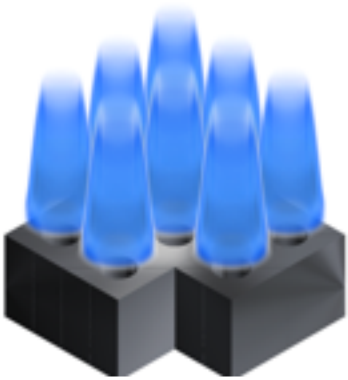
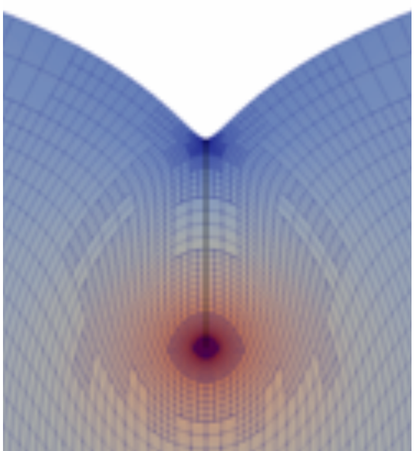


2020 2021

Course Programme



J.M.Burgerscentrum

Research School for Fluid Mechanics

TUD, TUE, UT, RUG, WUR, UU

Course Programme 2020 - 2021

JM Burgerscentrum
Research School for Fluid Mechanics

TUD, TUE, UT, RUG, WUR, UU

Cover : upper left (M Verbeek, TUD-Uijttewaal), upper right (DV Efimov, TUE-Deen), lower left (JH Damveld, UT-Hulscher), lower right (M Essink, UT-Snoeijer)

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Contents

Introduction

Introduction

This booklet provides an overview of the courses that are organised for the training of the PhD students of the JM Burgerscentrum (JMBC), the Dutch research school on fluid mechanics. The guide describes the general idea of the PhD programme and presents a framework in which individual training schedules can be developed. It gives a description of the PhD courses in the year 2020-2021, with information about the conditions to participate and instructions for registration. The courses are primarily organised for PhD students of the JMBC, although PhD students from other research schools and post-docs may also participate. Moreover, persons from industries and technological institutes are also welcome to attend the courses.

Also, information is provided about a selection of MSc courses given by several JMBC groups. These MSc courses may also be of interest to PhD students and postdocs willing to broaden and deepen their knowledge of fluid mechanics.

Additional information about courses and more general information about the JM Burgerscentrum may be found on our website www.jmburgerscentrum.nl.

Prof.dr.ir. GJF van Heijst
Scientific director

Structure of the PhD programme

Structure of the PhD programme

Purpose of the PhD programme

The purpose of the PhD programme of the JM Burgerscentrum is the development of PhD students into independent researchers in the field of fluid mechanics. To reach this goal a thorough and fundamental knowledge of fluid mechanics and its mathematical and numerical modelling is required, as well as the ability to further develop this knowledge and to apply it to solve scientific and technical problems. An important part of the PhD programme consists of the execution of a scientific research project under the supervision of an expert of the JMBC. That part is not discussed in this guide. A smaller part consists of the participation in courses. Details of that part of the programme (the training programme) are given in this guide.

Structure of the training programme

The training programme provides a framework, in which individual training schemes can be developed. It contains the following three components:
- MSc courses
- PhD courses
- Workshops, summer schools, seminars.

The different components are meant for broadening or deepening of knowledge, and also for specialisation in certain areas of fluid mechanics. Individual training programmes are composed from elements of the three components.

MSc courses

The MSc degree courses may be useful for PhD students (or other interested persons), with limited earlier formal training in fluid mechanics. The courses will bring those PhD students to the same level of knowledge in fluid mechanics as PhD students who did receive their MSc degree in fluid mechanics. The courses are usually selected from the advanced courses of the study programme for the MSc degree. An overview of the most relevant MSc degree courses is given in this guide, ordered according to the main research themes of the JMBC. Information about time and location of these courses can be obtained from the contact persons mentioned in the course descriptions given in this guide, or can be found in the study guides of the different universities participating in the JMBC.

JMBC PhD courses

For a PhD student it is essential to deepen his/her knowledge in fluid mechanics to a level significantly higher than that of a person with an MSc degree in fluid mechanics. The PhD courses of the JM Burgerscentrum fulfil this purpose. The deepening of knowledge is not restricted to the area of fluid mechanics, to which the research project of a PhD student belongs. After his/her PhD degree the PhD student must be able to quickly acquaint himself/herself with a new area of fluid mechanics and solve problems in that area. Therefore, each PhD student must at least participate in three PhD courses. The content of the courses is composed in such a way, that the courses can be followed by all PhD students (independent of their knowledge obtained in their MSc degree programme). The different PhD courses of the JM Burgerscentrum are usually given once every two years, depending on the number of participants. The courses are concentrated in time, usually during one week. The courses are given by senior staff members of the JMBC, but also by (internationally well-known) guest lecturers. The courses may contain different elements: theoretical training, own work, numerical simulations, demonstrations, etc. An active role of the participants is stimulated.

Workshops, summer schools, seminars or courses of other organisations

A less-structural part of the training programme of the JM Burgerscentrum consists of workshops, summer schools and seminars. It is recommended that a PhD student participates in a few (international) summer schools. Also courses organised by organisations such as the Von Karman Institute, ERCOFTAC, EUROMECH, CISM, etc. are highly recommended.

Individual training programme

For each PhD student an individual training programme has to be designed within the framework of the gradute school of the particular university at which the PhD student is working. These graduate schools provide a training in professional and personal skills, but not in the scientific expertise area in which the PhD student is working. That type of training is ideally provided by the research schools. The JM Burgers Centre provides this scientific training in the area of fluid dynamics. Although the specific requirements of the graduate schools differ from university to university, PhD students of the JM Burgers Centre are generally supposed to take at least three JMBC courses, to be selected in consultation with the supervisor.

JMBC certificate

After having attended at least three JMBC courses, each PhD student will receive the JMBC certificate. This document, listing the courses attended, may be helpful when applying for a job after the PhD graduation.

Registration for JMBC PhD courses

Registration for JMBC PhD courses

Conditions

The PhD courses organised by the JM Burgerscentrum are primarily organised for the PhD students of the JM Burgerscentrum. They have priority with respect to registration for these courses. However, also PhD students from other research schools, post-docs and staff members from industries and technological institutes can participate.

Fees

- € 250 | Officially registered JMBC PhD students and JMBC Postdocs.
  Registration fee includes: course material, lunches, a joint diner, and (if necessary) hotel accommodation. The hotel (if necessary) will be booked and paid by the JMBC.
- € 400 | All other national and international PhD students, scientific staff, postdocs, post-graduate students. Registration fee includes: course material, lunches, a joint diner. Participants have to book their own hotel accommodation; no reimbursement is provided by the JMBC.
- € 1000 | Staff members from industries, technological institutes or other participants. Registration fee includes: course material, lunches, a joint diner. Participants have to book their own hotel accommodation; no reimbursement is provided by the JMBC.

Registration

Registration for the JMBC PhD courses is possible by filling in the online registration form on https://jmburgerscentrum.nl/contact-registration.

Certificate of attendance

Upon request any participant in a JMBC course may receive from the JMBC secretariat a certificate confirming his/her participation. Note that the JMBC certificate is only obtained after having attended at least three JMBC courses.

Course evaluation form

Each participant of a JMBC course is asked to fill in a course evaluation form via the website of the JMBC https://jmburgerscentrum.nl/contact-registration. The evaluation form is anonymous. The JMBC scientific director will discuss the evaluation results with the course leader.

Course Programme 2020 - 2021

JMBC PhD courses

Registration via the online form (www.jmburgerscentrum.nl)
Registration preferably one month before the start of the course

Overview of the courses for the academic year 2020-2021

PIV (ONLINE)	12 -16 October 2020
Computational multiphase flows (ONLINE)	4 - 6 November 2020
CFD 2	18 - 22 January 2021
Micro- and nanofluidics	29 March - 1 April 2021
Shallow flows (VKI-JMBC)	19 - 22 April 2021
Experimental techniques	22 - 25 June 2021
Machine learning (NEW)	28 June - 2 July 2021
Particle-based modeling techniques	11 - 15 October 2021

Due to the COVID-19 pandemic some of the courses scheduled for 2021 may be given ONLINE as well.

PIV

12 - 16 October 2020
Location: ONLINE from TUD
Coordinators: Gerrit Elsinga (TUD), Andrea Sciacchitano (TUD)
Lecturers: Fulvio Scarano (TUD), Jerry Westerweel (TUD), Christian Poelma (TUD), Andrea Sciacchitano (TUD), Edwin Overmars (TUD), Bas van Oudheusden (TUD), Gerrit Elsinga (TUD), Rudie Kunnen (TU/e), Alvaro Marin (UT), Andreas Schröder (DLR), Ken Kiger (Maryland)

Particle Image Velocimetry is a measurement technique able to determine the instantaneous velocity field in a planar or volumetric domain. It is widely applied in both fundamental and applied fluid mechanics research. The course discusses the fundamentals of the technique and examples of specific applications, including typical problems in microfluidics, turbulence, multiphase flows and aerodynamics. Next to the lectures, a number of practical sessions will be organized, where the participants can practice their skills and see some state-of-art facilities (e.g. tomographic PIV, high-speed PIV). The course is primarily targeted at PhD students of the JM Burgerscentrum, with priority on registration. Due to limitations on the available space in the practical sessions, the maximum number of participants is set to 35. Other interested researchers (postdocs, faculty, researchers from institutes and industry) are welcome to apply as well.
Apart from a basic understanding of fluid mechanics, no prerequisite knowledge is required. The following topics are discussed:

- PIV system components: tracers, lasers, optics, cameras
- Measurement fundamentals: cross-correlation, image density, loss-of-pairs
- Measurement regimes: stereoscopic PIV, multiphase flows, microfluidics, high-speed systems, volumetric methods (e.g. 3D-PTV, tomographic PIV)
- Data processing techniques: multi-pass correlation, multigrid methods, deforming windows, correlation averaging, multi-frame methods
- Data reduction and post-processing: vector validation, estimation of vorticity, detecting coherent structures, uncertainty quantification

Experimental design and lab demos are given in practical sessions.

Note that all lectures and practical sessions are online. For PhD students of the JM Burgerscentrum, we aim to organize one lab session in Delft (subject to COVID measures) on the last day on the course.

For more information, contact:
Gerrit Elsinga | 015 278 8179 | g.e.elsinga@tudelft.nl

Computational multiphase flow

4 - 6 November 2020
Location: ONLINE from TUD
Coordinator: Ruud Henkes (TUD)
Lecturers: Wim-Paul Breugem (TUD), Ruud Henkes (TUD), Hans Kuipers (UT), Rob Mudde (TUD), Kees Vuik (TUD)

Multiphase flow denotes the combined transport of gas, liquid, and particles. The aim of this 3-day course is to give a broad overview of the possibilities and limitations of physical-numerical modelling and prediction of multiphase flows. This includes (1) fundamentals of physical models and their numerical representation and solvers, (2) application of Computational Fluid Dynamics to a wide range of environmental and industrial processes driven by multiphase flow, (3) assessment of a number of CFD packages widely used to solve industrial problems. At the end of the course the participants will have a good awareness of the types of computational methods, with their specific accuracy, that can be used for multiphase flows occurring in industry. This will help them to build realistic expectations for their own specific practical problems, which might be even more complex than the examples treated in the course. Participants will also be able to acknowledge gaps in our current knowledge, which may help them to define new future research directions..

For more information, contact:
Ruud Henkes | 015 278 1323 | r.a.w.m.henkes@tudelft.nl

CFD 2

18 - 22 January 2021
Location: TUD
Coordinator: Kees Vuik (TUD)
Lecturers: Kees Vuik (TUD), Fred Vermolen (Hasselt University, B)

This lecture course focuses on (1) finite element methods for the incompressible Navier-Stokes equations and on (2) iterative solution methods.
(1) A short introduction to the finite element method is given. The following fluid flow applications are used: Poisson equation, convection-diffusion equation and the incompressible Navier-Stokes equations. Subjects studied in more detail are: (streamline) upwind methods, problems originating from the incompressibility condition, and the linearisation of convective terms in the Navier-Stokes equations. Some remarks are given on time-dependent problems.
(2) The second part of the course is devoted to modern iterative methods. Furthermore the following related topics are considered:

- direct and iterative methods for (sparse) linear systems;
- iterative methods to compute eigenvalues of matrices;
- implementation of these methods on vector- and parallel computers.

As applications systems are used which originate from fluid flow problems. To illustrate the theory, practical work is done in the afternoons using MATLAB and the finite element package SEPRAN. Required background: a basic course in numerical analysis, partial differential equations and linear algebra.

For more information, contact:
Kees Vuik | 015 278 5530 | c.vuik@tudelft.nl

Micro- and nanofluidics

29 March - 1 April 2021
Location: TUE
Coordinator: Jaap den Toonder (TUE)
Lecturers: Jaap den Toonder (TUE), Hans Wyss (TUE), Eduard Pelssers (Philips), Herman Wijshoff (Canon)

Micro- and nanofluidics is the science and technology of manipulating and analyzing fluid flow on length scales ranging from millimeters down to nanometers. It is the key enabling technology for many emerging applications and disciplines, especially in the fields of medicine, environmental sensing, biology, and chemistry. Also in engineering and the physical sciences microfluidic systems are employed in applications such as advanced printers, heat management, and energy generation. This course will cover a range of aspects of micro- and nanofluidics. These include (1) fundamentals of flow at small scales; (2) physical principles that play an important role in micro- and nanofluidics, and how these can be used to manipulate fluids at small scales; (3) microfluidics in nature, that can be used as an inspiration; (4) applications of micro- and nanofluidics; (5) micro- and nanofluidic device fabrication; and (6) valorization and commercialization of micro- and nanofluidics. In addition, a practical workshop will be an important part of the course, aimed at gaining hands-on experience with basic micro-fluidics device manufacturing and testing. The maximum number of participants is 20.

For more information, contact:
Jaap den Toonder | 040 247 5767 | j.m.j.d.toonder@tue.nl

Shallow flows (VKI-JMBC)

19 - 22 April 2021
Location: VKI, Brussels (B)
Coordinator: GertJan van Heijst (TUE), Matias Duran Matute (TUE)
Lecturers: Matias Duran Matute (TUE), GertJan van Heijst (TUE), Heidi Nepf (MIT, USA), Scott Socolofsky (Texas A&M, USA), Huib de Swart (UU), Wim Uijttewaal (TUD)

Many flows in environmental and industrial settings can be characterized as 'shallow', with the typical horizontal scales being much larger than the vertical size of the flow domain. Examples are flows in rivers, estuaries, the coastal region, fresh water reservoirs, but also flows in settling chambers for water treatment and large-scale ocean and atmospheric flows. Shallowness implies a rather specific flow dynamics. The purpose of this course is to offer an overview of various aspects of shallow flows: fundamental as well as applied aspects, and numerical as well as laboratory studies and field observations. Topics that will be addressed are, for example, laboratory and numerical studies of fundamental processes and transport mechanisms in shallow mixing layers, wakes, jets, and open channels. Also, transport of heat, solutes, and pollutants in canonical shallow flows and generic flow configurations will be discussed. Other topics are sediment transport and morphodynamics, which are relevant features of environmental shallow flows, such as occurring in the coastal area, in estuaries, and in harbours. The course will be delivered by a number of internationally recognized experts.
The aim of the course is to give a wide overview of various aspects of shallow flows. No specific prior knowledge of geophysical or environmental fluid dynamics is required, although it is assumed that the participants have a general background in fluid dynamics

For more information, contact:
Matias Duran Matute | 040 247 2118 | m.duran.matute@tue.nl

Experimental techniques in fluid mechanics

22 - 25 June 2021
Location: UT
Coordinator: Alvaro Marin (UT), Michel Versluis (UT)
Lecturers: Nico Dam (TU/e), Fulvio Scarano (TUD), Jan van Dijk (TU/e), Michel Versluis

(UT), Alvaro Marin (UT), Christian Poelma (TUD), Willem van de Water (TUD), Rudie Kunnen (TU/e)

This course for JMBC PhD students gives a general overview of concepts of experimental methods for flow, pressure, concentration and temperature measurements. The course will discuss various classic techniques (thermocouples, Pitot-tubes, hot-wire anemometry) and optical techniques such as shadowgraphy and Schlieren. The course will also focus on modern non-intrusive laser techniques (Laser Doppler and Phase Doppler Anemometry, Particle Imaging and Particle Tracking Velocimetry and Laser-induced Fluorescence). We will discuss methods for flow visualization and high-speed imaging and we have special presentations on experimental methods used in two-phase flows, in rheology and in industrial applications.

For more information, contact:
Michel Versluis | 053 489 6824 | m.versluis@utwente.nl
Alvaro Marin | 053 489 2379 | a.marin@utwente.nl

Machine learning in fluid mechanics (NEW)

28 June - 2 July 2021
Location: TUE
Coordinator: Federico Toschi (TUE), Alessandro Corbetta (TUE)
Lecturers: Federico Toschi (TUE), Alessandro Corbetta (TUE), and others

Machine learning and deep learning are allowing the progressive automation of tasks that only few years ago were impossible or required labour-intensive human activity. Image processing, language processing/translation, automated control, digital pathology are examples of recently revolutionized sectors. From a scientific perspective, there are strong evidences that deep learning methods are capable of quantifying properties of complex and/or chaotic dynamical systems, among which turbulence, far better than the current state of the art. This opens new research possibilities in which machine learning supports or even unlocks new scientific discoveries. This course, aimed at students with a fluid mechanics background, has a two-fold aim: first it will provide an application-oriented primer on neural networks for inference and control tasks. Second it will present recent selected use-cases from fluid mechanics and non-linear dynamics. The course time will be evenly split between lectures and hands-on sessions. Students will be trained to state-of-the-art machine learning software tools (python/jupyter, keras).

For more information, contact:
Federico Toschi | 040 247 3911 | f.toschi@tue.nl

Provisional programme of JMBC courses 2021-2023

A couple of the JMBC courses are organised every two years, while others are given at a lower frequency. It is anticipated that the following JMBC courses will be organised in the coming few years:

2021 – 2022

Particle-based modeling techniques
Solution methods in computational mechanics (EM-JMBC)
CFD 1
Turbulence
Combustion
Capillarity-driven flows in microfluidics

2022 – 2023

CFD 2
PIV
Experimental techniques
Machine learning
Micro- and nanofluidics
Computational multiphase flows

The list will be completed with some additional courses, which are given less frequently. This will be announced in due time.

Related courses

PhD students of the JM Burgers Centre may also participate in courses organised by other graduate schools or institutions:

Engineering Mechanics (EM)

Graduate School on Engineering Mechanics
Information about EM courses: http://www.em.tue.nl

The course ‘Solution methods in compuational mechanics’ is organised jointly by Engineering Mechanics and the JM Burgers Centre.

OSPT

Research School in Process Technology
Overview of OSPT courses: http://www.ispt.eu/innovation_academy/ospt/

CISM

International Centre for Mechanical Sciences (Udine, Italy)
Information about CISM courses: http://www.cism.it/

VKI

Von Karman Institute for Fluid Dynamics (Brussels, Belgium)
Information about VKI courses: https://www.vki.ac.be/

The course ‘Shallow flows’ is organised jointly by VKI and the JM Burgers Centre.

MSc degree courses

General fluid dynamics

Advanced fluid dynamics I (3MT010)

prof.dr.ir. GJF van Heijst, dr.ir. LPJ Kamp, TUE
In this course some important fundamental aspects of fluid mechanics will be discussed which one often encounters both in theoretical problems and in industrial applications. The first part of the course concentrates on the subject of 'vortex dynamics'. Topics like vortex theorems, vorticity production and diffusion, coherent vortices in 2D flows and 3D vortex structures will be discussed. The second part of the course concentrates on the application of 'complex function theory' in fluid dynamics (complex flow potential, Milne-Thomson circle theorem, forces on bodies in potential flows, and conformal mapping). Also, attention will be given to aspects like kinetic energy of potential flows (Kelvin's minimum principle) and added mass of accelerating bodies in a fluid. Additional topics are: flows governed by the Helmholtz equation (application: spin-up), flows governed by the biharmonic equation (Stokes flows, application: swimming of micro-organisms) and characterization of 2D flows (Okubo-Weiss function).
In addition to the lectures, in which the theoretical concepts are discussed and explained, a number of numerical sessions are scheduled, in which numerical flow simulations will be carried out by the students.
For more information, contact :
GJF van Heijst | 040 247 2722 | g.j.f.v.heijst@tue.nl | 5 ECTS

Advanced physical transport phenomena (TN375-3)

Dr.ir. S Kenjeres, TUD
The covered subjects are: heat diffusion: stationary and instationary transport, moving boundary problems; mathematical methods: separation of variables, Laplace transformation, integral methods; momentum transport: potential flow, creeping flow, boundary layer flow; turbulence modelling; numerical methods in Computational Fluid Dynamics.
For more information, contact :
S Kenjeres | 015 278 3649| s.kenjeres@tudelft.nl

Compressible flows

Gasdynamics (4EM10)

Prof.dr.ir. DMJ Smeulders, TUE
Gas dynamics is that part of fluid mechanics in which fluid compressibility, characterized by the speed of sound, is important. The following subjects will be discussed during the course: compressible gas turbine flow, one-dimensional propagation of waves in tubes, distortion of high-amplitude waves, the formation of almost discontinuous pressure-waves, characterized by a large change in velocity and thermodynamic state (shock waves). The possibility to create well-defined shock waves in a laboratory using a shock tube and its use for studying physical and chemical properties of gases will be treated, as well as the analogy between waves in gases and waves in traffic density on a highway. We treat the generation and propagation of detonation waves. The principle and application of the Random Choice Method (RCM) is exercised.
For more information, contact :
DMJ Smeulders | 040 247 2140 | d.m.j.smeulders@tue.nl | 5 ECTS

Multiphase flow, dispersed media and rheology

Multiphase flow and heat transfer (AP3181D)

Dr.Eng. LM Portela, TUD
The course on multiphase flow covers basic parameters for design and operation of process equipment, interfacial phenomena, waves in two-phase flow, dimensionless numbers for scale-up, flow regime dependent modelling, two-phase pressure gradients and phase hold-ups for separated, slug and bubble gas/liquid pipe flow and flow regime maps for inclined tube flows. It will furthermore provide introductions to dispersed gas/liquid flows in simple and complex geometries and dispersed flows with solid particles. Moreover, it will address the two-phase heat transfer aspects of boiling liquids. The course is concluded with a brief introduction to the course on Computational Multiphase Flows.
For more information, contact :
LM Portela | 015 278 2842 | l.portela@tudelft.nl | 6 ECTS

Continuum mechanics

Dr. D van den Ende, UT
The continuum model, kinematics, conservatoin laws, the stress tensor, simple materials, special constitutive equations, special types of flow, rheological material functions. This course will not be lectured on specific dates, but on an individual base in the form of self-study, after making an appointment with Dr. D van den Ende.
For more information, contact :
D van den Ende | 053 489 3105 | h.t.m.vandenende@utwente.nl

Capillarity and wetting phenomena

Prof.dr. F Mugele, UT
Many physical and technological processes are affected by Capillarity and Wetting (C&W) phenomena. C&W phenomena dominate many processes in fluid dynamics on small scales. Compared to other fluid physics courses within APH curriculum this course focuses on the effect of interfaces and the related interfacial energies that control fluid flows by indirectly by imposing well-defined boundary conditions. The course focusses on fundamental concepts described within the context of fluid dynamics and discusses a variety of classical phenomena of microscopic fluid flows. The course covers the following topics: Molecular interaction force and interfacial tensions; Derivation of the fundamental equations of Young and Laplace; Wetting in external fields; Wetting and molecular forces (disjoining pressure); Thin film flows and lubrication approximation; Linear stability analysis and classical instabilities (Rayleigh Plateau, Rayleigh Taylor); Contact line dynamics; Dewetting; Surface tension-driven flows (Marangoni); Electrowetting.

The course is taught in the form of classical lectures (HCs) accompanied by seminars (WCs) in which homework problems prepared and submitted by the students beforehand are being discussed. The course will be given in the fourth quarter (Mei-Juli 2016).
For more information, contact :
F Mugele | 053 489 3094 | f.mugele@utwente.nl | 5 ECTS

Nanoparticulate materials

Prof.dr. A Schmidt-Ott, TUD
- What is special about nanoparticulate and nanophase materials? Basic properties (electrical, optical, magnetic, mechanical, chemical) and size effects
- Synthesis of nanoparticulate and nanophase materials, e.g.in flow reactors
- Characterization of nanoparticulate and nanophase materials, including on-line characterization of particles in gas suspension
- present and future applications of nano-composites including solar cells, fuel cells, hydrogen storage, catalysis, magnetic, optical, structural materials

For more information, contact :
A Schmidt-Ott | 015 278 3540 | a.schmidt-ott@tudelft.nl

Computational multiphase flow (AP3551)

Dr.Eng. LM Portela, TUD
This course consists of 12 weeks, starting in the begining of September, in which the behaviour and description of flows, whereby one phase is dispersed in another phase, will be discussed. The Euler-Lagrange and Euler-Euler approaches to dispersed multiphase flows will be discussed. During the course, the students will develop a small CFD code, to which subsequently the various important aspects of dispersed flows will be added. The influence of different interaction forces (drag, lift, added mass, etc.) between the phases and the effects of turbulence will be studied using the CFD code.
For more information, contact :
LM Portela | 015 2782842 | L.Portela@tudelft.nl | 6 ECTS

Multiphase reactor engineering (CH3061)

Dr.ir. JR van Ommen, TUD
This is an elective course for MSc en PhD students, taught in the third quarter of the academic year. The course treats the various types of multiphase reactors, such as packed beds, fluidized beds, and bubble columns. A large part of the course consists of modelling assignments, to be made in teams of two or three persons.
For more information, contact :
JR van Ommen | 015 278 2133 | j.r.vanommen@tudelft.nl | 4 ECTS

Multiphase reactor modeling (6EMA05)

Prof.dr.ir. M van Sint Annaland and dr.ir. EAJF Peters, TUE
In this course you learn how advanced mass and heat transfer problems accompanied by complex chemical transformations can be formulated and solved. Both single phase and multiphase systems (gas-solid, gas-liquid and gas-liquid-solid) will be considered. Topics covered are:

- Fixed bed reactors
- Fluidized bed reactors
- Slurry Bubble column reactors
- Generalized Maxwell-Stefan equations
- Particle models

Through tutorial sessions the students first will learn how to formulate, implement and solve these problems in Matlab. The assessment will be done by means of an assignment where you need to model a specified reactor type for a given process.
For more information, contact :
M van Sint Annaland | 040 2472241 | M.v.SintAnnaland@tue.nl | 5 ECTS

Transport in porous media (3MT130)

Dr. L Pel, dr. HP Huinink, prof.dr.ir. DMJ Smeulders, prof.dr.ir. CJ van Duijn, TUE
The transport of, e.g., water, oil in porous media is studied in various disciplines, e.g., civil engineering, building physics, chemical engineering, reservoir engineering and soil science. In all these disciplines, problems are encountered in mass and heat transport through a porous material. In these disciplines many models have been developed to describe the transport processes in porous media. It is beyond the scope of this course to go into the details of these various theories. This course is a first introduction and provides a basic theoretical background for modelling transport phenomena engaged in various engineering projects. Main subjects with respect to porous media: REV, capillary forces, absorption, component transport, multiphase transport, NMR + porous media, density-driven flow, drying, fire spalling, phase changes.
For more information, contact :
L Pel | 040 2473406 | l.pel@tue.nl | 5 ECTS

Multiphase flows

Prof.dr. S Luding, M van der Hoef, WK den Otter, AR Thornton, R Hagmeijer, E van der Weide, G Brem, J Kok, UT
In fluid mechanics, multiphase flow is a generalization of two-phase flow, i.e. cases where the phases are not chemically related (e.g. dusty gases, particles in fluid) or where more than two phases are present (e.g. propagating steam explosions, suspensions, aerosols, sprays,

clouds, ...). More general, multi-phase flow involves the interaction of solids with fluids, or of different fluids with each other and is of utmost importance in many engineering and science fields. Each of the phases is considered to have a separately defined volume fraction (the sum of which is unity), and its own velocity field. Conservation equations for the flow of each species (perhaps with terms for interchange between the phases), can then be written down straightforwardly. The momentum equation for each phase is less straightforward. It can be shown that a common pressure field can be defined, and that each phase is subject to the gradient of this field, weighted by its volume fraction. Transfer of momentum between the phases is sometimes less straightforward to determine, and in addition, a very light phase in bubble form has a virtual mass associated with its acceleration. (The virtual mass of a single bubble is about half its displaced mass). These terms, often called constitutive relations, are often strongly dependent on flow regime.

For more information, contact :

S Luding |s.luding@utwente.nl | 053 489 4212 | 5 ECTS

Numerical computations and modelling

Elements of computational fluid dynamics A (WI4011)

Dr.ir. DR van der Heul, TUD
Topics: The governing equations; finite volume methods; stability theory; singular perturbations; numerical methods for the incompressible Navier-Stokes equations; efficient iterative solution methods. MATLAB software is available at http://ta.twi.tudelft.nl/users/wesseling For more information look at http://ta.twi.tudelft.nl/users/wesseling/cfdcourse.html
For more information, contact :
DR van der Heul | 020 511 3113 | d.r.vanderheul@tudelft.nl

Advanced numerical methods (WI4212)

Prof.dr.ir. C Vuik and dr.ir. JE Romate TUD
This course is an introduction to hyperbolic partial differential equations and a powerful class of numerical methods for approximating their solution, including both linear problems and nonlinear conservation laws. These equations describe a wide range of wave propagation and transport phenomena arising in nearly every scientific and engineering discipline. Several applications are described in a self-contained manner, along with much of the mathematical theory of hyperbolic problems. High-resolution versions of Godunov's method are developed, in which Riemann problems are solved to determine the local wave structure and limiters are then applied to eliminate numerical oscillations. These methods were originally designed to capture shock waves accurately, but are also useful tools for studying linear wave-propagation problems, particularly in heterogeneous material.
More information : http://ta.twi.tudelft.nl/nw/users/vuik/wi4212/wi4212_eng.html
For more information, contact :
C Vuik | 015 278 5530 | c.vuik@tudelft.nl | 6 ECTS

Scientific programming (WI4260TU)

Prof.dr.ir.H.X.Lin and Ir.C.W.J.Lemmens TUD
This course tries to bring students to a level where they are able to change algorithms from e.g. numerical analysis into efficient and robust programs that run on a simple computer. It comprises: 1. Introduction to programming in general; 2. (Numerical) Software design; 3. Data Structures; 4. Testing, debugging and profiling; 5. Efficiency issues in computing time and memory usage; 6. Optimization and dynamic memory allocation; 7. Scientific software souces and libraries. This course only talks about simple sequential programming.

More advanced topics like threads or parallel (MPI/GPU) programming on supercomputers are not covered by this course (they are covered by other courses).
http://ta.twi.tudelft.nl/nw/users/vuik/wi4260/wi4260_eng.html
For more information, contact :
C Vuik | 015 278 5530 | c.vuik@tudelft.nl | 6 ECTS

Computational modelling of flow and transport (CIE4340)

Dr.ir. M Zijlema, TUD
Introduction to computational modelling of flow and transport in civil engineering, to be able to recognize the strengths and weaknesses of the various numerical recipes, and understand how numerical algorithms used by many well-known numerical packages (e.g. Delft3D-FLOW, SWASH) work. The following topics are dealt with during the course:
1. Ordinary Differential Equations (ODE), test equation and spring-mass system.
2. Time integration for ODE, consistency, convergence, stability and stiffness.
3. Partial Differential Equations (PDE), diffusion equation, convection or wave equation and convection-diffusion equation. Dirichlet and Neumann boundary conditions, well-posed problems.
4. Space discretization for PDE, finite differences, Von Neumann stability analysis, CFL condition, amplitude and phase error analysis, wiggles and monotonicity, modified equation approach, upwind and numerical diffusion.
5. 1D shallow water equations, method of characteristics, Riemann invariants, boundary conditions, spin up and Sommerfeld radiation, leapfrog and Preissmann schemes, staggered grids, SWASH and applications.
For this course is knowledge of solution of first order and second order differential equations and some mathematical techniques like Taylor series expansion and Fourier transform essential. Also some knowledge and experience with programming in Matlab is recommended.
For more information, contact :
M Zijlema | 015 278 3255 | m.zijlema@tudelft.nl | 4 ECTS

Computational hydraulics (CTwa5315)

Prof.dr.ir. GS Stelling and prof.dr. JD Pietrzak, TUD
Description: Theory and practice of 2D and 3D nonstationary flow and transport computations.
For more information, contact :
JD Pietrzak | 015 278 5466 | j.d.pietrzak@tudelft.nl

Computational fluid dynamics

Prof.dr. RWCP Verstappen, RUG
Introduction to numerical methods for simulating viscous flow problems: discretization on nonuniform grids, convection-diffusion equation, incompressible Navier-Stokes equations, free-surface flow, Burgers' equation, simulation of turbulent flow (DNS).
For more information, contact :
RWCP Verstappen | 050 363 3958 | r.w.c.p.verstappen@math.rug.nl

Boundary-layer flow

Prof.dr. RWCP Verstappen, RUG
Physical modelling and numerical simulation of laminar and turbulent boundary layers: boundary-layer equations, integral formulation, turbulence modelling, asymptotic structure, flow separation, strong viscous-inviscid interaction.
For more information, contact :
RWCP Verstappen | 050 363 3958 | r.w.c.p.verstappen@math.rug.nl

CFD 1 - Incompressible flows (AE4-151)

Dr.ir. MI Gerritsma, TUD
Subjects treated: Introduction to Computational Fluid Dynamics. Classification of partial differential equations and well-posedness. Finite volume methods, finite difference methods, finite element methods, boundary element methods and spectral element methods. For the incompressible Navier-Stokes equations two topics will be treated in depth: the relation between the (hyperbolic) convective terms and the (elliptic/parabolic) diffusive terms, and the role of the pressure in incompressible flows and the ensuing compatibility conditions between velocity and pressure approximation.Examination takes place in the form of an assignment in which the student writes and analyzes an incompressible Navier-Stokes solver. This assignment will be concluded with an oral examination.
For more information, contact :
MI Gerritsma | 015 278 5903 | m.i.gerritsma@tudelft.nl

Advanced programming in engineering (191158500)

Prof.dr. S Luding and dr. WK den Otter, UT
The goal of the course is to familiarize students with the basics of various algorithms and methods commonly used in mechanical engineering, civil engineering, and physics. The course goes deep into the basics, involving advanced computational programming and algorithms. The goal is not to master to use commercial software packages or functions from,

e.g., Matlab, but to understand the methods "from the inside". There are class room lectures to learn the basic algorithms and underlying theory, as well as practical exercises to implement and apply the gained knowledge on a computer. A wide range of topics is treated, including complexity, differential equations, finite elements and final volume methods, molecular dynamics, discrete particle method, signal processing, image analysis, and using an arduino micro-controller; suggestions for new topics are always welcome. Unique about this lecture is that some example problems are treated by multiple methods (for example diffusion can be dealt with by finite differences, finite elements, or stochastic methods). Required: basic programming skills and a background in maths, physics or engineering. Second and third quarter every year, or in self-study at any time.
For more information, contact :
WK den Otter | 053 489 2441 | w.k.denotter@utwente.nl | 5 ECTS

Cardiovascular fluid-structure interaction

Prof.dr.ir. FN van de Vosse, TUE
An important factor in the functioning of our cardiovascular system is the interaction between the fluid (blood) and elastic media like vessel walls and (heart) valves. In this course the necessary numerical tools to analyse these so-called fluid-structure interaction problems will be explained and the strengths/limitations of these methods will be discussed.
The course starts with a general introduction to the mathematical modelling of the cardiovascular system based on finite element approximation solutions of the governing equations and the role of fluid-structure interaction i.e. blood flow vessel wall interaction. Next, standard finite element solution methods for 2D and 3D flows in rigid arterial geometries and the choice of proper boundary conditions are discussed. After the introduction of 1D finite element methods for pressure and flow wave propagation and reflections in the arterial tree and the discussion of solution strategies for 2D and 3D non-linear solid deformation, Arbitrary Lagrange Euler (ALE) as well as Fictitious Domain (FD) methods for fluid structure interaction will be discussed. In addition to lectures about theory and applications, the course includes hands-on training in which the theory is applied to specific and well-defined problems using in-house finite element software tools.
For more information, contact :
FN van de Vosse | f.n.v.d.vosse@tue.nl

Object oriented scientific programming with C++ (WI4771TU)

Dr.M Möller, prof.dr.ir. C Vuik, TUD
Introduction to C++ programming (C++11 standard). Object-oriented scientific/parallel programming. Programming in team: source version control, build/testing systems. After the course the student will be able to apply modern software design patterns and state-of-the-art programming techniques to implement numerical algorithms in C++.

He/she will build up practical experience in turning a textbook numerical algorithm into an efficient and maintainable C++ code. The student will be able to apply profiling tools to identify performance bottlenecks and know how to overcome them by devising more efficient hardware-friendly implementations.

For more information, contact :

C Vuik | 015 278 5530 | c.vuik@tudelft.nl

Theory of chaos and dynamical systems

Chaos (3MT100)

Prof.dr. F Toschi, dr.ir. LPJ Kamp, TUE

Almost all flows in nature or in industry are chaotic and even turbulent. This course covers the basic fundamentals of chaos theory, including the concept of scaling and universal route to chaos, and its connection to these non-linear, deterministic but unpredictable dynamical systems. From simple chaotic maps, to the physics of fractals and multi-fractals via the concept of renormalization group. Applications in fluid dynamics, plasma and fusion physics will be discussed. Chaos is the seemingly erratic behaviour of simple dynamical systems. They are simple but nonlinear. The route to chaos is often universal, which will be illustrated in simple maps. The universal route follows from a renormalization theory, a theory of scales. The scaling concept is central to the entire course. We will see synchronization of two coupled oscillators, and the folklore of the golden mean. We will end with synchronization of a very large number of oscillators, which has the characteristics of a phase transition. Chaos in Hamiltonian systems will be described using intuitively appealing geometry; it can be applied directly to tokamaks, machines for nuclear fusion. The scaling concept will be extended to a thermodynamic description of fractals, and will be applied to fluid turbulence. Chaos is characterized by a continued sensitivity to variation of initial conditions. We will analyze the statistics and scaling properties of this sensitivity, a sensitivity which can be defied using chaos control. Essential for the course is hands-on experience using simple computer exercises that provide a vivid illustration of the theoretical concepts.

For more information, contact :

F Toschi | 040 247 3911 | f.toschi@tue.nl | 5 ECTS

Combustion

Chemically reacting flows (4BC00)

Dr.ir. JA van Oijen, TUE
Reacting flows play an important role in energy conversion systems. Chemical reactions are essential in the conversion of fuels in heat and other useable forms of energy. Some examples are heating boilers, biomass gasifiers, combustion engines, gas turbines and furnaces for steel and glass manufacturing. In order to design such conversion systems, good understanding of the fundamental physical and chemical processes that occur in chemically reacting flows is inevitable. The mathematical models that describe these processes will be presented and used to analyze simple chemical reactors and combustion systems. The use of numerical tools for the design of energy conversion systems will be trained in a practical work. These skills and knowledge are inevitable for the design of energy systems that convert future durable fuels in a clean and efficient way.
For more information, contact :
Dr.ir. JA van Oijen | 040 247 3133 or 2140 | j.a.v.oijen@tue.nl | 5 ECTS

Gasturbines (4P700)

Dr.ir. HC de Lange, TUE
The gasturbine is one of the most often used machines in the production of mechanical power. In this course a number of application areas (aero engines, turbochargers, industrial applications) will be discussed. Using the book by Cohen et al. the thermo- and fluiddynamics of turbmachines is studied. First, different systems (using intercooling, regeneration, etc.) are compared using simple thermodynamical theory. They show the applicability and efficiency of different processes. Second, the working principles of both radial and axial compressors are explained based on compressible flow equations (both one- and more dimensional). Using aerodynamical arguments the working of a combined compressor/turbine is discussed, both in the design-point as well as at offdesign conditions. Besides the stationary flow considerations, a number of dynamical aspects (acceleration, stall, surge, etc.) will discussed.
Books: H.I.H. Saravanamuttoo, G.F.C. Rogers and H. Cohen, ‘Gasturbine theory’, 2001.
For more information, contact :
HC de Lange | 040 247 2129 | h.c.d.lange@tue.nl

Turbulent reacting flows (ME1540)

Prof.dr. DJEM Roekaerts, TUD
Models for interaction between turbulent flow and chemical reaction are treated. The main question addressed is by which method or model the mean properties of the flow can be obtained without having to solve the transport equations in full detail. Such methods are useful

in the design of industrial combustion chambers, chemical reactors and in the description of reactions in the atmosphere. In the first part, basic aspects are developed (transport equations, reaction kinetics, non-dimensional numbers and regime diagrams, fundamentals of a statistical description, laminar flames). In the second part a more extensive introduction to turbulent combustion is presented. Methods for handling the closure problems arising in averaged or filtered transport equations are described and evaluated (RANS, LES, flamelet model, probability density function method). Simple application exercises are made. Depending on the specific interest of the student, additional topics can be added. This course will be given in the year 2017-2018.
For more information, contact :
DJEM Roekaerts | 015 278 2470 | d.j.e.m.roekaerts@tudelft.nl | 3 ECTS

Non-linear differential equations (WI4019TU)

Dr.ir. WT van Horssen, TUD
1st semester, second quarter.
F. Verhulst, Nonlinear Differential Equations and Dynamical Systems, 2nd edition, Springer-Verlag, 1996. Take home exam and oral exam.
Pre-knowledge: an introductory course on Differential Equations e.g. Boyce and DiPrima, Chapters 2-7, 9.
Contents: Existence and uniqueness of initial value problems, Gronwall’s lemma, Autonomous systems, Critical points, Periodic solutions, Stability theory, Linear systems and Floquet theory, Perturbation theory and asymptotic methods, Poincare-Lindstedt method, Averaging method, Multiple time-scales method, Elementary bifurcations.
For more information, contact :
WT van Horssen | 015 278 3524 | w.t.vanhorssen@tudelft.nl

Optical diagnostics for combustion and fluid flow (4BM40)

Dr. NJ Dam, TUE
After completion of this course the student will
· Have an general notion of molecular spectroscopy;
· Be able todiscuss on a basic level the possibilities to study individual fluid properties by means of optical techniques;
· Have a broad overview and basic knowledge of spectroscopy-based diagnostic techniques for the study of fluid flows;
· Be able to select appropriate experimental methods for studying particular research questions in the field of fluid dynamics (reacting or not);
· Be aware of the global inventory of modern optical equipment and components;
· Have a basic understanding of the role of polarisation and diffraction in optics.

Optical diagnostics are arguably the most powerful experimental tools for the study of reactive and non-reactive fluid flow. The light scattered by any object carries information on the state and properties of that object, like its temperature, chemical composition, speed,.. you name it. Moreover, light is minimally intrusive, and in contrast to mechanical probes typically does not perturb the phenomenon under study. In order to make full use of the potential of optical diagnostics, a basic understanding of the way light interacts with matter (spectroscopy) is required, as is a basic understanding of the special equipment that is typically used: lasers, CCD and CMOS camera's, and fancy optical components. This course covers all this, in lectures, demonstrations and specific literature. Specific Laser-diagnostic techniques that will be discussed include Laser-Induced Fluorescence (LIF), Incandescence (LII) and Phosphorescence (LIP); Rayleigh and Raman scattering, both the spontaneous and stimulated version; Four-Wave-Mixing techniques, like CARS; new developments.
For more information, contact :
NJ Dam | 040 247 2117 | n.j.dam@tue.nl | 5 ECTS

Engines: modeling and analysis

Dr.ir. LMT Somers, TUE
In this lecture series the student will apply the first law of thermodynamics to the general systems of reacting mixtures. The course covers aspects related to cycle simulation tools (modeling) and analysis approaches for engine experiments (analysis). Modeling: a matlab based computer program to simulate a real engine cycle using a modeled combustion progress (Wiebe-like). The oral lectures are short and only meant to give a concise introduction to the problem. A systematic approach is used to increase the complexity in a gradual way through the organization of the lectures series. Emphasis is not on numerics but on physics. Analysis: experiments performed on a Heavy-Duty diesel engine (12.4l DAF) will be analyzed. Using the same first law analysis as above, the Sankey diagram will be determined and engine parameters like thermal efficiency, BMEP etc, computed. A so-called heat-release model is developed. The course is mainly in hands-on exercise and a notebook and Matlab are required. Final term: written report and a final presentation (10-15 min).
For more information, contact :
LMT Somers | 040 247 2107 | l.m.t.somers@tue.nl

Powertrain components (4AT00)

Dr.ir. LMT Somers, dr.ir. T Hofman, TUE
This introductory course on automotive power trains (including engine and transmission), covers the basic technology behind automotive vehicle propulsion. In the introductory lecture, basic road load forces will be discussed in order to derive the amount of torque and power a vehicle power train should deliver. Next, the principles of 4-stroke Internal Combustion Engine are discussed (components, kinematics and operating characteristics). Some elements of ICE operation (a.o. gas exchange, cycles, thermo chemistry and fuels, fuel consumption and emissions) are discussed in

more depth in order to enable students to make quantitative computations. The course continues by treating the history and basic principles of the automotive drive train and its components. The aim of this part is to obtain a broad (and in some aspects deep) insight in components, systems and system designing of vehicle drive trains. Some basic powertrain modeling techniques will be treated, followed by the somewhat more detailed analysis of the Toyota Prius powertrain. This example and others will be used to explain the challenges that powertrain designers are facing nowadays. The course consists of 16 hours of lectures, approximately 12 hr's of guided selfstudy, and some additional practicals at the laboratories of Automotive Engineering Science (2x half a day). The course runs in the first quartile of the academic year.

For more information, contact :

LMT Somers | 040 247 2107 | l.m.t.somers@tue.nl

Clean engines and future fuels (4AT020)

Dr.ir. LMT Somers, ir. PC Bakker, TUE

Geopolitical, environmental and societal factors are forcing the automotive industry to develop more efficient and cleaner engines, running on a wide variety of fuels. In current engine design processes, fuels are regarded as "facts of life". New feedstocks (gas, bio) ask for detailed understanding of future fuel requirements. In the course, starting from knowledge of the molecular structure of fuels available today, the student will learn to compute or estimate the relevant physical (e.g. vapour pressure) and chemical properties (e.g. heating value). Essential engine processes such as spray formation, evaporation, and emission formation in an engine will be discussed with emphasis on the interplay between fuel properties and spray parameters. This knowledge will then be applied to new (low-temperature) combustion concepts. Homogeneous reactors and phi-T maps will be introduced and used to find the origin of low emissions and/or high efficiency. Eventually, students will put their ideas to test on one of our experimental rigs.

For more information, contact :

LMT Somers | 040 247 2107 | l.m.t.somers@tue.nl | 5 ECTS

Turbulence

Turbulence in hydraulics (CIE5312)

Prof.dr.ir. WSJ Uijttewaal TUD
This course is an introduction to turbulence with applications in hydraulics. The subjects treated are: statistical description of turbulence, Reynolds equations, energy equation, turbulent boundary layers, free shear flows, turbulence models, dispersion and diffusion, experimental techniques.
For more information, contact :
WSJ Uijttewaal | 015 278 1371 | w.s.j.uijttewaal@tudelft.nl

Turbulence A (wb1424A)

Dr.ir. WP Breugem TUD
In this course an introduction is given to the theory of turbulence. The course starts with the treatment of the properties of turbulence and the distinction between laminar and turbulent flows. This is followed by the treatment of linear stability theory applied to Kelvin-Helmholtz instability, the inflection criterion of Rayleigh and the Orr-Sommerfeld equation. Next follows a phenomenological treatment of turbulence, a discussion of Richardson's energy cascade and the Kolmogorov 1941 theory on the micro and macrostructure of turbulence. The statistical treatment of stochastic processes is discussed and the Reynolds-Averaged Navier-Stokes (RANS) equations are derived. This leads to a discussion of the closure problem for the Reynolds stress and the introduction of the gradient-diffusion hypothesis and K-theory for the turbulent viscosity. The RANS equations are then applied to boundary-free shear flows such as jets and wakes. For jets and wakes an analytical expression for the mean velocity profile can be derived based on an order-of-magnitude analysis and the assumption of self-similarity. Next the RANS equations are applied to wall-bounded shear flows such as channel and pipe flows. Approximate analytical expressions are derived for the mean velocity in the inner and the outer layer. The logarithmic law is derived for the mean velocity in the overlap region. The influence of wall roughness and a streamwise pressure gradient on wall-bounded turbulence is discussed. The transport equations are derived for the mean and the turbulent kinetic energy and related to Richardson's energy cascade. The effect of buoyancy is explained by means of the flux Richardson number and the Obukhov length. Several popular models are discussed for the turbulent viscosity such as the k-epsilon model. The strengths and weaknesses of these models are demonstrated by means of simulations with a commercial Computational Fluid Dynamics (CFD) package. The concept of Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES) is explained. Finally, an introduction is given to energy spectra and correlations of turbulent flows. The -5/3 law for the spectrum of turbulence in the inertial subrange is derived.
For more information, contact :
WP Breugem | 015 278 8663 | w.p.breugem@tudelft.nl | 6 ECTS

Turbulence (358001)

Prof.dr. D Lohse, UT
Subjects: Navier-Stokes equations, hydrodynamic instabilities, routes to chaos, transition to turbulence, Rayleigh-Benard convection, Boussinesq equation, fully developed turbulence, Kolmogorov, intermittency, phenomenological models for intermittency, cascade models, Keps model, boundary layer theory, turbulent diffusion.
For more information, contact :
D Lohse | 053 489 8076 | d.lohse@utwente.nl | 5 ECTS

Geophysical and environmental flows

Open channel flow (CTB3350/CIE3310-09)

Dr.ir. RJ Labeur, TUD
Subjects to be treated are: basic equations for long waves in open channels and in closed conduits; categories of long waves in open channels: translatory waves, tides, harbour oscillations, floodwaves in rivers; translatory waves of low and finite height; method of characteristics; harmonic method for sinusoidal wave propagation with linearised damping; flood waves in rivers.
For more information, contact :
RJ Labeur | 015 278 5069 | r.j.labeur@tudelft.nl | 4 ECTS

Stratified flows (CIE5302)

Prof.dr. JD Pietrzak, TUD
Flows influenced or caused by differences in density. Basic equations. The two-layer model. Internal and external long waves. Steady-state two-layer flows. Internal hydraulic jumps and gravity currents. Stability, turbulence and mixing. Salt intrusion in estuaries.
For more information, contact :
JD Pietrzak | 015 278 5466 | j.d.pietrzak@tudelft.nl

Ocean waves (CIE4325)

Dr. MFS Tissier, TUD
Subjects to be treated are: concepts from the theory of stochastic processes, energy-density spectrum, wind waves considered as stochastic processes in space and time, statistical properties, development and propagation of wind waves, wave climate, spectral calculations and responses.
For more information, contact :
MFS Tissier | 015 278 3255 | m.f.s.tissier@tudelft.nl

Physical oceanography (CIE317)

Prof.dr. JD Pietrzak, TUD
The course will deal with the following topics: The physics of free surface waves; Linear wave theory, non-linear waves; Short waves, shallow water waves; Numerical methods for various wave models, e.g. Delft3D and SWAN.
For more information, contact :
JD Pietrzak | 015 278 9455 | j.d.pietrzak@tudelft.nl

Water systems (201300077)

Dr.ir. DCM Augustijn, UT

Water systems gives a qualitative introduction into marine systems, river systems and water quality. The parts on marine systems and river systems prepare for the more quantitative and advanced courses Marine Dynamics and River Dynamics. The part on marine systems discusses essential physical processes such as tides, waves, sediment transport and morphology that play a role in the marine environment like shelf seas, estuaries and beaches. The part on river systems deals with the following topics: river forms, water flow in rivers, influence of tides on rivers, sediment transport, field measurements and human interventions in the river system. The part on water quality deals with the sources, fate and transport and effects of various types of pollutants in surface water. In addition, attention is given to water quality policies, the derivation of water quality standards and measures to improve water quality. If desired, the parts on Marine Systems, River Systems or Water Quality can be taken separately.

For more information, contact :

DCM Augustijn | 053 489 4510 | d.c.m.augustijn@utwente.nl

Marine dynamics (195400800)

Dr.ir. BW Borsje, dr.ir. PC Roos, UT

This course focuses on a quantitative description of marine processes, which were considered in a more qualitatively sense in the course Marine Systems (195400240) . The course consists of two parts. The first part deals with tides and ocean currents, involving e.g. Kelvin waves and Ekman dynamics. The second part is about short waves and nearshore morphodynamics, covering e.g. linear wave theory, sediment transport and coastline evolution models.

For more information, contact :

BW Borsje | 053 489 1094 | b.w.borsje@utwente.nl | 7,5 ECTS

Morphology (195410200)

Prof.dr. SJMH Hulscher, UT

In the course Morphology five topics are discussed that have a relation with morphology of rivers, estuaries, coasts and seas. Physics play an important role in this. Because understanding and predicting morphology is often necessary to support control, the link with practice often comes into play. An example is the widening of the Westerschelde, maintaining the coast line, controlling pipe lines in a dynamic seabed with sand waves. By means of recent articles these

topics are studied; the articles are presented by students and the topic is discussed using the associated assignments. Moreover, every student reviews a paper, written by a researcher form the Water Engineering and Management department.
This paper is ready to submit or just submitted to a peer-reviewed journal. Finally, every student focuses on a subject, individually or in pairs, which is laid down in a short report and a poster. This poster is presented and commented to other students and lecturers during a final poster session.

For more information, contact :
SJMH Hulscher | 053 489 4256 | s.j.m.h.hulscher@utwente.nl

River dynamics

Dr.ir. B Vermeulen, UT
In the River Dynamics course students learn to apply the basic principles of fluid flow, sediment transport and morphology (erosion / sedimentation) to quantify the response or fluvial systems to natural or man-made changes. During the lectures, students learn to recognize the physical processes relevant to specific engineering problems, and translate these into 1D equations for steady and unsteady shallow water flows, sediment transport and 1D morphology. Using simple analytical solutions, students can provide a first quantitative estimate of the effect of measures on backwater flows, flood waves, tidal flows and short and long term morphology. Subsequently, students will use a state of the art 1D numerical model as is used in research and engineering practice, to quantify the impact of more complex measures and learn the basic principles of numerical modelling. During a one day excursion students will visit several river engineering projects that illustrate how the course content can be applied in the day to day practice.

For more information, contact :
B Vermeulen | 053 489 2367 | b.vermeulen@utwente.nl

Geophysical fluid dynamics (3MT110)

Dr.ir. RPJ Kunnen, prof.dr.ir. GJF van Heijst, prof.dr. HJH Clercx, TUE
This course focusses on some basic features of the dynamics of large-scale geophysical flows as occurring in oceans and planetary atmospheres, which are essentially affected by background rotation and density stratification of the medium. Topics that are discussed: geostrophic flow, conservation of potential vorticity, Ekman boundary layers, spin-up, wind-driven ocean circulation, Boussinesq approximation, waves in rotating and stratified fluids, density currents, geostrophic adjustment, barotropic and baroclinic instability. Additionally, attention will be given to aspects of tides and estuarine circulation, rotating convection, rotating and/or stratified turbulence, and aspects of 2D turbulence.
A laboratory course is organized with experimental and computer sessions, in which students can investigate some dynamical features of rotating and stratified flows in the laboratory and by numerical simulations.
For more information contact
RPJ Kunnen | 040 247 3194 | r.p.j.kunnen@tue.nl | 5 ECTS

Environmental fluid mechanics (3MT150)

Dr. M Duran Matute, TUE
This course offers an introduction to and an overview of various aspects of fluid mechanics phenomena occurring in the natural environment. After a short discussion of some basic fluid-dynamical concepts and approaches (such as mass and momentum balances), the following topics will be covered: basic elements of instability and turbulence, diffusion, mixing and dispersion, convection, jets and plumes, water waves, fluid dynamics of rivers and streams, lakes and reservoirs. Attention will also be given to the atmospheric boundary layer, to local and global air pollution, and to dispersion in the built environment.
For more information contact
M Duran Matute | 040 247 3110 | m.duran.matute@tue.nl | 5 ECTS

Sports and building aerodynamics (7LL1M0)

Prof.dr.ir. BJE Blocken, TUE
Have we reached the boundaries of what can be achieved in sports and building design? The answer is definitely “NO”. This course contains basic and applied lectures on sports and building aerodynamics. The basic lectures consist of basic aspects of fluid flow, wind tunnel testing and Computational Fluid Dynamics (CFD). The applications either focus on sports aerodynamics or on building aerodynamics, and in one exceptional case on the combination of both. Sports applications include the 100 m sprint and cycling aerodynamics. Building applications include wind comfort and wind danger, wind-driven rain, wind energy in the built environment, adaptation of buildings and cities to climate change and air pollution.

This course is intended for anyone with a strong interest in these topics. Key fields addressed are urban physics, wind engineering and sports engineering. Key societal challenges addressed are health, energy and climate.
This course consists of three parts: (1) the MOOC (= Massive Open Online Course) Sports & Building Aerodynamics on the Coursera platform, (2) a number of lectures given at TUE, and (3) a practical hands-on training supplemented with some self-study for practical work in CFD simulation in sports & building aerodynamics.
For more information, contact:
BJE Blocken | 040 272 2138 | b.j.e.blocken@tue.nl

Micro-scale fluid mechanics

Microfluidics (WB1429)

Prof.dr.ir. J Westerweel, TUD
This course is an introduction to fluid mechanics at small scales. The subjects treated are: Scaling laws, Navier-Stokes equations for micro-scale gas and liquid flows, for electroosmotic flow, electrophoresis, dielectrophoresis, dispersion and diffusion, capillary effects, experimental techniques, applications in flow control, flow sensors, valves, pumps, mixers, filters, separators, heaters and life science applications.
For more information, contact :
J Westerweel | 015 278 6887 | j.Westerweel@tudelft.nl

Micro- and nanofluidics (3MT020)

Prof.dr. AA Darhuber, dr. HP Huinink, TUE
This course provides students with an overview of micro- and nanofluidics, i.e. aspects of fluid mechanics, heat- and mass transfer at small length scales, where surface- and interface effects dominate the dynamics. The students will gain insight into the forces and physical mechanisms that determine and that are available for transport at micro- and nanoscales. The course does not focus on microfabrication and device design, but will provide students with a basis for estimating quantities such as stresses exerted by liquids on microscopic objects, flow velocities, permeabilities and mixing efficiencies.
Course structure and contents:
1. The predominance of viscous friction and interfacial effects: - The Stokes equation and corresponding boundary conditions
2. Liquids in contact with other phases: Surface tension, Van der Waals forces, contact angles, superhydrophobic surfaces
3. Mixing: - Brownian motion and diffusion, - Micromixing and chaotic advection
4. Electrophoresis and electroosmotic flows
5. Applications: - Transport in porous media
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Microfluidics put-to-work (4UM10)

Prof.dr.ir. JMJ den Toonder, TUE
Micro-fluidics is the science and technology of manipulating and analyzing fluid flow in sub-millimeter dimensions. It is the key enabling technology for many emerging applications and disciplines, especially in the fields of medicine, environmental sensing, biology, and

chemistry. Also in engineering and the physical sciences microfluidic systems are employed in applications such as control systems, heat management, and energy generation. Microfluidics approaches can be used to characterize and even manufacture in a controlled way functional particles based on soft materials. Concrete examples of applications are biosensor devices for molecular diagnostics, polymerase chain reaction chips, in-line water quality sensing, high-throughput screening, controlled drug delivery systems, drug discovery methods, forensic analysis instruments, and so on. In this course, you will learn about physical principles that play an important role in micro-fluidics, how these principles can be applied in practical applications, and which device manufacturing principles can be used to realize these applications. The emphasis will be on concepts and their practical applications, rather than on scientific in-depth theoretical understanding. All of the principles and concepts will be introduced in a bottom-up approach, focusing on examples of actual application areas already in use today. For each of these applications the relevant design concepts and physical mechanisms are categorized in application domains, so that the relation with practice is immediately evident. Special attention will be given to probing properties of soft materials using microfluidics. A practical workshop forms an essential component of the course as well as the examination, aimed at gaining hands-on experience with basic micro-fluidics device manufacturing and testing.

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Heat and flow in microsystems (4EM40)

Dr. AJH Frijns, Dr. SV Nedea, prof. JMJ den Toonder, TUE

Microfluidic systems become more and more important in engineering, since their low costs, low weights, high efficiency and flexibility enable to realize applications such as lab-on-chip, micro-cooling, environmental sensors, e.g. realized in systems-in-foil. For designing such microfluidic systems, a good physical understanding of the phenomena is needed and proper (numerical) models are required. In micro- and nanofluidic devices, length scales can be reached where a continuum approach starts to fail (e.g. due to rarefaction effects): the local properties cannot be averaged out anymore and individual particle properties have to be taken into account, boundary effects and surface and interface forces become dominant.

In this course we will start at the basis: the interactions that take place at a molecular level. We will show that these small interactions sometimes can have major influences on macroscopic level, e.g. slip velocities and temperature jumps. We start modelling at a molecular level (Molecular Dynamics models for heat and mass transfer) and scale it up via Monte Carlo models (DSMC) and the kinetic theory to the continuum level. We will show that by using the appropriate assumptions these models can be directly related to each other.

After deriving the appropriate models, we will apply them to design microfluidic systems making use of different small-scale phenomena, for gas cooling, evaporative cooling, evaporative pumping, gas-surface reactions, mixing, AC electro-osmosis, acoustic streaming, droplet, particle or cell manipulation, etc.
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Nanofluidics

Prof.dr. F Mugele, UT
Nanofluidics is a key element of nanotechnology. Nanofluidics plays a central role in many Lab-on-a-chip systems and is key for filtration and separation processes (e.g. water purification, desalination, environmental remediation). Moreover the physical principles discussed in the course are essential for many biophysical questions and modern material science of soft (colloidal) matter. This course gives an introduction into nanofluidics, considering fundamental aspects, intrinsic length scales and geometry.
A number of different selected topics in the field of nanofluidics are discussed, such as:
- basic fluid dynamics for micro- and nanochannels
- solid-liquid interfaces (interactions, adsorption/desorption)
- hydrodynamics at small scales (laminar flow, slip versus no-slip, mixing)
- 3-phase systems (capillary forces, wetting, superhydrophobicity)
- electrokinetic effects (electroosmotic pumping, electroviscous effect)
- electrophoresis and separation techniques
- (Nano)colloidal particles and colloidal assembly

The course is taught in the form of classical lectures (HCs) accompanied by seminars (WCs) in which homework problems prepared and submitted by the students beforehand are being discussed. Each student gives a final presentation on a specific topic based on a set of original articles from the literature.The course will be taught in the third quarter.
For more information, contact :
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Bio fluid dynamics

Cardiovascular fluid mechanics

Prof.dr.ir. FN van de Vosse, TUE
The course cardiovascular fluid mechanics focuses on fluid mechanical phenomena that occur in the human cardiovascular system. These phenomena are complex due to non-linear and non-homogeneous properties of the blood and arterial wall, the complex geometry and the pulsatile flow properties. After a physiological introduction, a short review of the equations governing fluid mechanics is given, including the main concepts determining the constitutive equations for both blood and arterial wall. An important part of the course is dedicated to the description of flow in straight, curved and bifurcating, rigid tubes. With the aid of characteristic dimensionless groups the flow phenomena will be classified and related to specific physiological phenomena in the cardiovascular system. In this way differences between flow in the large arteries and flow in the micro-circulation will be elucidated. Flow in distensible tubes is characterized by wave propagation of the pressure pulse. Hence, wave propagation including attenuation and reflection of waves at geometrical transitions will be discussed. As blood consists of blood cells suspended in plasma its rheological properties differ from that of a Newtonian fluid. Constitutive relations for Newtonian, non-Newtonian and suspensions will be compared. In addition, the importance of the rheological properties of blood for the microcirculation will be dealt with. Finally, mass transfer at the vessel wall and the influence of tapering of the arterial lumen will be discussed.
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Cardiovascular fluid-structure interaction

Prof.dr.ir. FN van de Vosse, TUE
An important factor in the functioning of our cardiovascular system is the interaction between the fluid (blood) and elastic media like vessel walls and (heart) valves. In this course the necessary numerical tools to analyse these so-called fluid-structure interaction problems will be explained and the strengths/limitations of these methods will be discussed. The course starts with a general introduction to the mathematical modelling of the cardiovascular system based on finite element approximation solutions of the governing equations and the role of fluid-structure interaction i.e. blood flow vessel wall interaction. Next, standard finite element solution methods for 2D and 3D flows in rigid arterial geometries and the choice of proper boundary conditions are discussed. After the introduction of 1D finite element methods for pressure and flow wave propagation and reflections in the arterial tree and the discussion of solution strategies for 2D and 3D non-linear solid deformation, Arbitrary Lagrange Euler (ALE) as well as Fictitious Domain (FD) methods for fluid structure interaction will be discussed. In addition to lectures about theory and applications, the course includes hands-on training in which the theory is applied to specific and well-defined problems using in-house finite element software tools.
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Experimental techniques in fluid mechanics

Experimental techniques in physics of fluids (193580020)

Dr. Dennis van Gils, UT
Experimental techniques for flow measurements, like particle image velocimetry, laser-Doppler anemometry, hot-wire anemometry, and high-speed imaging, are to be included in the course. Various modern techniques, as Tomographic PIV/PTV and micro/nano-PIV, will also be covered in this course. In the lectures, principles and specific advantages and limitations of the techniques will be discussed. This knowledge will be taught in lectures and deepened with research articles and homework questions. Following the lectures, hands-on experiments will be organized. In groups of two students, a specific measurement problem will be solved with one of the techniques presented in the course. The participants write a concise report and prepare a presentation on their work.
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Experimental methods in transport physics (3MT140)

Dr. RM Cardinaels, prof.dr. AA Darhuber, dr. SJF Erich, dr.ir. MFM Speetjens, dr. Nicolae Tomozeiu (Océ), ir. HM Wyss, TUE
This course focusses on the following measurement challenges and methods:

- Flows inside intransparent solids
  Nuclear Magnetic Resonance (NMR) / MRI; X-ray Computed Tomography (CT) and X-ray Diffraction (XRD)
- Liquid films as thin a single molecule
  Brewster Angle Microscopy (BAM); Surface Plasmon Resonance (SPR) and Ellipsometry
- Droplets and particle suspensions
  Light scattering
- Material composition
  Confocal Raman Microscopy; Infrared Spectroscopy
- Three-dimensional velocity fields
  3D-Particle Tracking- and Particle Image Velocimetry (PTV & PIV)
- Flow properties of complex liquids
  Rheology and rheometry methods

The goals of this course are to

- Provide an overview of experimental methods in fluid mechanics that are useful in scientific research & technological applications.
- Enable the selection of the optimal technique for a certain measurement problem.
- Enable the optimization of an experimental setup.

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JMBC Course Programme
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