation being avoided all the way to the trailing edge. A further decrease of the drag can therefore only be achieved by decreasing the skin friction by passive means like for example the use of riblets or active means like plasma actuators. The aim of the project is to review the state-of-the-art of active and passive devices for reducing the skin friction drag (theoretical part) and to design and perform a set of experimental investigations on a simple geometry in the L1 wind tunnel of the VKI (experimental part). The drag measurements will be performed using an existing balance.

4. BIOLOGICAL FLOWS

Flows of air in lungs and aerosol deposition
Studies of air flows within the lungs attracted considerable interest in the last ten years. This is mostly due to the development of curative aerosols techniques and computer assisted surgery. It is also related to the large amount of cardiac illnesses due to apnea syndrome diseases. A research programme is underway at the VKI. It aims at modelling the flow of air in lungs. For that purpose, an experimental approach has been performed in parallel with a numerical modelling. The experiment consists in characterising the flow in multiple bifurcations that simulate a section of the bronchial tree. Three dimensional models are used with two successive bifurcations. Numerical modelling of the flow has also been performed using the commercial code FLUENT. The human body is characterised by its high complexity due to the large amount of geometrical parameters. The advantage of numerical modelling on experiments is the ability to modify easily parameters. Before entering in a phase of systematic numerical tests, further experiments have to be performed to validate the code results. An investigation of steady and unsteady flows is proposed using measurement techniques such as Particle Image Velocimetry.
A more recent study aims at developing a realistic three-dimensional model of the lower pulmonary airways of the human lung in which the effect of flow patterns on aerosol particles motion is investigated in steady and unsteady conditions. The last researches have developed

techniques to cast adequately the models, to choose particles simulating the aerosols motions, to measure low flow rates and to develop Particles Tracking Techniques (PTV) to follow the particles in their motion and to adequately simulate the deformations of the airways during the breathing cycle. The long-term objective of this study is to better understand the fate of inhaled particles in the human lung. Exposure to particulate matter (PM) and its implications in human health have been a major concern in the recent years as more evidence links air pollution and morbidity and mortality. The recent threats of biological warfare have reemphasized the need of a better understanding of the fate of aerosols in the human lung. Such understanding is also of considerable importance in medical applications such as inhalation drug therapy.

5. FILM COATING

Jet wiping

The deposition of a very thin liquid film on a solid surface is the basis of many industrial coating processes. Several research programs are pursued in this field at the VKI. Experimental set-up simulating jet wiping technique is available to investigate the occurrence of instabilities such as wave formation and splashing. Projects are proposed on the fundamental aspects of the formation of free-surface instabilities in jet-wiping processes. Advanced optical measurement techniques to measure the instantaneous film thickness will be used. Nonlinear theory of free surface flows will be developed and compared to multidimensional CFD simulations using LES/VOF approach.

6. HEAT TRANSFER

Inverse method for convective heat transfer

Advanced designs of aerothermal devices require accurate predictions of the governing heat transfer mechanisms. In many situations, the phenomena involved are so difficult to be investigated with conventional measurement approaches that the inverse analysis is the only way for reaching the aim. This method combines intimately experimental and numerical approaches. In particular it allows the investigation of the complex conjugate heat transfer situation. In this objective, projects will be proposed to study basic problems such as the backward facing step, the cavity and the rectangular channel of high aspect ratio. All these configurations are often encountered in many industrial thermal systems such as compact, plate or lamella heat exchangers. Infrared thermography measurements and CFD simulations will be performed.

Impinging Jets

Array of gas jets are found in many industrial processes such as the fast cooling of metal strips, the quenching of glass sheets and the thermal anti-icing of aircraft wings. Fundamental investigations of the turbulent heat transfer can be performed applying the Large Eddy Simulation with general purpose codes. In-house post-processing software allows the study of the phenomenology of Coherent Structures in the flow. The optimisation of these heat exchange devices requires deep knowledge of the mean flow description and turbulence level in the impaction area, the effect of jet confinement and nozzle arrangement on the local convective heat transfer. In particular advanced design of slit and round jet nozzles will be tested on a dedicated experimental set-up. Measurement could be performed by means of Laser Doppler and Particle Image Velocimetry as well as Quantitative Infrared Thermography. The experimental data would allow validation of numerical simulations.

Heat Transfer in a ribded duct

The investigation of turbulent heat transfer in the cooling duct of a gas turbine is studied thanks to the Large Eddy Simulation technique. The conjugate heat transfer is specially investigated in a duct equipped with 5, 6 or 7 ribs. The LES allows studying the impact of the coherent structures on the heat transfer at the wall. This project provides high level of autonomy in the use of LES of commercial codes together with state of the art in post processing techniques. The comparison/validation with experimental data is possible thanks to the collaboration with a team of experimentalist from the TU department.

7. POLLUTANT DISPERSAL

Dispersion in urban environment

Pollutant dispersal in the atmospheric boundary layer is of increased interest due to ever increasing urbanisation and upcoming European regulations. The prediction and subsequent control of dispersion processes by active and passive means in semi-confined urban areas is investigated in VKI wind tunnels and compared to physical modelling. Applications such as underground garages are envisaged, including sprinkler systems and ventilation units. Concentration and velocity measurements are performed using techniques suitable for wind tunnels, such as laser tomography and gas aspiration probes. Commercial and opensource CFD-codes are employed in addition to non-CFD modelling.

8. PEDESTRIAN WIND COMFORT

Wind confort in urban areast

Wind comfort on pedestrian level has to be assessed according to the human activities that are planned near tall buildings, open places, corridors and tunnels in urban areas. Wind tunnel studies are performed with the help of the sand erosion technique. Contours of wall shear stresses are deduced, correlated with meteorological data and then translated to comfort levels. The validity of the erosion technique is assessed by Particle Image Velocimetry, Laser Doppler Velocimetry and intrusive techniques, such as hot wires, hot spheres and Irwin pressure probes. Ground shear stresses and wind speed up maps are also simulated by CFD packages and validated against the experimental results.

9. WIND TECHNOLOGY

Wind turbine

Wind resource assessment is studied for wind turbine siting, and includes small and medium urban wind turbines as well as wind turbine park effect for MW turbines. Wind tunnel results and CFD modelling are combined with Weather Research Forecasting (WRF) and compared to field data for European wind turbine sites.

Wind effect on structures

Wind effect on structures is studied in wind tunnels and by numerical simulations, and focuses on steady and unsteady forces on buildings, cladding systems and suspension bridges.

10. TWO-PHASE FLOWS

Two-phase flows are widely encountered in industrial processes. The configurations to be dealt with are gas bubbles in a liquid flow and liquid droplets or solid particles in a gas flow. A proper modelling of the behaviour of the continuous and discrete phases is essential to improve the process effectiveness.

Bubble flow

Multiphase flows are encountered in electrochemical processes, with heat and mass transfer often dominated by the presence of gas bubbles. Measurement of liquid bulk velocity and bubble velocity and size will be performed by laser techniques. Ion concentration will be assessed using absorption spectroscopy and heat transfer near the electrodes by infrared thermography.

Multiphase flows are also encountered in liquid metal reactors where dedicating reacting gas is injected in the liquid bath through a submerged lance. The behaviour of the resulting gas bubbles is of extreme importance since it controls the performances of the whole process. At the VKI experimental investigations of this problem are performed using laboratory facilities. The different parts of the process are reproduced using water and helium to simulate liquid metals and gas, respectively. This allows to visualise the gas bubbles evolution and to deduce their formation frequency and diameter growth by Digital Image Processing. However other

measurement techniques such as Particle Image Velocimetry (PIV), Laser Doppler Velocimetry (LDV), Fibre Optics probes and pressure probes can be also applied.
The presence of bubbles in a flow may change drastically the pressure drop. This is crucial to design security valve or control valve in general. At VKI, a dedicate setup allows to study the effect of bubbles (diameters, mean void faction,…) flowing through different geometrical accidents. The research involves measurement of diameters with optical fibre probes, visualisation with high speed camera, measurement of pressure drop and different other optical techniques (such as two-phase PIV). A numerical part of the subject is also proposed; it will be conducted with commercial codes in an Euler-Euler configuration.

Liquid sprays
Hydrodynamic and transport phenomena in liquid sprays will be studied. Gas entrainment phenomena, physico-chemical absorption of gas by droplets, convective and radiative heat transfer in a polydispersed medium, phase change processes such as flashing, evaporation and freezing of droplets have to be modelled. Innovative measurement techniques such as the Particle Tracking Velocimetry & Sizing, Phase Doppler Interferometry and Global Rainbow Thermometry will be used to determine all the characteristics of the spray or cloud droplets.
The applications are found in airborne diagnostics of cloud droplets, the mitigation of toxic heavy gas release, protection of structures against fire, cooling of hot surfaces, direct contact heat exchangers, rocket boosters and spray coating. In particular, projects on the spray cooling of hot solid surfaces coated by liquid metal are proposed.

Two-phase hammer
The operation of spacecraft propulsion systems is regularly faced with adverse fluid hammering effects during the priming operation. This maneuver is done by fast opening of an isolation valve and the classical liquid hammer taking place also involves multi-phase phenomena such as cavitation, boiling front and absorption and desorption of a non-condensable gas.
A new experimental facility designed at the VKI is available to reproduce all the physical phenomena taking place in the propellant lines during the priming process.
Experimental and/or numerical projects are proposed to investigate the fluid hammer phenomenon in a confined environment.
The creation of an experimental database, together with numerical simulation will be used to certify the spacecraft propulsion systems facing fluid hammer phenomenon.

Nanoparticle Project
VKI is involved in a research program aiming to produce nanoparticles with a plasma reactor. A team of researchers across the EA and AR department is dealing with:

- The design and qualification of the injection of micro solid particles through a combined system composed of fluidised bed and cyclonic separator.
- The study of the life time of micro particle in the plasma reactor.
- The development of nucleation system for a controlled formation of the nanoparticles.

Several experimental and numerical challenging projects can be defined in this field.

11. PARTICLE IMAGE VELOCIMETRY

PIV development
A new PIV technique is under development for measuring very large flow fields such as those encountered in Ventilation problems. In this project, the technique will be applied to convective flows generated by ventilation in large rooms. Improvements are to be made in the hardware such as illumination process as well as in the distribution of tracer particles but also in the processing software. In the latter domain, alternative image processing methods, more suitable to these large scale images, will be investigated.

Interested students should contact Prof. J.M. Buchlin
and indicate a tentative choice(s) of project.
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