von Karman Institute for Fluid Dynamics
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APPLICATION FORM FOR

Master thesis Program in fulfillment of the requirements of a Belgian University or Industrial Engineering school

2014-2015

Personal information (Please PRINT)

Family name :

First name :

Date and place of birth :

Home Address :

Please attach photograph here

Personal phone number where you can be reached (preferably GSM):
Personal e-mail :

Nationality: a) at birth : b) now :

Information about university or engineering school

University / Eng. School :

Faculty / Orientation :

Department (add phone number or e-mail of secretariat if available) :

Name of the responsible supervisor at the University/Engineering school:

e-mail address of supervisor at the University/Engineering school :

Name of Diploma you expect to receive:

When do you expect to receive this Diploma (month and year) ?

1. Please select a project from the enclosed list of projects available at VKI, after having contacted the corresponding supervisor at the VKI and in agreement with your university/school.

2. Indicate the approximate period(s) of time you will be available to work at VKI; for example, 3 February – 27 April. List more than one period if the work has to be split over several periods.

3. What are your plans after you leaving the university ? E.g. further advanced study, research, work in industry, etc.

Date : **Signature :**

Please return the application form to the VKI at the address below, or send a scan by e-mail to secretariat@vki.ac.be :

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von Karman Institute for Fluid Dynamics

MASTER THESIS PROJECTS

for
Belgian University students /
Students at Belgian Engineering Schools

2014-2015

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 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.

Contact persons: Philippe Planquart, planquart@vki.ac.be; Jeroen van Beeck, vanbeeck@vki.ac.be

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.

Contact person: Jean-Marie Buchlin, buchlin@vki.ac.be

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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von Karman Institute for Fluid Dynamics

T U R B O M A C H I N E R Y & P R O P U L S I O N

Project Subjects for Graduation Theses 2014-2015

The TURBOMACHINERY AND PROPULSION Department has facilities for research on the flow in turbomachine components such as compressors, pumps and turbines. Fast response instrumentation and data acquisition systems are available. The theoretical effort concentrates on the calculation of the flow and performance prediction schemes for turbomachinery components.
Several Graduation projects are proposed in each of the following areas:

1. INTERNAL COOLING IN GAS TURBINES

The increased performance of gas turbines calls for higher turbine entry temperatures and higher aerodynamic loadings. Important areas of investigation include the development of efficient internal cooling schemes, the investigation of the flow- and temperature fields, and the development of dedicated instrumentation chains for pressure and temperature measurements.

Contact person: Tony Arts, arts@vki.ac.be

2. TURBINE AERO-THERMODYNAMICS

The main research activities in the domain of turbine aerodynamics are related to unsteady wake flow characteristics, wake-blade and shock-blade interferences and the aero-thermodynamics of cooled turbine blades. Progress in the understanding of these complex flow problems depends on the use and/or the development of advanced measurement and testing techniques such as fast response pressure and temperature probes, thin film gauges, data transmission systems and optical methods e.g., Laser Doppler Velocimetry, Particle Image Displacement Velocimetry, holographic interferometry and ultrafast flow visualisation. Students eager to learn and use advanced data acquisition and data processing techniques are welcome to participate in this advanced research.
The use of Computational Fluid Dynamics also plays an important role in the understanding of turbomachinery flow field at different levels. Multistage configurations are analysed with 1D codes, unsteady aspects of the flow field in a stage with quasi-3D or 3D Euler codes and detailed steady aero-thermal flow fields with 3D Navier-Stokes stage calculations.

Contact person: Tony Arts, arts@vki.ac.be

3. GAS TURBINE CYCLE ANALYSIS
Supervisor :

This project is related to the analysis and optimization of gas turbine cycles used in subsonic and high-speed propulsion. Performance of the individual components are considered together with the internal heat transfer on steady and transient operation.

Contact person: Tony Arts, arts@vki.ac.be

4. AXIAL COMPRESSOR AERODYNAMICS AND STABILITY

Over the past 30 years there has been a continuous research concerning possible benefits of casing treatments for improving axial compressor performance at off-design conditions. This problem has gained recently new interest with the trend to increased blade and stage loading to reduce costs and weight of the engine.
It is proposed to investigate new engine designs, with higher bypass ratios but with reduced weight in order to gain on propulsive efficiency and hence save on fuel burn. It is also proposed to investigate new engine architectures, like geared turbofans or contra-rotating turbofan engines, which would enable substantial noise reductions by lowering the fan speed. All these objectives result in higher stage loadings and require aerodynamic designs which go beyond classical know-how.

Current projects are of both experimental and numerical nature :

- Accurate measurements of the performance of the compressor, its stability margin, including the determination of efficiency by different methods / comparison with CFD.
- Development of accurate temperature probes for efficiency measurements
- Development of entropy probes
- Detailed fast response measurements with unsteady pressure probes (single- and multi-hole pressure probes), comparison with single- and X-hot wires, measurements of inlet turbulence. Comparison with CFD.
- Stall detection probes and investigation stall inception mechanisms.
- Parametric study and numerical optimization of casing treatment configurations.
- Numerical optimization of the 3D aerodynamic design of the compressor stage (lean, sweep, platform contouring).

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5. ADVANCED INSTRUMENTATION TECHNIQUES FOR TURBOMACHINES

Experimental techniques to measure the highly unsteady and three-dimensional flow field in turbomachines have tremendously improved over the last decades. Still higher temperature instrumentation is required, with smaller probe sizes, and better frequency response.
Current projects include :

- Development of fast response directional and static pressure probes.
- Assessment of unsteady errors on measurements (in an axial compressor for example), comparison with CFD.
- Determination of frequency response of a probe system by shock tube tests, development of a fast opening mechanism to determine the frequency response of slower systems.
- Experiments with an infinite line pressure probe used for remote pressure measurements in high temperature environments. Comparison to theoretical predictions.
- Development of ultra-high temperature (2000K) cooled fast response pressure probes.
- Development of high temperature (800K) miniature uncooled fast response pressure probes
- Assessment of turbulence measurements with fast response pressure probes

Contact person: Jean-François Brouckaert, brouckaert@vki.ac.be

6. DESIGN OPTIMIZATION OF TURBOMACHINERY COMPONENTS

This numerical work focuses on automated design optimization techniques to assist the designer in improving the performance of typical turbomachinery components such as axial and radial compressors and turbines in the virtual design environment based on Computer Aided Engineering (CAE) tools. Projects in this field target to improve existing industrial designs in a multidisciplinary context. The successful candidate will explore the paradigm of optimization techniques using a hands-on application while improving the optimization algorithm. The real challenge is to improve aero-performance of components while still satisfying structural integrity including stress and vibration analysis. The multidisciplinary context of this project requires candidates to work with different CFD and CSM codes.

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A E R O N A U T I C S / A E R O S P A C E

Project Subjects for Graduation Theses 2014-2015

The AERONAUTICS/AEROSPACE Department is involved in a variety of research projects with both experimental and numerical aspects. Experimental facilities cover the entire speed range of aerial vehicles from low to hypersonic speed and are equipped with modern instrumentation and data acquisition systems. Numerical projects are concerned with the development of new physical models (e.g. for reacting flows, turbulence, plasma's) and advanced numerical algorithms for solving fluid flow (higher order schemes, solvers, grid generation).
Graduation projects are proposed in the following areas:

1. AEROTHERMODYNAMICS OF RENTRY VEHICLES IN PERFECT GAS TEST FACILITIES

Development of hypersonic vehicles for future access to space or civil transport applications requires improved knowledge of shock-wave boundary layer interactions and transition to turbulence in the hypersonic regime. Experimental and numerical investigations of these phenomena are currently being conducted in the framework of ESA programmes (e.g. EXPERT program for in-flight testing and validation with simulation and ground testing). For the experiments, two VKI facilities are being used : Longshot, which is a free-piston tunnel that produces high Reynolds and Mach number flows of short duration and H3, which produces Mach 6 flow for a range of Reynolds numbers. Topics of current interest include : control surface simulation, heat flux and pressure distribution measurements, instrumentation development, aerodynamic coefficients determination, and facility flow characterization.

1.1 Simulation of Mach 14 Longshot facility

The Longshot is a facility designed to produce a flow for a very short time but at high Mach number and high Reynolds number. This facility can be operated with nitrogen or carbon dioxide.

The purpose of this project is to study the behavior of the piston during all the phase of compression. When the piston is released, it reaches very high speed and a shock appears in front of it. This shock is reflected at the end of the tube before to impact the piston. After several reflections, the pressure can reach up to 4000 bar and the piston stops at the end of the tube.
Tools are now available for 1D modelisation of the behavior of the piston. This new program has first to be adapted to the Longshot configuration. The final objective is to be able to define new conditions with nitrogen, carbon dioxide or other gases. A correct modelisation can also be used to improve the capability of the tunnel by increasing the Reynolds number or the enthalpy. This new tool gives the possibility to investigate the use of the tunnel with air in order to obtain more real gas effects…
The project consists mainly in programming the new code. Existing experimental data will be used for comparison. Participation to new measurements can eventually be included.

This project requires capabilities in numerical modelling, aerodynamics and thermodynamics.

1.2 Unsteady computation on oscillating capsule in supersonic regime

The stability of reentry vehicles can be critical in low supersonic and transonic regime. Experiments were performed in this range of condition in order to deduce the stability criteria. Several methods were already tested in these conditions and give results.

This project is proposed in the field of a general study on the dynamic stability of space vehicle during the atmospheric reentry. In order to better understand the relation between the dynamic stability and the flow topology, it is propose in this project to study the flow when the capsule is oscillating. Different experimental approaches have been investigated like unsteady pressure measurement on the capsule or in the wake.

It is propose in this project to simulate the flow around a reentry vehicle. The first step consists in static computation in order to assess the effect of the support and how it can affect the flow. Then, unsteady computation should be done on a static model. Comparison with existing experimental results should help in a better understanding. The final objective is to perform unsteady CFD on an oscillating capsule.

The results will be analyzed to better understand the relation between the flow topology and the behavior of the vehicle.

Models tested will be the BLAST capsule because this model was recently tested in the transonic/supersonic wind tunnel.

1.3 Validation of the experimental methods used on oscillating capsule in supersonic regime to find the aerodynamic derivatives

The stability of reentry vehicles can be critical in low supersonic and transonic regime. Experiments were performed in this range of condition in order to deduce the stability criteria. Several methods were already tested in these conditions and give results.

This project is proposed in the field of a general study on the dynamic stability of space vehicle during the atmospheric reentry. The experimental method used to compute the damping of a space vehicle was never validated properly.

A special set-up to impose a force proportional to the angular speed will be designed and manufactured. The solution can be electric, mechanic, hydraulic … .
Instrumentation associated to the set-up should be installed in order to measure accurately the applied forces. This set-up will be used with a real vehicle and a deep error analysis will be done on the results: the model under investigated for this study will be the BLAST capsule which was recently tested in the transonic/supersonic wind tunnel.

1.4 Design of a new experimental set-up to study the aerodynamic derivatives thank to the forced oscillation capsule

The stability of reentry vehicles can be critical in low supersonic and transonic regime. Experiments were performed in this range of condition in order to deduce the stability criteria. Several methods were already tested in these conditions and give results.

This project is proposed in the field of a general study on the dynamic stability of space vehicle during the atmospheric reentry.

Up to now, the study of the stability of capsule by experimental tools was limited to the pitch damping. Only 1 degree of freedom was considered.
The purpose of this project is to design the new generation of experimental set-up. The new equipment will allow deducing the pitch damping of course, but also the other derivatives.
Two or more degree of freedom can be considered in order to study the coupling between the different movement
The different possibilities will be studied and special care will be taken to limit the support effect. Associated measurement techniques will be investigated.

This project required a good mechanical engineer with solid knowledge in aerodynamics.
Numerical simulation can be used during this project in order to validate some choices.

Models under consideration in this project will be the BLAST capsule and the IXV vehicle. These models represent the two main configuration or a reentry vehicle.

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2. AEROTHERMODYNAMICS OF SPACE REENTRY VEHICLES

2.1 Experimental investigations on aerothermodynamics

Spaceships entering a planetary atmosphere are exposed to very high temperature flows. To study the thermal resistance of their heat shields, two wind tunnels generating a high temperature (up to 10 000 °K) plasma jet are available at the VKI. Also a large number of computational models of high temperature flows have been developed over the past decade.
A number of projects are available in this area and they include accurate simulation of re-entry conditions, characterization of plasma flows, thermal protection system (TPS) tests and use and development of numerical tools to investigate aero-thermodynamic phenomena:

2.1.1 Simulation of re-entry conditions

This research activity focuses on the duplication of the aero-heating environment on the critical components of spacecraft for different planetary re-entry conditions in a ground-test facility. Current projects include:

- Simulation of Mars aerocapture
- Thermal history of the heat shield during the entry phase
- Entry condition in dusty atmosphere and CO_2 atmosphere

2.1.2 Characterization of plasma flows and TPS tests

This research activity is concerned with the development of specific measurement techniques for high enthalpy flows. It includes adaptation of classical intrusive measurement techniques in severe environments, combined instrument measurements and plasma diagnostics by emission or absorption spectroscopy.

Specific topics are:
- Unsteady pressure and temperature measurement
- Catalycity determination
- Hemispherical and multispectral emissivity determination
- Reacting boundary layer characterization by spectroscopy measurements

2.1.3 Development of hypersonic flight extrapolation methodology for supersonic plasma wind tunnels

In the context of space vehicle design for ESA missions, the project will deal with an investigation of the duplication of the aerothermodynamics features for a hypersonic flight in high-enthalpy wind tunnels. Hypersonic similarity laws, local duplication of real flight, reactive boundary layer, wall chemistry will be considered.

2.1.4 Development of a new probe for intrusive radiative heat flux measurements in high enthalpy flows

(theory/experiments)

The aim of this project is to extend to radiative heat flux measurement the set of intrusive diagnostic capabilities available at the VKI for high enthalpy facilities. Starting from available material, the student will be involved in designing, building, and qualifying a new and challenging probe for in situ measurements of radiation in the UV and visible spectral ranges for air plasmas representative of Earth entry conditions. An extensive experimental campaign will be carried out by means of the new diagnostic probe for different test and operating conditions.

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2.1.5 Boundary layer control using DBD plasma actuator

(theory/experiments)

The control of the boundary layer separation is a challenging topic regarding potential active control using Dielectric Barrier Discharge (DBD) plasma. The aim of the project is to provide a phenomenological performance map of the DBD plasma actuator applied to a simple configuration (flat plate, step) for subsonic flow separation control. The student will be involved in the experimental bench design and implementation. For a wide range of operating conditions, he will characterize the effect induced by the plasma on the flow by means of simple visualization techniques and analyze the experimental data.

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Yacine Babou, babou@vki.ac.be

2.1.6 Enthalpy Measurement in plasma flow

(theory/experimental)

To increase the accuracy of the free stream characterization at Plasmatron facility, a direct enthalpy measurement probe for Plasma flows is being developed at VKI. Starting from available material, the student will be involved in improving the current design, building and qualifying a new and challenging probe. A number of experiments in VKI Plasmatron facility will be carried out to build a database for a large pressure range and preferably at high heat flux rates. This subject also includes using other available tools at VKI to validate the probe design.

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2.2 Numerical investigation on aerothermodynamics

2.2.1 Study of non equilibrium phenomena in compression and expansion flows

In the frame of atmospheric re-entry conditions, investigations are made using 1D codes (like Shock tube code and Nozzle code) to study non equilibrium phenomena in expansion and compression situations. The starting point is the classical thermal non equilibrium approach developed by Park at NASA and can proceed with the implementation of vibrational specific model (STS).

2.2.2 Heat flux modelling for hypersonic experiment instrumentation

The VKI is actively involved in hypersonic flight experiments. In the framework of an ESA flight experiments project, we intend to perform inflight temperature measurements on the surface. It is known that several aspects influence the quality of the results. The VKI proposes that a detailed model of the Flight Instrumentation will be developed with a focus on the thermal behaviour. The heat flux into the surface and body shall be determined from the temperature measurements. Critical points shall be analysed.

2.2.3 *Catalysis in hypersonic flows*

The heat flux into the body of a hypersonic vehicle is one of the limiting parameters in its design. It is strongly dependent on the chemical gas-surface interaction. The VKI proposes to review existing models, implement them into a CFD code, and compare the obtained results. Optionally, a further model shall be developed based on the findings that represent correctly the phenomenological behaviour of the interaction.

2.2.4 Energy accommodation in gas surface interactions

It is known that exothermic reactions close to the wall contribute only partially their reaction heat to the wall. A non negligeable part serves to excite the recombined molecules leading to a non-Boltzmann distribution of internal energies. The VKI proposes to review recent techniques to determine this ratio of heat contributions and develop a methodology applicable in the VKI Plasma Facilities and to implement it into a CFD code.

2.2.5 Transition in supersonic/hypersonic flow

This subject will start by an update of the state of the art bibliography on the transition models/experiments in very high speed flow. The configuration under interest is a cubical or cylindrical roughness inducing transition in its wake. The subject will is containing benchmark exercises of existing transition models. These exercises will involve the use of the CFD framework CoolFluid or results obtained with this frame work by VKI researchers. Finally, new models or variation of previous models will be proposed, implemented and tested. The different part of the subject may be tackled independently.

2.2.6 Turbulence models for supersonic/hypersonic flow

This subject will start by an update of the state of the art bibliography on the turbulence models/experiments in very high speed flow. The subject will continue with the validation of previous VKI implementation of turbulence models by developers on the CFD framework CoolFluid. Finally, new models or variation of previous models will be proposed, implemented and tested. The different part of the subject may be tackled independently.

2.2.7 Computation of full Re-entry Trajectory

This subject involves the development of a simple and fast code allowing the computation of orbital trajectories of nano satellites once released by the launcher. The code will take into account all the physics allowing to tracks the Cubesat from its original altitude in the Mesosphere Thermosphere layer till its re-entry up to 80 km. The subject is part of a larger Cubesat project.

2.2.8 Development of a hypersonic flight extrapolation methodology for supersonic plasma wind tunnels

(theory /numerics/experiments)

In the context of space vehicle design for the space exploration program of ESA, this project deals with the duplication of the aerothermodynamics features of hypersonic flight into supersonic plasma wind tunnels.

Keywords: hypersonic similarity laws, flight extrapolation, parabolic equations, reactive boundary layer, wall chemistry.

2.2.9 Development of advanced nonequilibrium models for compressing and expanding flow simulations

(theory/numerics)

Understanding thermo-chemical nonequilibrium effects is important for an accurate prediction of the radiative heat flux to the surface of hypersonic vehicles and for a correct interpretation of experimental measurements in wind tunnels. We propose an innovative work, at the interface between computational chemistry and CFD, in collaboration with NASA Ames Research Center. Rate coefficients and cross-sections computed from first principles, for rovibrational excitation and dissociation of molecular nitrogen, will be used to study the dynamics of the excitation / dissociation mechanism in compressing and expanding flows. Then, kinetic theory will allow for the macroscopic conservation equations to be derived, together with the expressions for the transport fluxes and chemical production rates.

2.2.10 Study of detailed chemistry / radiation coupling in atmospheric entry flows

(theory/numerics/experiments)

During atmospheric entries, the gas heated in the shock layer emits radiation that contributes to the incident heat-flux to the vehicle surface. Radiation modeling involves determination of the population distributions over the internal energy levels and of the radiative contribution of each of these levels. At the early reentry stages for lunar and Martian missions, the electronic energy populations depart from equilibrium. We propose to develop a reduced collisional-radiative model that will be used for the first time in 3D CFD simulations. The metastable electronic excited states of the nitrogen and oxygen atoms will be considered as separate species. The high-lying excited states, that produce radiation, will be grouped in a limited number of electronic levels.

2.2.11 Pre- and post-flight data analysis for the EXPERT mission
(numerics/experiments)
The VKI is currently the primary investigator for two payloads for the EXPERT mission of ESA, dealing with: 1) gas-surface interaction over a thermal protection material junction, 2) characterization of an isolated roughness induced transition. These payloads have been designed and qualified to be integrated into the vehicle, which is expected to fly in early 2011. Physico-chemical models and computational tools developed in the Aeronautics and Aerospace Department at the VKI will be used for pre- and post-flight data analysis for this flight demonstrator.

2.2.12 Development of physico-chemical models for ablative materials
(theory/numerics/experiments)
The choice of the heat shield material is a critical problem for engineers. A new class of ablative materials, low density carbon / resin composites, is considered for numerous forthcoming missions. We propose to calculate the kinetic data for carbon-phenolic resin decomposition and transport of gaseous species for these materials. These data will be implemented in a high-fidelity model for ablation developed in collaboration with the Space Technology Division of NASA Ames Research Center. The model developed will be used for simulation of ablation experiments carried out in the VKI plasma facilities, for carbon / resin composites.

2.2.13 Uncertainty Quantification for the space exploration program
(theory/numerics/experiments)
To avoid mission failure and ensure safety of the astronauts and payload, engineers resort to safety factors to determine the heat shield thickness, at the expense of a reduced mass for the embarked payload. Determination of safety factors relies on Uncertainty Quantification (UQ) that aims at developing rigorous methods to characterize the impact of “limited knowledge” on (here) the heat flux. We propose to address the issue of stochastic aerothermodynamics in collaboration with Stanford University and the University of Texas at Austin. Their state-of-the-art tools for UQ will be adapted to quantify the influence of uncertain parameters related to the advanced physico-chemical models developed at the VKI. Experimental data will be used for validation (plasmatron and shock-tube facilities, as well as several ESA flight demonstrators, such as Expert).

2.2.14 Stability of hypersonic flows in the transition regime from laminar to turbulent
(theory/numerics)
The transition from laminar to turbulent is currently not well understood in hypersonic flows. This phenomenon is associated with an undesirable rise of the heat transfer on the thermal protection material for atmospheric entry vehicles. A conventional linear stability approach cannot be used to study hypersonic flows. We propose to derive a general Parabolized Stability Equation (PSE) accounting for generally curved surfaces, three dimensional disturbances, and thermo-chemical nonequilibrium effects, based on specialized software such as SAGE. The general PSE derived will be compared to partial equations available in the literature and will be implemented in code starting from an existing VKI solver. Strong interactions with VKI researchers studying hypersonic transition by means of a broad spectrum of tools (experimental and numerical models) will be crucial for the success of this project.

2.2.15 Development of an approximate Riemann solver for plasmas in thermal nonequilibrium
(theory/numerics)
Developing shock-capturing numerical schemes for plasmas in thermal nonequilibrium is a challenge due to the nonconservative mathematical structure of the system of macroscopic equations. For nonconserva
tive systems, the jump relations for discontinuous solutions depend on diffusion. We propose to develop an approximate Riemann solver for a new set of equations, for plasmas in thermal nonequilibrium, derived from kinetic theory. This problem is related to important applications such as plasma control of hypersonic cruise vehicles for the US Air Force, influence of precursor electrons in reentry flows for ESA and NASA missions, and supernova radiation.

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2.2.16 Plasma (ICP) Simulations for a Re-Entry CubeSat
(theory/numerics)
In the framework of the QB50 project, VKI's reentry CubeSat will carry a number of in-flight experiment payloads on board. The in-flight experiments will be designed according to the scientific questions associated with the re-entry physics. This project deals with preparing and making ICP (Inductively Coupled Plasma) simulations on the full CubeSat, also developing post processing tools. The outcome of this work will eventually provide suggestions for scientific payload design such as TPS recession sensors, heat flux gages, spectrometers etc.
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2.2.17 CFD of a CubeSat during Re-Entry
(numerics)
Development of a reentry CubeSat requires significant computational work based on the re-entry trajectory. In the framework of QB50, computations have to be done in order to provide input not only to the stability mechanism development to achieve the desired atmospheric re-entry but also to the in-flight experiment design in case of side panels (i.e skin friction measurements) and base flow (i.e fast response pressure transducers) investigations. The entire vehicle and the regions of interest should carefully be studied to contribute instrumentation decision process. Based on previous work done at VKI, the optimum nose shape design can be further developed.
Contact person: Jan Thoemel, jan.thoemel@vki.ac.be

2.2.18 Rarefied flow simulations for the stability of a CubeSat in orbit
(numerics)
The QB50 Project aims at realizing a network of CubeSats in very low Earth Orbits (altitude less than 320 km) and this results in the opportunity to develop aerodynamic stability tools for CubeSats. Aerodynamic attitude control mechanisms would have significant mass, power and volume budget reductions compared to traditional attitude control subsystems with reaction wheels. For this purpose, rarefied flow simulations of various innovative aerodynamic control mechanisms (fins, tethers, flower or badminton style panels, parachute, etc) and aerodynamic drag augmentation systems need to be performed by Direct Simulation Monte Carlo (DSMC) and 6-DoF trajectory simulators.
Contact person: Jan Thoemel, jan.thoemel@vki.ac.be

2.2.19 Plasma (ICP) Simulations for a Re-Entry CubeSat
(theory/numerics)
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Contact person: Jan Thoemel, jan.thoemel@vki.ac.be

3. Model form uncertainty quantification for RANS turbulence and mixing models

Turbulence and turbulent mixing are fundamental processes in the vast majority of aerospace applications. While large-eddy simulations can provide accurate solutions for turbulent flow problems, they impose a significant increase in computational cost, and Reynolds-averaged Navier-Stokes simulations remain the most commonly used tool within the engineering community because of the affordable computational cost. The drawback of RANS turbulence and turbulent mixing models is the introduction of uncertainties in the solutions, and a tool to quantify these uncertainties could significantly improve the predictive capabilities of the approach. The following projects all aim to contribute to the development of such a tool.

3.1 Evaluating RANS turbulence model performance

This project will consider different flow configurations (channel flow, wavy wall with separation, jet in crossflow) for which DNS or LES datasets are available to evaluate turbulence model performance. The model errors will be evaluated by comparing the Reynolds stresses obtained from different RANS models to the DNS or LES results. The effect of the coupling to the mean flow will be eliminated by freezing the flow to the time-averaged DNS flow field and only solving the transport equations for the turbulence quantities. Special focus will be on investigating the role of turbulence production and dissipation terms in the prediction of the turbulence kinetic energy.

3.2 Implementing a turbulence model uncertainty quantification framework in OpenFOAM

This goal of this project is to implement an existing model form uncertainty quantification framework in the opensource code Openfoam. The framework consists of:

1. Computing a marker that identifies in which regions of the flow the model is not trusted.
2. Performing an eigenvalue decomposition of the anisotropy tensor obtained with the original Reynolds stress model.
3. Introducing perturbations in the magnitude, eigenvalues and eigenvectors in the previously identified regions.
4. Recompose the perturbed Reynolds stresses.
5. Compute the divergence of the perturbed Reynolds stresses and impose the modified source term in the momentum equations.

The framework will be tested for flow fields of different complexity (channel flow, wavy wall with separation, jet in crossflow)

3.3 Evaluating RANS turbulent mixing model performance

This project will consider different flow configurations (channel flow, wavy wall with separation, jet in crossflow) for which DNS or LES datasets of the flow and scalar fields are available to evaluate turbulent mixing model performance. The focus will be on mixing models based on the generalized gradient diffusion hypothesis. The model errors will be evaluated by comparing the scalar field and the turbulent scalar fluxes obtained from different mixing models to the DNS or LES results. The effect of the coupling to the flow and turbulence equations will be eliminated by freezing the mean and turbulent flow quantities to the time-averaged DNS or LES result, hence only solving the transport equations for the scalar. The validity of the generalized gradient diffusion models and the importance of correctly predicting the different terms in the tensorial diffusion coefficient will be investigated

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von KARMAN INSTITUTE FOR FLUID DYNAMICS

ACCEPTANCE FORM FOR BELGIAN UNIVERSITY & ENGINEERING SCHOOL STUDENTS PREPARING THEIR GRADUATION THESIS AT THE VKI (*)

to be completed together with your VKI supervisor

(Note to VKI supervisor : please add the VKI enrolment form upon acceptance)

Family name : …………………………………………………………………….

First name : …………………………………………………………………….

Home address : …………………………………………………………………….

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Telephone number : …………………………………………………………………….

E-mail address : …………………………………………………………………….

University/School and Dept : …………………………………………………………………….

Period of regular presence at the VKI: From …………………… to ……………………

Subject of research to be carried out at VKI (title of thesis if possible) : ………………………………………

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Supervisor at the University : ………………………………..…………………………………………………….

Supervisor at VKI :……………...………………………………………………………………..

VKI Department in which research is to be carried out :

Aeronautics/Aerospace
Environmental and Applied Fluid Dynamics
Turbomachinery and Propulsion

Name of diploma expected at the University : ……………………………………………….

When do you expect to receive the diploma? : ………………..………………………………

I commit myself to have the full name "von Karman Institute for Fluid Dynamics, Department of ……", as well as the VKI logo and the name of my supervisor at VKI clearly appearing on the front cover of my thesis, in addition to the names of my University and thesis director at my University. In the text of my thesis, the help received at the VKI and the use of VKI facilities will be duly described and acknowledged.

I understand that the von Karman Institute reserves the right to publish the results obtained, with acknowledgement to the author and to his or her supervisor, in the Institute's technical notes or other publications.

Prior to my thesis defense, I will give three printed copies of my thesis, in their final form, to the VKI library.

Date : ……….....

Acceptance approved by:

………………………….	………………………..	…………………
Signature Student	Signature VKI supervisor name:	Signature VKI Director J. Muylaert

* original to be returned to the VKI secretariat with enrolment form
1 copy to be returned to the student after signature VKI Director