von Karman Institute for Fluid Dynamics

ENVIRONMENTAL AND

APPLIED FLUID DYNAMICS

Project Subjects for Graduation Theses 2014-2015

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.

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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.

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3. AERODYNAMICS OF GROUND VEHICLES

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 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.

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4. 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.

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5. 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 ribbed 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.

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6. WIND TECHNOLOGY

Dispersion in urban environment
Pollutant dispersal in the atmospheric boundary layer is of increased interest due to ever increasing urbanisation and new 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 CFD and non-CFD modelling. Applications such as underground garages and tunnels are envisaged, including ventilation units. Concentration and velocity measurements are performed using techniques suitable for wind tunnels, such as laser tomography and gas aspiration probes. Opensource CFD-codes are employed in addition to non-CFD modelling.

Wind Energy
Wind turbine micrositing from urban to MW turbines is studied in wind tunnels and by CFD.. Also Weather Research Forecasting (WRF) is used for wind energy prediction and compared to field data for European wind turbine sites, off-shore, onshore, including mountaneous terrains and roughness effects. Focuss goes to the characterisation of the unsteadiness of wind turbine wakes within wind farms

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 high-rise buildings and towers, cladding systems and suspension bridges.
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7. 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.

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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 (PDI), Global Rainbow Thermometry, Interferometric Laser Imaging and Droplet Sizing (ILIDS) 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.

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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.

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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.

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Development of non-intrusive measurement technique for nanoparticle characterization

At the present age the fields of fuel spray combustion, nuclear reactor safety, meteorology, steam turbine application and product manufacturing necessitate to grow in competitiveness and efficiency. At this aim, the improvement of on-line measurement techniques, as the ones measuring particles size in real time, is extremely important in industrial production. The majority of natural and manufactured products involve the presence of "nanoparticles", either in their final state or at some stage in their production. Particle size and particle size distribution are, therefore, critically important parameters. At the simplest level, information on particle size can help maintain a more consistent product, enhancing end-use value and profitability. At a more complex level, careful control of particle size can reduce the need for in-process modifications and reworking, so making products more competitive. The main subject of this research topic is the development of non intrusive an on-line and real-time optical technique to characterize nanoparticles. The development is both experimental and theoretical.

The optical technique used to characterize the flow is the "Multi Wavelength Light Extinction - MWLE", which allows to measure the granulometry and the concentration of nanoparticles or nanodroplets. In the Optics Laboratory of the Environmental and Applied Fluid Dynamics Department of Von Karman Institute for Fluid Dynamic (Belgium), a facility has been built to produce the nanoparticle and nanodroplet flows, and a dedicated optical set-up is developed to implement MWLE technique.

One of the major difficulties in the MWLE technique consists in the regularization of the data inversion algorithm. Numerical methods have to be implemented in the inversion code (MATLAB environment) in order to speed up the experimental data analysis.

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