Delft Center of Computational Science and Engineering

Courses with scientific computing and numerical analysis content at TU Delft in 2010-2011

Source: official TU Delft study guide

Luchtvaart- en Ruimtevaarttechniek

Bachelor Aerospace Engineering
AE2206: Applied Numerical Analysis
AE2208: Computational Modeling
AE2210: Aerodynamics II
AE3031: Computational Fluid and Solid Mechanics including Practical
AE3205: Simulation, Verification and Validation

Master Aerospace Engineering
AE4120: Viscous Flows
AE4131: CFD I
AE4133: CFD II
AE4141: Gas Dynamics II
AE4212: Aircraft Performance Optimization
AE4394: Modern Flight Test Technologies and System Identification
AE4520: Advanced Structural Analysis
AE4525: Advanced Computational Modeling
AE4530: Special Topics in Vibration and Buckling
AE4542: Advanced Simulation - Dynamics & Mechanisms
AE4543: Advanced Simulation - Crash & Impact
AE4930: Aeroelasticity
AE4E08TU: Satellite Navigation
AE4W12: Rotor Aerodynamics

Technische Natuurwetenschappen

Bachelor Applied Physics
TN1721: Introduction to Imaging Physics
TN2513/TN2513TU: Computational science

TN2780-HT: Honours Class Fysische Transportverschijnselen

Bachelor Molecular Science & Technology
IMM: Introduction to Multiscale Modeling
MQM: Molecular Quantum Mechanics

Master Applied Physics
AP3081TU G: International Masters Course on Computational Physics
AP3171 D: Advanced Physical Transport Phenomena
AP3551: Computational Multiphase Flow
AP3561: Turbulent Reacting Flows

Extern Institute
UL38: Stellar dynamics

Master Chemical Engineering
CH3131: Applied Numerical Mathematics
CH3421: Computational Transport Phenomena
CH3671: Molecular Simulation

Master Life Science and Technology
LM3761: Numerical Methods, Modeling & Simulation Techniques

Master Nanoscience
NS3621: Quantum Information Processing

Werktuigbouwkunde, Maritieme Techniek & Technische Materiaalwetenschappen

Bachelor Mechanical Engineering
WB1424ATU: Turbulence A

Master Mechanical Engineering
ME1600: Reliability and Uncertainty Models in Engineering Mechanics
WB1416: Numerical Methods for Dynamics
WB1428-1, -3: Computational Fluid Dynamics
WB1440: Eng. Optimization: Concept & Applications
WB1441: Engineering Optimization 2
WB1443: Matlab in Engineering Mechanics
WB2454-07: Multiphysics Modelling using COMSOL
WB4421: Gas Turbine Simulation/Application

Master Biomedical Engineering

BM1200: Computational Mechanics of Tissues and Implants

Master Materials Science and Engineering
MS3031: Computational Materials Science
MS3412: Processing of Metals
MS4131NS: Solid State Physics 2

Master Marine Technology
MT523: Numerical Methods for MT
MT524 : Hydromechanics of Special Ship Types
MT815 : Construction and Strength, Special Subjects
MT830: Applications of the Finite Element Method

Master Offshore Engineering
OE4630 D1, D2, D3, D4: Offshore Hydromechanics

Minors Werktuigbouwkunde
WB3600: Computational Engineering Project
WB3663: Modelleertechnieken

Civiele Techniek en Geowetenschappen

Master Civiele Techniek
CT4143: Shell Analysis, Theory and Application
CT4180: Plate Analysis, Theory and Application
CT4310: Bed, Bank and Shoreline Protection
CT4340: Computational Modelling of Flow and Transport
CT4350: Numerical Soil Mechanics
CT4380: Numerical Modelling of Geotechnical Problems
CT4801: Transportation and Spatial Modelling
CT5123: Introduction to the Finite Element Method
CT5142: Computational Methods in Non-linear Solid Mechanics
CT5144: Stability of Structures
CT5146: Micromechanics and Computational Modelling of Building Materials
CT5148: Computational Modelling of Structures
CT5315: Computational Hydraulics
CT5802-09: Advanced Transportation Modelling

Master Applied Earth Sciences
EMC-H/MM: Numerical Mine Modelling

Elektrotechniek, Wiskunde en Informatica

Bachelor Applied Mathematics
WI2604: Numerical Methods 1
WI3097TU: Numerical Methods for Differential Equations
WI3097TU-c: Numerical Methods for Differential Equations
WI3097TU-p: Numerical Mathematics (Lab)
WI3603: Numerical Methods 2

Master Applied Mathematics
WI4011: Computational Fluid Dynamics
WI4012ta: Mathematics, Special Subjects
WI4014TU: Numerical Analysis
WI4017TU: Parallel Computing
WI4051TU: Introduction to Operation Research
WI4054: Environmental Simulation and Data Assimilation
WI4055: Computational Aspects of Stochastic Differential Equations
WI4141TU: Matlab for Advanced Users
WI4154: Computational Finance
WI4201: Scientific Computing
WI4204: Advanced Modeling
WI4205: Applied Finite Elements
WI4212: Advanced Numerical Methods
WI4218: Convex Optimization and Systems Theory
WI4219: Discrete Optimization

Master Electrical Engineering
ET4107: Power Systems Analysis II
ET4162: Computational Electromagnetics A
ET4163: Computational Electromagnetics B
ET4255: Electronic Design Automation
ET4288: Applied Electromagnetic Analysis in Wireless, Microwave and Radar Engineering
ET4356: Electromagnetics

EWI Electives Service-Education
WI3405TU: Waarderen van derivaten
WI3230IN I/II: Numerical Mathematics and Simulation

Appendix: Courses with summaries

Luchtvaart- en Ruimtevaarttechniek

AE2206: Applied Numerical Analysis
Bachelor Aerospace Engineering
ECTS: 4
Prof.dr.ing. R. Klees, Dr. R.P. Dwight, Dr. S.J. Hulshoff
Education period 3
Language: English

1. Fundamentals: Computer arithmetic and round-off errors; Accuracy, consistency, stability, convergence; Advantages and limitations of numerical methods
2. Solution of non-linear equations: Bisection method; Fixed-point iteration;Newton’s method; Derivative-free methods; Convergence.
3. Optimization: Unconstraint optimization without derivatives; Golden section search; Successive parabolic interpolation; Unconstrained optimization with derivatives; Newton’s method; Steepest descent; Conjugate gradient search.
4. Numerical interpolation & approximation: 1D interpolation; Polynomial interpolation; Spline interpolation; 2D interpolation; Polynomial interpolation; Spline interpolation; Patch interpolation; Least-squares approximation; Least squares and normal equations; QR factorization; Perspective on alternative concepts and more advanced methods.
5. Numerical differentiation and integration: Numerical differentiation; Finite difference formulas; Rounding error; Extrapolation; Numerical integration; Interpolatory quadrature (Newton Cotes); Composed integration formulas; Gauss-Legendre quadrature; Error estimates; 2D integration (Cartesian products and product rules)
6. Numerical methods for solving ordinary differential equations: Basic concepts and classification; Single-step methods (Euler-Cauchy, Heun, Runge-Kutta); Multistep methods (Adams Bashforth, Adams-Moulton, predictor-corrector); Stability and convergence; Choice of a method.

C.F. Gerald & P.O. Wheatley, Applied Numerical Analysis, 7th edition, Pearson, Addison Wesley, 2004

AE2208: Computational Modeling
Bachelor Aerospace Engineering
ECTS: 3
Prof.dr.ir.H.Bijl
Education period 4
Language: English

This course will cover the basics of solving partial differential equations(PDEs) using numerical methods. We will begin by describing the basic properties of PDEs derived from common physical problems and discuss how these influence the selection of a numerical discretisation technique. We will then consider the most widely used methods for numerical discretisation, the finite-difference and finite-element methods, applied to steady problems. After that, we will demonstrate the application of time-march methods to solve unsteady problems, and introduce techniques for analysing the behaviour of arbitrary discretisations in terms of accuracy and stability. Since the application of finite difference and finite-element methods often leads to large sparse matrices, we will also discuss and compare the use of direct and iterative techniques for the solution of large algebraic systems. We will demonstrate how their rates of convergence and total work can be estimated, and give a perspective on the advanced techniques which have found widespread use. A detailed list of topics is given below:
1. Classification of PDEs: Elliptic, hyperbolic and parabolic equations; Definition of characteristics; Dirichlet and Neumann boundary conditions, Well-posed problems
2. Basic Discretisation of PDEs: Finite difference methods (modified equation, upwinding and artificial dissipation); Finite element methods, (method of weighted residuals, functions, assembly); Boundary conditions for elliptic and hyperbolic problems; Convergence studies and Richardson extrapolation
3. Analysis of time march methods: Systems of ODEs, semi-discrete eigenvalues; Wave space, relation to Fourier analysis; Fully-discrete eigenvalues, stability, stiffness; Phase and amplitude errors; Analysis including boundary conditions
4. Iterative solution of algebraic systems: Direct solution methods versus iterative solution methods; Jacobi and Gauss-Seidel techniques; Convergence rates, stopping criteria; Introduction to modern methods (CG, GMRES)

- Text: Gerald, C. F. and Wheatley, P. O., Applied Numerical Analysis (7th Edition) (Paperback)
- Additional course notes

AE2210: Aerodynamics II
Bachelor Aerospace Engineering
ECTS: 3
Prof.dr. F. Scarano
Education period 4
Language: English

How to apply the basic laws of mechanics and thermodynamics to describe compressible flows? What are the essential phenomena that are relevant and specific to aerodynamic behaviour under compressible flow conditions?
How to apply the theory in the prediction and computation of compressible flows (airfoils, engine intakes, nozzles)?
At the end of this course, the student will be able to:
1. Understand aerodynamic concepts and apply aerodynamic theory for compressible flows.
2. Explain which essential phenomena occur in compressible flows and explain the relevance of different flow regimes (transonic, supersonic, hypersonic)

3. Apply the fundamental equations of fluid mechanics and thermodynamics to describe compressible flows; derive the governing equations for compressible flow
4. Calculate the flow through channels and nozzles.
5. Calculate the flow properties of airfoils in supersonic flows (linearized theory, shockwave-expansion theory).
6. Explain the effects of viscosity on the behavior of airfoils in compressible (transonic) flow.
7. Describe the basic steps towards non-linear supersonic flow and hypersonic flow; explain the basics of numerical simulation.
8. Perform a supersonic flow experiment and calculate basic shock wave properties.

J.D. Anderson, Fundamentals of aerodynamics, 3rd ed., McGraw-Hill, 2001 ISBN 0072373350

AE3031: Computational Fluid and Solid Mechanics including Practical
Bachelor Aerospace Engineering
ECTS: 9
Prof.dr.ir.H.Bijl
Education period 1,2
Language: English

This course will give an introduction to computational techniques. In the first 7 weeks finite difference/finite volume methods will be addressed. In the second period the finite element method will be introduced.

AE3205: Simulation, Verification and Validation
Bachelor Aerospace Engineering
ECTS: 3
E. Mooij
Education period 3
Language: English

Theoretical analysis, computer simulation and measuring or testing are used to evaluate, verify and validate observed performance or failure of real aerospace vehicles and phenomena.

1. Move forward from theory to testing for (conceptual) design
2. Move backward from testing to theory for design optimization and incident investigation.
3. Identify the variables to analytically describe an authentic physical problem.
4. Select the (numerical) methods to perform the analysis (e.g. CFD, FEM techniques).
5. Produce numerical solutions to simulate the problem.
6. (Experimentally) test the models.
7. Interpret experimental data for design/system optimization.
8. Summarize results from different methods (analytical, simulation, testing) and explaining their differences.
9. Apply previous items to simulate, verify and validate systems by accounting their material behavior,aerodynamics, structural responses, cost analysis, integration, flight mechanics and

dynamics , and their interactions.

1. Lecture Notes
2. From Internet: Oberkampf, Trucano and Hirsch, Verification, Validation, and Predictive Capability in Computational Engineering and Physicsâ, SAND2003-3769, Sandia National Laboratories, 2003

AE4120: Viscous Flows
Master Aerospace Engineering
ECTS: 3
Dr.ir. B.W. van Oudheusden
Education period 1
Language: English

Basic inviscid incompressible and compressible fluid dynamics, thermodynamics, partial differential equations. The transport equations of mass, momentum and energy for flows with viscosity and heat conduction: the Navier-Stokes equations; molecular transport properties; boundary layer simplifications. Incompressible laminar flows: exact solutions, self-similar and non-similar boundary layers; approximate (integral) methods for boundary layer computations. Laminar flows with thermal and compressibility effects. Stability of laminar flows; transition. Turbulent flows: basic concepts, law of the wall and defect law, equilibrium boundary layers, turbulence modelling.

F.M. White, Viscous fluid flow, McGraw-Hill, 2006, 3rd ed ISBN 0-07-124493-X (or 2nd edition)

AE4131: CFD I
Master Aerospace Engineering
ECTS: 3
Dr.ir. M.I. Gerritsma
Education period 1,2
Language: English

Introduction to Computational Fluid Dynamics; Discretisation principles; Finite Volume method, Finite Difference method, Finite Element method, panel/boundary element methods for incompressible potential flows, integral equations, numerical approximations; Compatibility between velocity and pressure approximation; The convection-diffusion equation and the relation with high Reynolds number flows; Incompressible Navier-Stokes equations.

In the first part of the course an introduction to CFD is given. After finalizing the first part of this course the student should be familiar with the various discretisation techniques. The second part focuses on the relation between the incompressibility constraint and the pressure, and the competing contributions of convection and diffusion. One should be able to understand and apply the various mathematical tools in real-life problems.

AE4133: CFD II
Master Aerospace Engineering
ECTS: 4
Prof.dr.ir. H. Bijl et al
Education period 3,4
Language: English

This course covers several concepts which should be of interest to both numerical specialists and advanced users of computational fluid dynamics. Some of these concepts are phenomenological in nature, and some are fundamental in the sense that they can be applied to a wide range of problems. The course starts with a review of techniques for treating compressible flows, including the design of discontinuity-capturing schemes and approaches to higher-order upwinding using finite volumes and finite elements. Then the computation of turbulent flows is discussed including direct numerical simulation, both filter-based and variational-multiscale large-eddy simulation, and techniques based on Reynolds averaging. After this, course switches to more fundamental topics including advanced time march and solution techniques, uncertainty quantification and error estimation. The uncertainty quantification section describes how the influence of stochastic problem inputs (atmospheric conditions, surface roughness, material or chemical properties) can be accounted for in an efficient manner, using concepts such as polynomial chaos. The error estimation section deals with the computation of local contributions to the numerical error in a specific quantity of interest by solving adjoint problems. Aside from allowing the accuracy of a computation to be established, such estimations are essential ingredients for optimal discretisation adaptation procedures.

AE4141: Gas Dynamics II
Master Aerospace Engineering
ECTS: 3
Prof.dr.ir. P.G. Bakker
Education period 4
Language: English

1. Non-viscous steady 2D flows.
2. Diagonalisation, characteristic directions, hyperbolicity.
3 'Time-like' and 'space-like', flow aligned co-ordinates, compatibility relations.
4 Characteristic methods, Prandtl-Meyer expansion.
5 Characteristic methods.
6. Nozzle design, transonic flow in nozzle throat.
7 Burgers equation for 2D simple waves.
8. Non-viscous Burgers equation.
9. Shock formation, biconvex airfoil.
10. Farfield behaviour of shocks, wave interaction.

11. Qualitative theory of quasi 1D viscous flow, equations, Fanno equation.
12 Qualitative theory of 2nd order systems.
13 Application to quasi 1D flow equations, influence of viscosity.
14. Internal structure of a normal shockwave.

P.G. Bakker, lecture notes Gasdynamics 2000
- U. Ganzer, Gasdynamik, Springer, 1988 .
- M.J. Zucrow, J.D.Hoffman, Gasdynamics - vol. 1, 1976, ISBN 047198440X.
- M.J. Zucrow, J.D.Hoffman, Gasdynamics - vol. 2, 1985, ISBN 0898748402.
- John D. Anderson jr., Modern Compressible Flow with Historical Perspective, 2nd edition MacGraw-Hill 1990;
- Ya. B. Zeldovich and Yu. P. Raizer, Elements of Gasdynamics and the Classical Theory of Shock Waves, Academic Press 1968;
- H.W. Liepmann and A. Roshko, Elements of Gasdynamics, Wiley, 1957;
- R. Courant and K.O. Friedrichs, Supersonic Flow and Shock Waves, Interscience, 1948.
- G.B. Witham, Linear and Non-linear Waves, Wiley 1974;
- C. Hirsch, Numerical Computation of Internal and External Flows. Vol. I: Fundamentals of Numerical Discretization. Vol. II Computational Methods for Inviscid and Viscous Flows, Wiley 1988.
- B.H. Bulakh, Nonlinear Conical Flows, translated from the Russian by J.W. Reyn and W.J. Bannink, D.U.P. 1984.
- P.G. Bakker, Bifurcations in Flow Patterns, Kluwer Academic Publishers 1991.
- J. Guckenheimer and P.J. Holmes, Non-linear oscillations, dynamical systems and bifurcation of vector fields, Springer 1983.

AE4212: Aircraft Performance Optimization
Master Aerospace Engineering
ECTS: 3
Dr.ir. H.G. Visser
Education period 4
Language: English

1. Background and outline of course; relation with basic courses in flight mechanics.
2. Mathematical notation and review of some basic mathematical facts; foundations of unconstrained parameter optimization.
3. Foundations of constrained parameter optimization; applications in flight mechanics.
4. Introduction to optimal control theory; problem formulation; open-loop and closed-loop control; system classification; some intrinsic system properties.
5. Variational approach to dynamic optimization; transversality conditions; first integral; elementary examples.
6. Minimum Principe van Pontryagin; Hamilton’s Principe in mechanics; numerical solution techniques.
7. Synthesis of optimal closed-loop control; the Optimality Principle of Bellman; dynamic programming; the Hamilton-Jacobi-Bellman equation.

8. Graphical interpretation of the Minimum Principle; Jacobi condition; linear-quadratic (LQ) problems; the matrix-Riccati equation; autopilot design via LQ-synthesis.
9. Bang-bang and singular optimal control problems.
10. Application of optimal control theory to trajectory optimization problems in atmospheric flight mechanics; equations of motion; reduced-order modeling; transformation of variables.
11. Reduced-order models for solving the “Minimum Time-to-Climb” problem; introduction to the energy-state concept.
12. (Approximate) solutions to the “Minimum Time-to-Climb” problem; solution accuracy assessment.
13. Optimal flight profiles for commercial airline operations.
14. Examples of flight optimization results established in the ongoing research program.

The course aims at providing the foundations as well applications of static and dynamic optimization. The emphasis is on practical applications in flight mechanics. However, also applications in related (possibly non-aerospace) fields are given. In view of the fact that the numerical resolution of practical optimal control problems is usually far from trivial, specific attention is given to computational aspects and system model simplifications.

Recommended literature
G.J.J. Ruijgrok, Elements of airplane performance, Delft University Press, Delft, 1996.

AE4394: Modern Flight Test Technologies and System Identification
Master Aerospace Engineering
ECTS: 3
Dr. Q.P. Chu
Education period 4
Language: English

1. Introduction to aerospace state estimation and parameter identification; optimal state estimation, prediction and smoothing (Kalman filter KF and Kalman smoother KS)
2. State estimation/smoothing for nonlinear systems (Extended Kalman filter/smoother EKF/EKS), computational aspects of KF/KS and EKF/EKS, and applications to aerospace navigation, attitude determination, on-board sensor calibration, sensor integration, and data fusion
3. Least squares (LS), Weighted Least squares (WLS) parameter estimation, Total Least Squares (TLS) parameter estimation, Maximum likelihood (ML) parameter estimation techniques.
4. Recursive LS, WLS, TLS and ML parameter estimation, computational aspects of LS, WLS and ML (batch and recursive), and applications to sensor calibration, spacecraft orbit determination, aircraft model parameter identification.
5. Joint state and parameter estimation and adaptive state estimation with applications
6. Aircraft aerodynamic model identification with one step approach ML approach
7. Two-step approach for state and parameter estimation and its applications to aircraft aerodynamic model identification

State estimation and parameter identification have been widely applied to aerospace vehicle guidance, navigation, control, and modelling. Vehicle state vector components (such as vehicle position, velocity, rotation rate, attitude and aerodynamic flow angles) and model parameters (e.g. stability and control derivatives, sensor errors and calibration parameters) are essential information for guidance and control. In many cases these state vector components and parameters can only be estimated from noisy measurements of the dynamic response of the vehicle on control input signals or random disturbances. This lecture presents the most relevant algorithms and techniques for aerospace state and model parameter estimation (parameter estimation is often referred to as 'identification' to express the need for searching for the adequate mathematical form of the mathematical model). These techniques are demonstrated on several practical applications and examples. The Kalman filter and smoother for the estimation (present time) and the reconstruction (past time) of the state vector trajectory of linear state space models are discussed in detail. Next extensions to nonlinear state estimation and reconstruction problems are discussed. Examples of applications are GPS navigation, integrated inertial/GPS navigation, attitude and heading reference systems, navigation sensor on-board calibration, and multi sensor data fusion. The lecture is continued with Least Squares, Weighted Least Squares, Total Least Squares, and Maximum Likelihood approaches for aerospace parameter identification. Application examples of sensor calibration, spacecraft orbit determination, aerospace vehicle model parameter identification are addressed next. It is shown that the aerospace vehicle parameter identification problem constitutes a joint parameter-state estimation problem which can be formulated in terms of Maximum Likelihood estimation theory. The solution of the problem requires the nonlinear optimisation of the Likelihood Function of either prediction errors or output errors. It is shown that in case of aircraft parameter identification problems this nonlinear optimization problem can be decomposed in a state reconstruction problem and a linear parameter identification problem if certain conditions on the onboard sensor configuration and accuracies are met ('two step approach'). It is shown that the parameter estimation accuracies depend on the form and amplitude of the control input test signals. The concept of optimal flight test manoeuvres is introduced. Finally adaptive state estimation techniques using recursive least squares, recursive total least squares, and recursive maximum likelihood approaches, are highlighted for advanced applications.

• Q.P. Chu, 'Modern flight test technologies and system identification', lecture notes, Faculty of Aerospace Engineering, Delft University of technology.

Recommended literature

• J.A. Mulder, J.K.Sridhar, J.Breeman, Nonlinear Analysis and Manoeuvre Design', 'Identification of Dynamic Systems, Applications to AircraftAGARD AG-300, Vol. 3, Part. 2, , May 1994
• R.E. Maine, K.W.Iliff, AGARD Flight Test Techniques Series on 'Identification of Dynamic Systems, Applications to Aircraft', AGARD AG-300, Vol. 3, Part. 1, , December 1986 .
• Eric Walter and Luc Pronzato, Identification of parametric models, Springer, ISBN 3-540-76119-5.

AE4520: Advanced Structural Analysis
Master Aerospace Engineering
ECTS: 3
Dr.ir. G.N. Saunders
Education period 1
Language: English

1. Computation of structural deflections for thin-walled structures - continuation. (Applying the Dummy Unit Load Method, computation of relative displacements).
2. Analysis of Statically Indeterminate Structures. (External vs internal redundancies, multiple redundancies, applications to wing and fuselage structures).
3. Engineering theory of bending for open and closed tubes an overview. (General stress, strain and displacement relationships for open and closed tubes).
4. Shear flow in open and closed tubes.
5. Twist and warping of shear loaded closed tubes.
6. Displacements associated with the Bredt-Batho shear flow.
7. Warping distribution of a doubly symmetrical rectangular closed tube subjected to a torque.
8. Warping of open tubes.
9. Axial constraint stresses in open tubes. (The Wagner torsion-bending theory, calculation of the torsion bending constant, the wire analogy for flat sided sections).
10. Axial constraint stresses in closed tubes. (Doubly symmetrical single cell, 4-boom tube under torsion).
11. Shear diffusion. (Axial constraint stresses in a doubly symmetrical single cell 6 stringer tube subjected to a transverse shear force).
12. Elements of plate bending theory. (Kirchhoff's assumptions, equilibrium equations via the stationary value of the potential energy, Kirchhoff's derivation of the boundary conditions, simply supported rectangular plate under sinusoidal loading, Navier's solution for simply supported rectangular plates, the Green's function of the rectangular plate).

This course is designed to introduce students who wish to specialize in stress analysis of thin-walled structures to more advanced topics such as the analysis of statically indeterminate structures, warping, constraint stresses, shear diffusion, and elements of plate bending.

T.H.G. Megson, Aircraft structures for engineering students, Edward Arnold, 4th edition

AE4525: Advanced Computational Modeling
Master Aerospace Engineering
ECTS: 3
Ir. J.M.A.M. Hol
Education period 1
Language: English

Finite elements in structural analysis including non-linear material and geometric behaviour and contact problems. Covers theoretical aspects, practical use and application examples. At the end of this course a student is able to use non-linear finite element methods to solve structural problems in a validated and verified manner.

R.D. Cook: "Concepts and Applications of Finite Element Analysis"
O.C. Zienkiewicz & R.L. Taylor: "The finite element method"
R.H. MacNeal: "Finite elements: their design and performance"
V. Adams & A. Askenazi: "Building better products with finite element analysis"

AE4530: Special Topics in Vibration and Buckling
Master Aerospace Engineering
ECTS: 3
Ir. J.M.A.M. Hol
Education period 3
Language: English

The course will cover advanced topics in non-linear buckling and vibration analysis of thin-walled shell structures. Content of the 2010-2011 course is not yet defined. Typical topics covered in earlier years were:

1. Nonlinear analysis of shells: Perturbation methods and fully nonlinear analysis. Semi-analytical methods. Path-following methods.
2. Effect of initial geometric imperfections: Koiter's initial postbuckling theory. Effect of special imperfection modes. Effect of mode interactions.
3. Effect of boundary conditions: Reduction from partial differential equations to ordinary differential equations. Numerical solution of the two-point boundary value problem (shooting method and finite difference method).
4. Hierarchical analysis approach. Probabilistic approach.
5. Random vibrations: Random loads and random response characteristics.
6. Statistical Energy Analysis: Response characteristics of random structures due to random loads.
7. Component Mode Synthesis: Model reduction, boundary conditions, and synthesis (coupling) methods.

AE4542: Advanced Simulation - Dynamics & Mechanisms
Master Aerospace Engineering
ECTS: 3
Ir. J.M.A.M. Hol
Education period 3
Language: English

Finite element methods applied to flexible mechanisms and multi-body systems. At the end of this course a student is able to use non-linear finite element methods to solve structural problems in a validated and verified manner. Workshop on MD Motion software.

AE4543: Advanced Simulation - Crash & Impact

Master Aerospace Engineering
ECTS: 3
Ir. J.M.A.M. Hol
Education period 3
Language: English

Implicit finite element methods applied to crash, impact and penetration problems. At the end of this course a student is able to use implicit finite element methods to solve structural problems in a validated and verified manner. Workshop in implicit FE software (MD FEA, Abaqus, LD-Dyna).

AE4930: Aeroelasticity

Master Aerospace Engineering
ECTS: 3
Dr. S.J. Hulshoff
Education period 1,2
Language: English

This course provides an introduction to the physical and analytical aspects of aeroelasticity. The course begins with illustrations of aeroelastic phenomena using simplified aerodynamic and structural models. Then experimental results and analytical solutions for unsteady flows are described, and the influence of unsteady aerodynamics on aeroelastic phenomena is discussed. After a presentation of reduced-order modelling for continuous structures, efficient flutter-prediction methods are described. Commonly-used dynamic-response prediction procedures are also presented. An overview of modern computational aeroelasticity is then given, with an emphasis on comparing sources of error and the strengths and weaknesses of different methods. Finally, experimental techniques are briefly discussed, and the use of the methods presented in the course is described in the context of aircraft design.

AE4E08TU: Satellite Navigation

Master Aerospace Engineering
ECTS: 4
Dr.ir. A.A. Verhagen
Education period 2,3
Language: English

Global Satellite Navigation Systems (GNSS), such as GPS, have revolutionized positioning and navigation. Currently, four such systems are operational or under development. They are the

American GPS, the Russian Glonass, the European Galileo, and the Chinese Beidou-Compass. This course will address: (1) the technical principles of Global Navigation Satellite Systems (GNSS), (2) the methods to improve the accuracy of standard positioning services down to the millimeter accuracy level and the integrity of the systems, and (3) the various applications for positioning, navigation, geomatics, earth sciences, atmospheric research and space missions. The course will first address the space segment, user and control segment, signal structure, satellite and receiver clocks, timing, computation of satellite positions, broadcast and precise ephemeris. It will also cover propagation error sources such as atmospheric effects and multipath. The second part of the course covers autonomous positioning for car navigation, aviation, and location based services (LBS). This part includes the integrity of GNSS systems provided for instance by Space Based Augmentation Systems (e.g. WAAS, EGNOS) and Receiver Autonomous Integrity Monitoring (RAIM). It will also cover parameter estimation in dynamic systems: recursive least-squares estimation, Kalman filter (time update, measurement update), innovation, linearization and Extended Kalman filter. The third part of the course covers precise relative GPS positioning with two or more receivers, static and kinematic, for high-precision applications. Permanent GPS networks and the International GNSS Service (IGS) will be discussed as well.In the last part of the course there will be two tracks (students only need to do one): (1) geomatics track: RTK services, LBS, surveying and mapping, civil engineering applications (2) space track: space based GNSS for navigation, control and guidance of space missions, formation flying, attitude determination. The final lecture will be on (scientific) applications of GNSS.

The course includes assignments and computer exercises using Matlab and related GPS software.

P. Misra and P. Enge: Global Positioning System, Signals, Measurement and Performance. 2nd edition, 2006, Ganga-Jamuna Press, ISBN 0-9709544-1-7

AE4W12: Rotor Aerodynamics
Master Aerospace Engineering
ECTS: 3
Prof.dr. G.J.W. van Bussel, Dr.ir. C.J. Simao Ferreira
Education period 3,4
Language: English

• Introduction to rotary wing aerodynamics. Applications in aircraft, propulsion, fans and wind turbines.
• Conservation laws. Actuator disk/momentum theory. Limitations. Helicopter rotor vertical flight and “windmill brake” state. Figure of merit. Wind turbine Betz optimum. Lift and drag devices
• Blade element–momentum method, “Tip” correction methods. Correction for finite nr. of blades and heavily loaded rotors.
• Aerodynamic characteristics of airfoils for rotor application. Aerodynamic properties of pitch and stall controlled wind turbine. Wind turbine rotor blade design.

• Vortex line methods. Vortex wake structure. Frozen and free wake, vortex core modelling.
• Vortex panel methods. Advanced wake models. Acceleration potential method.
• CFD-Navier Stokes calculations and solutions: current developments.
• Detailed rotor near wake structure. Experimental wake velocities and wake vorticity structure.
• Experiments on wind turbine rotor blades. Pressure distributions. Inflow measurements
• 3D effects, Stall delay. Yawed flow and dynamic inflow. Autogiro, helicopter rotor in forward flight.
• Unsteady aerodynamics and dynamic stall effects. Theodorsen's Theory. Effects of tower shadow and wind shear.
• Vertical axis wind turbine rotor and Voight-Schneider propeller
• Effects of inflow turbulence intensity on blade loads. Near and far wake structure
• Wind farm aerodynamics. Rotor-wake interaction. Single and multiple wakes. Effects upon loads and performance.

"Hands on" introduction to the different computational models used nowadays to analyse the aerodynamics of rotors.

Technische Natuurwetenschappen

TN1721: Introduction to Imaging Physics
Bachelor Applied Physics
ECTS: 3
S. Stallinga, Prof.dr.ir. L.J. van Vliet
Education period 3, 4
Language: English

Based upon optical theory as developed in Physics 1, we will describe and analyze various types of optical microscopy including widefield microscopy, fluorescence microscopy, confocal microscopy, and TIRF. We will also look at modern developments in quantitative microscopy, computational microscopy and super-resolution methods.

TN2513/TN2513TU: Computational science
Bachelor Technische Natuurkunde
ECTS: 3
Dr. B. Rieger, S. Stallinga
Education period 1, 3, 4
Language: Nederlands

De bedoeling van het vak Computational Science is de student te introduceren in het gebruik van modellen en simulatie-technieken voor onderzoek aan fysische verschijnselen en processen. Allereerst wordt de student geleerd te programmeren in een programmeer-omgeving: MATLAB. Vervolgens voeren de studenten een aantal opdrachten uit, die verschillende aspecten van het gebruik van simulaties binnen de natuurkunde illustreren. Aan de hand hiervan maakt de student tevens kennis met een aantal veelgebruikte numerieke technieken, de stabiliteit van de gebruikte methoden en de foutafschatting.

TN2780-HT: Honours Class Fysische Transportverschijnselen
Bachelor Technische Natuurkunde
ECTS: 1
Prof.dr.ir. C.R. Kleijn
Education period 4
Language: Nederlands

Een aantal onderwerken uit het reguliere vak "Fysische Transportevrschijnselen" (TN2785) worden diepgaander en meer mathematisch behandeld. Een aantal formules die in TN2785 worden geponeerd, zullen worden afgeleid. Ook is er aandacht voor numerieke oplosemethoden voor complexe problemen. Bestudering van geavanceerde literatuur.

IMM: Introduction to Multiscale Modeling
Bachelor Molecular Science & Technology
ECTS: 3
Prof.dr.ir. J.G.E.M. Fraaije
Education period 2
Language: English

Multiscale modeling is an exiting new approach to a wide variety of problems in chemistry, including supramolecular chemistry, (bio)self-assembly and nanotechnology. The course deals strictly with the fundamentals of computational multiscale modeling. The following topics are covered: Molecular Dynamics (atomtypes, force fields), Fokker-Planck Theory, Monte Carlo methods, and Mesoscopic Dynamics.

MQM: Molecular Quantum Mechanics
Bachelor Molecular Science & Technology
ECTS: 3
Prof.dr. F. Buda
Education period 1
Language: Dutch (on request English)

The course gives a survey of the quantum-mechanical (QM) basis of the molecular modeling techniques that are now available in academic and commercial packages for the study of (bio) molecular structure and function. The students will have an insight into the possibilities and limitations of the various QM approaches, as well as the different methods and approximations. The basic concept of a hierarchical modeling scheme will be introduced. During the course there will be a number of practical sessions by using a molecular modeling package (Spartan).

Essentials of Computational Chemistry, C.J. Cramer, Wiley

AP3081TU G: International Masters Course on Computational Physics
Master Applied Physics
ECTS: 6
Dr.J.M.Thijssen
Education period 3
Language: English

Several computer projects are be executed by Delft students in collaboration with students from Michigan State University (US). There will be exchange visits, collaborative projects and video linked discussion meetings. Projects are on molecular dynamics, (quantum) Monte-Carlo calculations, lattice Boltzmann simulations, finite elements for mechanical deformation, parallel computing, assembling a Beowulf cluster, electronic structure, etc. The course projects are close to the research level.

Students completing this course have knowledge about computational schemes for physics problems. In particular, the student is well aware of the theory and implementation of molecular dynamics and Monte Carlo simulation, as well as elementary electronic structure calculations. He or she has experience with setting up simulation codes for scientific problems in physics. The student is able to collaborate in the field of computational physics in an international setting. Students can present the results of their projects in a clear and interesting manner. In particular, the study goals of the applied physics degree course addressed in this course are:
1. Mastery of Applied Physics at an advanced academic level.
3. Thorough experience with research in (applied) physics and complete awareness of the applicability of research in technological developments.
4. Capable of understanding a wide variety of different problems and being able to formulate these at an abstract level. To see, from the abstract level, the relation between diverse problems
and to contribute creatively to their solution focused on practical applications.
5. Capable of creating innovative technical designs, taking account of feasibility issues.
6. Capable of working in a (possibly interdisciplinary) team of experts performing the aforementioned activities and communicating easily in both written and oral English.
8. Capable of making English language presentations of one's own research activities to diverse audiences. Being able to adapt to the background and interest of the audience.

This course does not contain any formal teaching, but is completely project-based. The student learns all the necessary theoretical knowledge directly from literature and from contact with the lecturers. Videoconferencing and e-mail are the tools used to facilitate the international collaboration.

The first week in Michigan and the last week in Delft are expected to be filled entirely with this course. The remaining 80 hours work load are more or less evenly divided over the three months in between, i.e about 7 hours/week.

Computational Physics by J.M. Thijssen (2nd edition, Cambridge University Press)

AP3171 D: Advanced Physical Transport Phenomena
Master Applied Physics
ECTS: 6
Dr.ing. S. Kenjeres
Education period 3
Language: English

Analytical/Numerical/Modelling Aspects of Advanced Physical Transport Phenomena (Fluid Flow, Heat Transfer and Turbulence):
1. Basic Equations of Transport Phenomena - Field Description;
2. Mathematical Methods for Solving Transport Equations (PDE, separation of variables, eigenfunctions and eigenvalues, Bessel functions, Laplace transformation, Error-Gamma functions, integral methods)
3.Transport in Stagnant Media (diffusion, moving front problems, diffusion with source terms)
4. Momentum Transport (potential flows, creeping flows, boundary layers)
5.Transport in Flowing Media (stationary transport in flows with uniform velocity, heat transfer in laminar pipe flow, natural convection)
6.Numerical Heat and Fluid Flow (discretization methods for heat conduction, convection and diffusion; differencing schemes, numerical diffusion; steady and time-dependent convection and diffusion; calculation of flow field/velocity-pressure coupling, SIMPLE algorithm)
7. Turbulence: Some Features and Rationale for Modelling (some generic types of turbulent flows and convective processes, wall-bounded turbulent flows: velocity and temperature distributions/wall functions, Reynolds decomposition, RANS)
8. Turbulence Modelling (closure problem, eddy viscosity/diffusivity models, k-e model, other two-equation eddy-viscosity models)

1. Book: "Analysis and Modelling of Physical Transport Phenomena", Hanjalic K.,Kenjeres S.,Tummers M.J.,Jonker H.J.J., VSSD Book, ISBN-13 978-90-6526-165-8, First Edition, December 2007.
2. Book: "Transport Phenomena", Bird R.B.,Stewart W.E.,Lighfoot E.N.,2nd edition,Wiley (2002)
3. Book: "Fysische Transportverschijnselen II", Hoogendoorn C.J. and van der Meer, Th.H., Delftse Uitgevers Maatschappij (1991)
3. Handouts: For computational/computer exercises a reference manual and quick start manuals will be provided.

AP3551: Computational Multiphase Flow
Master Applied Physics
ECTS: 6
Dr. L. Portela
Education period 1,2
Language: English

The course is based on the Learning by Doing approach. During the course, the students will write their own CFD code for (turbulent dispersed) multiphase flow. In the lectures, several aspects of the numerics and physics of multiphase flows will be introduced and incorporated into the CFD code, which will slowly expand during the course. Attention will be given to the interaction and forces between the phases, as well as to the different types of models and approaches that can be used.

AP3561: Turbulent Reacting Flows
Master Applied Physics
ECTS: 6
Prof.dr. D.J.E.M. Roekaerts
Education period 1,2
Language: English

Models for interaction between turbulent flow and chemical reaction. Methods to obtain mean properties without having to solve the transport equations in full detail. Application to industrial combustion chambers, chemical reactors and atmospheric flows. Transport equations, reaction kinetics, non-dimensional numbers and regime diagrams, fundamentals of a statistical description, laminar flames. Introduction to turbulent combustion (RANS, LES, flamelet model, probability density function method).

Thierry Poinsot and Denis Veynante, Theoretical and numerical combustion, Second Edition, Edwards, 2005, ISBN 1-930217-10-2

UL38: Stellar dynamics
Extern Institute
ECTS: 3
Prof.dr.ir. T.M. Klapwijk, S.F. Portegies Zwart (U. Leiden)
Education period 1
Language: English

This course is part of Leiden-Delft specialization on Astronomy and Instrumentations. This specialization is set up by the Leiden Observatory of Leiden University and the Faculty of Applied Sciences of TU Delft. It underlines that observational astronomy and atmospheric research uses and develops leading edge technology in particular in the field of highly sensitive detection (such as at ESA/ESTEC in Noordwijk, at TNO Science and Industry in Delft, at ASTRON in Dwingeloo and at SRON in Utrecht/Groningen).

You will learn how to use the computer for your scientific research in computational science and astrophysics. You will use the most advanced computer hardware to simulate the Universe and to process the data resulting from your calculations. You will learn how to program the computer, debug your source code and optimize it until the full potential of the computer is utilized. During this course you will learn to use multiple languages, parallel computers and special-purpose hardware to solve astrophysical problems. You will be part of a small research group consisting of computational scientists and astrophysicists, together with whom you compete to write the most efficient simulation software.

CH3131: Applied Numerical Mathematics
Master Chemical Engineering
ECTS: 6
Dr. G. Biskos, Prof.dr.ir. C.R. Kleijn, Ir. S.J. Huynink
Education period 1
Language: English

Linear algebra: Gaussian elimination, determinants, inversion, norm, rank, sparse/banded matrices; Nonlinear algebra: bracketing, iterative methods, Newton, secant, systems of nonlinear equations, Levenberg-Marquart, steepest descent; Eigenvalues; Initial value problems: ODE's, Euler, implicit/explicit, stability/accuracy, stiff problems, DAE systems; Optimization: parameter estimation, least squares; Boundary value problems: finite differences, upwinding, preconditioning; Fourier analysis: convolution, correlation; Probability: distributions, Monte-Carlo;

Numerical Methods for Chemical Engineering: Applications in Matlab, Kenneth J. Beers, Cambridge University Press, 2007

CH3421: Computational Transport Phenomena
Master Chemical Engineering
ECTS: 6
Prof.dr.ir. H.E.A. van den Akker
Education period 3, 4
Language: English

An introductory course: elementary fluid mechanics; computational aspects; turbulence & turbulence modelling; RANS vs Large-Eddy Simulations; operations and transport processes in process equipment; chemical reactions; two-phase flows. Building an understanding of CFD, its promises and its limitations; acquire experience in numerical and computational exercises; understanding turbulence; becoming capable of interpreting and assessing CFD results.

CH3671: Molecular Simulation
Master Chemical Engineering
ECTS: 6
Dr. F.C.Grozema, Dr.ir. T.J.H. Vlugt
Education period 4
Language: English

Quantum chemical techniques:
• Hartree-Fock (variation principle, basis set)
• Electron correlation (CI, DFT, MP2)
• Semi-empirical methods

• Potential energy surfaces and geometry optimizations (vibrations, transition states and chemical reactions)
• Electrostatic properties of molecules (dipole moment, charge distribution, polarizability)
• Electronically excited states
• Intermolecular interactions (VdWaals, electrostatic)
• Calculation of parameters for classical force fields (intra-, intermolecular)

Classical methods for molecular simulations:
• Computing ensemble averages (Boltzmann distribution, partition function, importance sampling)
• Monte Carlo simulation of interacting particles (calculating thermodynamic properties, equation of state, radial distribution function etc.)
• Monte Carlo in various ensembles (NVE, NVT, grand-canonical, and Gibbs ensemble)
• Molecular Dynamics (integrating the equations of motion, temperature control, computing self- and transport diffusivities)
• More advanced simulation techniques and applications (computing phase diagrams, free energy calculations for solids, computation of adsorption isotherms)

C.J. Cramer, “Essentials of computational chemistry”

LM3761: Numerical Methods, Modeling & Simulation Techniques
Master Life Science and Technology
ECTS: 6
Ir. C. Picioreanu
Education period 1, 2
Language: English

The course deals with formulation and numerical solution of mathematical models and with different simulation techniques in bioengineering. After this course the students should:
- be able to formulate coherent mathematical models for certain bioengineering problems
- be able to recognize the type of numerical problem they have
- learn how to put the model equations in a format that is solvable with numerical (computer-based) techniques.
- be aware of the numerical tools existing for the solution of a certain type of problem
- understand the principle of the main numerical techniques and to be able to choose an adequate method for their specific problem
- be able to use general simulation-oriented software such as Matlab
- be able to critically analyse the results obtained and formulate a report, conclusions and recommendations.

There is extensive computer use in lectures, but mostly in practical applications. Individual exercises on using computational software for at least 16 h with MATLAB and 4 hours using COMSOL.

- G. Lindfield, J. Penny (1999) â€œNumerical methods using MATLAB
- J. Kiusalaas (2005, 2010) "Numerical Methods in Engineering with MATLAB"
- W.H. Press, S.A. Teukolsky, W.T. Vetterling, B.P. Flannery (2007) Numerical Recipes in C
- MATLAB and COMSOL tutorials

NS3621: Quantum Information Processing
Master Nanoscience
ECTS: 5
Prof.dr.ir. L.M.K. van der Sypen
Education period 1, 2
Language: English

Quantum Information Processing aims at harnessing quantum physics to conceive and build devices that could dramatically exceed the capabilities of today's "classical" computation and communciation systems. In this course, we will introduce the basic concepts of this rapidly developing field. Topics include
(1) Quantum states (pure, mixed)
(2) Quantum gates and circuits
(3) Quantum algorithms
(4) Quantum measurement
(5) Decoherence
(6) Quantum error correction
(7) Quantum communication and cryptography
(8) Implementations and experiments

M.A. Nielsen and I.L. Chuang, “Quantum Computation and Quantum Information”, (Cambridge University Press, 2000).

Werktuigbouwkunde, Maritieme Techniek & Technische Materiaalwetenschappen

WB1424ATU: Turbulence A
Bachelor Mechanical Engineering
ECTS: 6
Dr.ir. W.P. Breugem, Prof.dr.ir. B.J. Boersma
Education period 3, 4
Language: English

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 treament 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 Oboukhov 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.

S.B. Pope, Turbulent Flows, Cambridge University Press, ISBN 0 521 59886 9

WB1428-1, -3: Computational Fluid Dynamics
Master Mechanical Engineering
ECTS: 4
Dr.ir. M.J.B.M. Pourquie
Education period 2, 3
Language: English

• Introduction, the finite difference method and the finite volume method for diffusion problems.
• The finite difference method and the finite volume method for convection-diffusion problems
• Stability of discretization schemes for the convection-diffusion equation.
• Conservation laws for flowing media and boundary conditions.
• Simulation of steady flows.
• Methods for the solution of discretized equations.
• Simulation of time-dependent flows.
• The pressure correction method for mass conservation.
• Turbulence and turbulence models.
• Implementation of boundary conditions.
• Grid generation.
• Several lecture hours are used for practical exercises with matlab and Fluent.

J.H. Ferziger and M. Peric, Computational methods for Fluid Dynamics, Springer Verlag.

WB1440: Eng. Optimization: Concept & Applications
Master Mechanical Engineering
ECTS: 3
Dr.ir. M. Langelaar, Prof.dr.ir. A. van Keulen
Education period 3
Language: English

Formulation of optimization problems; Typical characteristics of optimization problems; Minimization without constraints; Constrained minimization; Simple optimization algorithms Discrete design variables; Approximation concepts; Sensitivity analysis.
More specifically, the student must be able to:
1. formulate an optimization model for various design problems
2. identify optimization model properties such as monotonicity, (non-)convexity and (non-) linearity
3. identify optimization problem properties such as constraint dominance, constraint activity, well boundedness and convexity
4. apply Monotonicity Analysis to optimization problems using the First Monotonicity Principle
5. perform the conversion of constrained problems into unconstrained problems using penalty or barrier methods
6. compute and interpret the Karush-Kuhn-Tucker optimality conditions for constrained optimization problems
7. describe the complications associated with the use of computational models in optimization
8. illustrate the use of compact modeling and response surface techniques for dealing with computationally expensive and noisy optimization models
9. perform design sensitivity analysis using variational, discrete, semi-analytical and finite difference methods
10. identify a suitable optimization algorithm given a certain optimization problem
11. perform design optimization using the optimization routines implemented in the Matlab Optimization Toolbox
12. derive a linearized approximate problem for a given constrained optimization problem, and solve the original problem using a sequence of linear approximations
13. describe the basic concepts used in structural topology optimization

P.Y. Papalambros et al. Principles of Optimal Design: Modelling and Computation

WB1441: Engineering Optimization 2
Master Mechanical Engineering
ECTS: 3
Prof.dr.ir. A. van Keulen
Education period 3
Language: English

The course is intended as a follow-up course to wb1440. However, the focus is more on the use of numerical models. Aspects that will be presented are: Optimization techniques; Sensitivity analysis; Coupling with simulation techniques; Multi-objective optimization; Multi-disciplinary optimization

R.T. Haftka and Z. Gürdal: Elements of Structural Optimization.

WB1443: Matlab in Engineering Mechanics
Master Mechanical Engineering
ECTS: 2
Dr.ir. A.L. Schwab, Ir. J.J.L. Neve
Education period 2
Language: English

Matlab in Engineering Mechanics is an introductory course in technical computing, Matlab, and numerical methods. The emphasis is on informed use of mathematical software. We want you to learn enough about the mathematical functions in MATLAB that you will be able to use them correctly, appreciate their limitations, and modify them when necessary to suit your own needs.
The topics include:
- introduction to MATLAB
- linear equations
- zero finding
- least squares
- ordinary differential equations
- eigenvalues and singular values

The weekly homework assignments are on these topics. The final project is an individual choice from various fields of application like: Multibody System Dynamics with Matlab, Control Theory with Matlab/Simulink, or Finite element calculations with FEMLab.

Cleve Moller, "Numerical Computing with MATLAB", SIAM, 2004

ME1600: Reliability and Uncertainty Models in Engineering Mechanics
Master Mechanical Engineering
ECTS: 2
Prof.dr.ir. M.A. Gutierrez De La Merced
Education period 4
Language: English

This course provides an introduction to the most common computational techniques to study the influence of parameter uncertainty in the performance of mechanical systems. Rather than modelling the problem by means of stochastic differential equations, advantage is taken of existing numerical techniques for deterministic problems in order to characterise the stochastic response. The focus is in modelling the spatial variability of material and geometric properties by means of random fields and studying how this randomness propagates to the response field. The preferential techniques for this purpose belong to the family of Stochastic Finite Element Methods and are presented in this course for the purpose of both uncertainty and reliability analysis. In the former attention is paid to how characteristics of the random parameters such as the expectation and the covariance propagate to those of the response. In the latter the focus is on approximating the probability distribution of any characteristic of the structural performance.

WB1416: Numerical Methods for Dynamics
Master Mechanical Engineering
ECTS: 3
Prof.dr. D.J. Rixen, Prof.dr.ir. A. van Keulen
Education period 3, 4
Language: English

Using engineering tools as black boxes can be dangerous and inefficient. This is especially true when performing dynamic analysis of structures in a finite element package. Choosing the right finite element types and the suitable solution procedure is critical to get accurate results and to compute solutions efficiently. In order to discuss basic principles of numerical methods for dynamics and to explain fundamental concepts related to dynamic analysis, the course will cover the following topics:
- Elastodynamic equations for a continuous media (short recap)
- Discretization techniques: Rayleigh-Ritz and Finite elements (bar, beam)
- Linear solvers, storage techniques and singular systems
- Free vibration modes, mode superposition techniques and eigensolvers for large systems
- Accuracy of modal superposition, modal acceleration, system excited through support
- model reduction, including dynamic substructuring
- time-integration of linear and non-linear systems
- computing senstitivity of modes and eigenfrequency to design parameters, model updating
- Parallel computing techniques for fast solvers

Some topics might be dropped depending on students background. Specific topics might also be discussed if time permits. In this courses emphasis will be put on understanding fundamental concepts of numerical methods and how they relate to the mechanics of structures. Therefore, the oral (open book) exam will concentrate on the mastering of concepts rather than on formulation details. A computational project will be included (using Matlab pre-cooked routines and/or Ansys-Nastran).

Use of ANSYS and/or Matlab for assignment and illustration.
Mechanical Vibrations, Theory and Application to Structural Dynamics, M. Géradin and D. Rixen, Wiley, 1997.
The Finite Element Method: Linear Static and Dynamic Finite Element Analysis, T.J.R. Hughes Prentice-Hall, 1987.
Finite Element Procedures, K.J. Bathe, Prentice-Hall, 1996
Structural Dynamics: an introduction to computer methods, R.R. Craig, Wiley, 1981, ISBN 0-471-04499-7

Matrix Computation, G.H. Golub and C.F. Van Loan, Johns Hopkins University Press, 1996.

WB2454-07: Multiphysics Modelling using COMSOL
Master Mechanical Engineering
ECTS: 4
Dr.ir. R.A.J. van Ostayen, Ir. J.J.L. Neve, Dr.ir. M. Langelaar
Education period 3
Language: English

In applied mechanics one is often confronted with a multi-physics or coupled problem: A problem that requires the (simultaneous) solution of more than one type of physical process or phenomenon in order to accurately describe the problem. Examples of multiphysics problems are fluid-structure interaction, thermal-structure interaction and electro-thermal-structure interaction, possibly combined with a control problem. Particularly in the field of Mechatronic design and MEMS multiphysics problems are frequently encountered. COMSOL MultiPhysics is a finite element code, which can be used both as a MATLAB toolbox and as a standalone program, which is particularly suited for the simulation of multi-physics systems. In this course the student will learn to recognize different types of multi-physics coupling and methods for their efficient numerical solution using COMSOL. Short homework assignments are used to practise the use of COMSOL on different types of problems and in a final assignment the student is asked to study a multi-physics problem using COMSOL.

WB4421: Gas Turbine Simulation/Application
Master Mechanical Engineering
ECTS: 3
Prof.ir. J.P. van Buijtenen
Education period 3, 4
Language: English

The course consists of two parts: one part is about off-design behaviour of gas turbines (with simulation-practicum with GSP) and a part application.
Part 1: Performance characteristics of gas turbine components, procedures and computer programs for the calculation of the static and dynamic part load behaviour of gas turbines, the effect of ambient conditions on performance. Operating envelope, flow phenomena in compressors: stall, surge, choking. Performance monitoring: trend analysis, the use of parameter estimation techniques in case only limited data are available.
Part 2: In part 2 the student is expected to carry out an assignment with GSP, consisting of the analysis and the generation of solutions for a practical example of the behaviour of a gas turbine under deviating operational conditions, as component wear, a different fuel , application of water- of steam injection.

Prof. Ir. J. P. van Buijtenen; Ir. W.P.J. Visser, "Gas Turbines, WB4420 / 4421"

BM1200: Computational Mechanics of Tissues and Implants

Master Biomedical Engineering
ECTS: 6
Dr. A.A. Zadpoor
Education period 3, 4
Language: English

The course consists of two parts: lectures and hands-on workshops. The lectures are designed to give students in-depth knowledge of the mechanical behavior of skeletal tissues and how their behavior can be formulated in terms of the theories of continuum mechanics. Another important topic is the interaction of tissues and implants and how that can be analyzed using computational mechanics.

The hands-on workshops give students the opportunity to apply what they have learned in the lectures in real modeling practice. A commercial FEM package is used to make FEM modeling as practical as possible. The emphasis is therefore shifted from the technical details of the FEM modeling to understanding the material models and applying them for analysis of modeling problems. The problems are chosen to be as close to the real-world problems as limitation of a graduate course allows.

Prior knowledge of continuum mechanics is necessary for following the course. The following topics will be covered in the lecturing part:

1. A brief review of elementary continuum mechanics
2. Large deformations and anisotropic elasticity
3. Formulation of constitutive equations
4. Viscoelasticity (viscoelastic fluids and solids)
5. Poroelasticity
6. Remodeling
7. Tissue-implant interactions

The workshops start from very simple modeling exercises that introduce the FEM package and show how it can be used for simple modeling tasks. The level of difficulty will gradually increase up to the point that students can do FEM modeling of tissues and tissue-implant systems.

Recommended texts for the course:
1- Cowin, Stephen C., Doty, Stephen B., 2007, Tissue Mechanics, Springer.
2- Cowin, Stephan C. (Editor), 2001, Bone Mechanics Handbook 2nd Ed., CRC Press.
3- Bartel, Donald L., Davy, Dwight T., Keaveny, Tony M., 2006, Orthopaedic Biomechanics: Mechanics and Design in Musculoskeletal Systems, Prentice Hal.
4- Mow, van C., Huiskes, Rik, 2004, Basic Orthopaedic Biomechanics & Mechano-biology 3rd Ed., Lippincott Williams & Wilkins.

MS3031: Computational Materials Science
Master Materials Science and Engineering

ECTS: 4
Dr. M.H.F. Sluiter
Education period 4
Language: English

Computer modeling of materials. Length and time scales. Modern modeling techniques. Simulation of materials structure, change, and properties. Student computer projects.
1. Introduction to materials modeling.
2. Phase field methods.
3. Background statistical mechanics.
4. Quantum-level modeling.
5. Molecular dynamics.
6. Ising model, Cluster Variation Method, Monte Carlo techniques.
7. Finite volume methods.
8. Discrete dislocation dynamics.
9. Computer lab classes.

MS3412: Processing of Metals
Master Materials Science and Engineering
ECTS: 4
Dr.ir. M.J.M. Hermans
Education period 1
Language: English

Subjects covered include transport phenomena in metals processing. The module will focus on quantitative descriptions of processes using physical and material models in terms of fundamental and essential building blocks. Numerical approximation methods are discussed to obtain quantitative results and are related to process conditions and process performance. Microstructural evolution models are also included. These concepts are illustrated with selected case studies.

MS4131NS: Solid State Physics 2
Master Materials Science and Engineering
ECTS: 3
Dr. M.H.F. Sluiter
Education period 1
Language: English

Computer modelling of materials. Quantum mechanical basis for materials properties and behaviour. Explanations for trends in materials properties. Modern modelling techniques. Simulation of materials structure, change, and properties. Student computer projects.
1. Universal equation of state for metals.
2. structure maps.
3. The diatomic molecule.

4. Real space tight-binding electronic structure models.
5. Band gaps: origins and consequences.
6. s-p bonding and a case study in silicon.
7. Free electron theory; Properties of free electron metals.
8. The transition metals; Structural stability of compounds.
9. Modern quantitative theory; Where band theory breaks down.
10. Individual computer lab.

Some of the exercises will benefit from the ability to use a computer algebra program of your choice (maple, mathematica, octave, etc.) or some low-level programming (C, fortran, basic, etc.)

MT523: Numerical Methods for MT

Master Marine Technology
ECTS: 4
Dr.ir. H.J. de Koning Gans
Education period 2
Language: English

Explanation of several flow models and their fluid mechanics properties (pressure, velocity, mass and volume flow, momentum, energy flow etc.) and fluid domain in contrast with aerodynamics. Modeling flow models into numerical flow models. Elementary solutions for potential flow and how to use them for panel codes which used these elementary solutions. Greens' function theory. Grid generation techniques and how to use them. Several numerical error in the developing stage, desing and applications stage. Application for numerical method: Viscous flow Diffraction, Wave making pattern.

Koning Gans, Dr. Ir. H.J. de "Numerical Methods in Ship Hydromechanics"
Koning Gans, Dr. Ir. H.J. de "Manual of Numerical Methods in Ship Hydromechanics"
Katz, J. & Plotkin, A."Low Speed Aerodynamics from Wing Theory to Panel Methods"

MT524 : Hydromechanics of Special Ship Types

Master Marine Technology
ECTS: 3
Dr.ir. J.A. Keuning
Education period 3
Language: English

The student is able to understand, determine and analyze the particular points of interest and the differences in the hydromechanics involved between regular ship types and special ship types such as in particular sailing yachts and fast ships. More specifically, the student is able to:
1. list the various computational techniques ranging from CFD to regression based empirical formulas that are being used for the determination of the forces and moments involved in the equilibrium of a sailing yacht under way
2. apply the various methods and techniques that are being used for the determination of the

specific problems encountered with sailing yachts in in-stationary conditions (i.e. motions and added resistance due to wind waves)
3. describe the differences between linear and non linear approaches to ship motion calculation techniques for both sailing yachts and fast ships
4. describe the special conditions, forces and moments that come into play when dealing with fast ships sailing in calm water and waves
5. apply the different calculation techniques used on the fast ships with their strong non linear behavior and to understand and analyze their differences
6. describe (the need for) the various different experimental techniques used in fast ship towing tank experiments
7. explain the special problems associated with fast ships in waves with respect to; the strong non linear behavior, high encounter frequencies and vertical accelerations, large motions and special events like surfing and broaching in following waves
8. describe the various aspects with fast ships with respect to safety
9. apply the various aspects with respect to ultimate stability

MT815 : Construction and Strength, Special Subjects
Master Marine Technology
ECTS: 2
X. Jiang
Education period 2
Language: English

The course aims at establishment of methods for probabilistic modeling and analysis of structural behavior and safety applying to ships, offshore platform, pipelines and other marine and/or civil engineering structures. Different methods for calculating reliability of components, including FORM and advanced FORM, SORM and Monte Carlo simulation methods are discussed. Systems reliability method and updation of reliability based on inspection and maintenance are introduced. Properties of and solution to different reliability problems, ultimate strength reliability and fatigue reliability are illustrated.

MT830: Applications of the Finite Element Method
Master Marine Technology
ECTS: 3
X. Jiang
Education period 2
Language: English

The course gives the theoretical framework for the finite element method, formulates elements for beams, plates, shells and assembly structures. Element properties, symmetric and asymmetric issues, convergence requirements and modeling errors are discussed. The course emphasizes rational modeling, choice of element type, discretization, introduction of loads and boundary conditions and results control. Further, an introduction to geometric modeling of simple two- and three-dimensional structures and typical structural details is given.

OE4630 D1, D2, D3, D4: Offshore Hydromechanics
Master Offshore Engineering
ECTS: 8
Prof.dr.ir. R.H.M. Huijsmans, P. de Jong, Dr.ir. S.A. Miedema, Ir. P. Naaijen
Education period 2, 3
Language: English

Module 1 (1,5 EC): Hydrostatics, floating stability and 2-D potential flows, as well as regular and irregular waves and their spectra.
Module 2 (2 EC): Computations relevant for first order forces on and resulting motions of ships.
Module 3 (3 EC): Nonlinear forces on and resulting ships motions; workability prediction.
Module 4 (1,5 EC): Hydrodynamic forces on slender structures including marine pipelines.
In addition, successful participants completing module 1 will have a basic awareness of ship propulsion systems and their computations. Those completing module 4 will have an advanced knowledge of sea bed morphology.

WB3600: Computational Engineering Project
Minors Werktuigbouwkunde
ECTS: 10
Ir. M.G. van de Ruijtenbeek
Education period 1, 2
Language: Nederlands

Een beperkte onderzoek- of analyseopdracht moet zelfstandig uitgevoerd worden. De student formuleert een hypothese of de aan een ontwerp te stellen eisen, schrijft een Plan van Aanpak (onderzoek of analyse scenario, inclusief voorstellen hoe de onderzoek c.q. analyseresultaten te verifiëren en te valideren), ontwikkelt modellen voor numerieke simulaties, voert simulaties uit, analyseert en interpreteert resultaten. De resultaten, inclusief verificatie en interpretatie, worden gepresenteerd door middel van een geschreven mini-paper, een poster, en een verbale presentatie op een mini minor congres. De student kan:
1) (numerieke) wiskunde toepassen (b.v. verschillende oplosmethodes voor stelsels vergelijkingen gebruiken etc.)
2) verschillende modelleer technieken toepassen (discrete methoden, “multi-scale concepts”, etc.)
3) natuurkundige verschijnselen in ontwerpen toepassen (onderwerpen uit stromingsleer, mechanica, materiaalkunde, elektriciteit, elektronica, magnetisme, etc)
4) numerieke hulpmiddelen (software) ontwikkelen, zowel m.b.v. hogere programmeertalen als met MatLab-achtige programmatuur
5) data beheren, bewerken, en (grafisch) weergeven
6) software op het gebied van ontwerp en engineering gebruiken in een realistisch en up-to-date ontwerp en engineering proces of een onderzoeksproject

WB3663: Modelleertechnieken

Minors Werktuigbouwkunde
ECTS: 1
Ir. M.G. van de Ruijtenbeek
Education period 1, 2
Language: Nederlands

De student wordt een indruk gegeven van:
- huidige mogelijkheden op het gebied van computational engineering
- ontwikkelingen op het gebied van computational engineering
De student kan:
- naast de gebruikelijke vloeistof en vaste stof toepassingen ook andere toepassingen van CE beschrijven, bijvoorbeeld voor gebieden als scheikunde, biologie, elektromagnetisme, optica
- modelleer technieken (bijvoorbeeld diverse discretisering technieken en multi-scale concepts) beschrijven

Civiele Techniek en Geowetenschappen

CT4143: Shell Analysis, Theory and Application
Master Civiele Techniek
ECTS: 4
Dr.ir. P.C.J. Hoogenboom
Education period 4
Language: English

The course covers analytical and numerical methods for analysing shell structures. The governing differential equations will be derived. Analysed will be cylinders, cones, spheres and hypars. Deflections, membrane stresses and bending stresses will be calculated. Influence lengths and edge disturbances will be derived. Finite elements will be presented and the limitations discussed. Computational analyses will be performed and checked by small scale experiments. Instability of several shell shapes and the effect of imperfections will be discussed.

CT4180: Plate Analysis, Theory and Application
Master Civiele Techniek
ECTS: 4
Dr.ir. A. Scarpas
Education period 2
Language: English

Plates loaded in plane: The three systems of basic equations (kinematic, constitutive, equilibrium); rigid body displacements and deformations; several analytic solutions for rectangular plates; application of plane stress/strain to engineering structures; introduction to the finite element method; formulation of plane stress/strain elements; numerical integration schemes. Plates loaded out of plane (slabs): The three systems of basic equations for plate bending including shear deformation; simplification to the pure bending equation; formulation of special boundary conditions; several analytical solutions and various load and boundary conditions; finite element formulation of slab element; computational issues.

CT4310: Bed, Bank and Shoreline Protection

Master Civiele Techniek
ECTS: 4
Ir. H.J. Verhagen
Education period 2
Language: English

Design of shoreline protection along rivers, canals and the sea; load on bed and shoreline by currents, wind waves and ship motion; stability of elements under current and wave conditions; stability of shore protection elements; design methods, construction methods. Flow: recapitulation of basics from fluid mechanics (flow, turbulence), stability of individual grains (sand, but also rock) in different type of flow conditions (weirs, jets), scour and erosion. Porous Media: basic equation, pressures and velocities on the stability on the boundary layer; groundwater flow with impermeable and semi-impermeable structures; granular filters and geotextiles. Waves: recapitulation of the basics of waves, focus on wave forces on the land-water boundary, specific aspects of ship induced waves, stability of elements under wave action (loose rock, placed blocks, impermeable layers). Design: overview of the various types of protections, construction and maintenance; design requirements, deterministic and probabilistic design; case studies, examples. Materials and environment: overview of materials to be used, teraction with the aquatic environment, role of the land-water boundary as part of the ecosystem; environmentally sound shoreline design.

Students are advised to make some computational examples with the computer package CRESS; a probabilistic computation using matlab is a compulsory exercise. The exercise will be made available via Blackboard.

CT4340: Computational Modelling of Flow and Transport

Master Civiele Techniek
ECTS: 4
Dr.ir. M. Zijlema
Education period 1, 2
Language: English

Elementary notions of computational modelling of flow and transport. The following topics are dealt with during the course:
1. Ordinary Differential Equations (ODE), box models and spring-mass systems.
2. Time integration for ODE, consistency, convergence, stability and stiffness.
3. Partial Differential Equations (PDE), advection and diffusion.
4. Space discretization for PDE, finite differences, Von Neumann stability analysis, CFL condition, amplitude and phase error analysis and numerical diffusion.
5. 1D shallow water equations, Leapfrog and Preissmann schemes, staggered grids and

applications.

1) C. Hirsch (1991), Numerical computation of internal and external flows, Vol. 1, John Wiley and Sons, New York.
2) M.B. Abbott (1979), Computational Hydraulics, elements of the theory of free surface flow, Pitman, London.

CT4350: Numerical Soil Mechanics
Master Civiele Techniek
ECTS: 4
Prof.dr. M.A. Hicks
Education period 3
Language: English

Introduction to finite element analysis. Theoretical aspects: basic principles; 1D finite elements, including application to beam bending theory and beam on an elastic foundation; 2D finite elements; derivation of finite element equations for linear elasticity; material non-linearity; derivation of finite element equations for steady state seepage; 3D finite elements, including comparison between 2D and 3D analysis; finite element mesh numbering; storage schemes; equation solvers; local coordinate systems; programming the finite element method; structure charts. Related topics: mesh generation; adaptive mesh refinement; stochastic analysis; finite differences. Applications: case histories; coursework examples.

CT4380: Numerical Modelling of Geotechnical Problems
Master Civiele Techniek
ECTS: 3
Dr.ir. O.M. Heeres
Education period 1
Language: English

During the last decades, the numerical modeling of geotechnical problems has become increasingly important. Therefore, this course focuses on this issue. After an introduction into finite element theory, the course is clustered around common problems such as building pits, embankments, tunneling, and groundwater flow. As much as possible, engineering engineering examples are discussed. The choice of appropriate numerical techniques and soil models is addressed. Attention is given to parameter determination. Capabilities and limitations of various analysis types are discussed. Also special topics are addressed: pollution transport, dynamics, installation of foundations, inverse modeling, and use of finite elements within Eurocode 7. Emphasis is put on interpretation, checking and judging numerical results, from the viewpoint of the user, which can be the modeler itself, or the person who checks finite element results.

CT4801: Transportation and Spatial Modelling
Master Civiele Techniek
ECTS: 6

Dr. M.C.J. Bliemer
Education period 1
Language: English

1. Objectives of modelling in transport and spatial planning. Model types. Theory of travel and locational behaviour. System description of planning area. Theory of choice models. Aggregate and disaggregate models. Mode choice, route choice and assignment modelling. Locational choice modelling. Parameter estimation and model calibration. Cases and exercises in model application;
2. Role of models in transportation and spatial systems analysis; model types; designing system description of study area (zonal segmentation, network selection); role of shortest path trees;
3. Utility theory for travel and location choice; trip generation models, trip distribution models; applications;
4. Theory of spatial interaction model; role of side constraints; distribution functions and their estimations; constructing base matrices and estimating OD-tables;
5. Theory of individual choice models;
6. Disaggregated choice models of the logit and probit type for time choice, mode choice, route choice and location choice;
7. Integrated models (sequential and simultaneous) for constructing OD-tables;
8. Equilibrium theory in networks and spatial systems;
9. Route choice and assignment; derivation of different model types (all-or-nothing model, multiple route model, (stochastic) equilibrium model); assignment in public transportation networks; analyses of effects;
10. Calibration of parameters and model validation; observation, estimation, validation; estimation methods;
11. Individual exercise computing travel demand in networks; getting familiar with software; computing all transportation modelling steps; analyse own planning scenarios; writing a report.

CT5123: Introduction to the Finite Element Method
Master Civiele Techniek
ECTS: 4
Prof.dr.ir. L.J. Sluys, Dr.ir. A. Simone
Education period 3
Language: English

This course provides an introduction to the finite element method. Aspects of the finite element method, from the mathematical background through to practical implementation and use are discussed. Emphasis is placed on solving problems in elasticity and structural mechanics.
Topics include:
1. Development of weak governing equations;
2. Galerkin methods for calculating approximate solutions;
3. Finite elements for plane and 3D continua;
4. Discretisation, finite element shape functions, isoparametric mapping, numerical integration, formation of element stiffness matrices;

5. Finite elements for structural applications (rods, beams and plates);
6. Continuity requirements, thick and thin plate theories, different element formulations, shear locking;
7. Computer implementation of the finite element method;
Storage, assembly and solution of finite element equations;
8. Analysis of the finite element method;
Galerkin orthogonality, rates of convergence for different elements, basic error estimates;
9. Dynamics;
10. Lumped and consistent mass matrices, modal analysis, implicit and explicit direct time integrators, wave propagation in elastic continua.

"The Finite Element Method: An Introduciton", by G.N. Wells

CT5142: Computational Methods in Non-linear Solid Mechanics
Master Civiele Techniek
ECTS: 3
Prof.dr.ir. L.J. Sluys
Education period 4
Language: English

In the lecture series computational techniques for the description of nonlinear behaviour of materials and structures will be treated. Topics of the course are:
1. Mathematical preliminaries;
2. Structure of nonlinear finite element programs;
3. Solution techniques for nonlinear static problems;
4. Solution techniques for nonlinear dynamic problems;
5. Plasticity models for metals and soils;
6. Fracture models;
7. Visco-elastic and viscoplastic models for time-dependent problems;
8. Computational analysis of failure and instabilities;
9. Geometrically nonlinear analysis.

Lecture notes: "Computational methods in non-linear solid mechanics", R. de Borst and L.J. Sluys

CT5144: Stability of Structures
Master Civiele Techniek
ECTS: 3
Prof.ir. A.C.W.M. Vrouwenvelder
Education period 4
Language: English

Elastic Stability. Single-degree-of-freedom systems; Pendulum systems; Exact second-order stiffness matrix; Linearised second-order stiffness matrix for FEM packages; Formulas for lateral buckling and torsional buckling; Buckling of elastically supported beams; Snap-trough behaviour; Minimum potential energy.

Plastic Stability. Virtual work for nonlinear systems; Influence of geometrical nonlinearities on the failure load and the failure mode; Elastic-plastic stability of frames; Determination of the critical load with the Merchant-Rankine formula.

Vrouwenvelder, A.C.W.M., "Structural Stability", Delft University of Technology, 2003

CT5146: Micromechanics and Computational Modelling of Building Materials
Master Civiele Techniek
ECTS: 3
Prof.dr.ir. K. van Breugel, Dr.ir. H.E.J.G. Schlangen
Education period 2
Language: English

This course concentrates on chemical, physical, stereological and fracture mechanics aspects of building materials with emphasis on cement-based materials. Materials are looked at on the nano-, micro- and meso-level and materials properties are explained by referring to those fundamental levels. Modern developments in the field of experimental research techniques and numerical modelling of materials are dealt with. The following topics will be dealt with:
1. Reaction kinetics of hydration processes in cement-based systems;
2. Development and modelling of the microstructure and pore structure of cement paste and concrete;
3. Fracture processes: cause and effect;
4. Time dependent processes: creep and relaxation;
5. Transport- and degradation processes;
6. Experimental research techniques: microscopy, calorimetry, porosimetry, ct-scanning, nano-indentation;
7. multi scale modelling;
8. Towards design of materials (Computational Materials Science);
This course is open for both Master students and PhD students.

"Simulation of hydration and formation of structure in hardening cement-based systems - Part I"
Recommended other materials:
1. "Construction materials: Their nature and behaviour" Ed. J.M. Ilston & P.L.J. Domone. Spon Press 2001, ISBN 0-419-25860-4
2. "Materials Science and Engineering - An Introduction" William D. Callister, John Wiley & Sons. Standard work. Valuable but expensive)
3. "Fracture processes of Concrete". J.G.M van Mier, CRC-press.

CT5148: Computational Modelling of Structures
Master Civiele Techniek
ECTS: 4

Dr.ir.M.A.N.Hendriks
Education period 1
Language: English

The course focuses on finite element modeling of civil and building engineering structures, both linear and non-linear. The choice of element types, constitutive models, selection of material parameters, boundary conditions, loading schemes, control procedures and other modeling aspects are discussed and critically reviewed, from a user's point of view. Possibilities, limitations and pitfalls of analysis types and models are treated, in connection to the underlying theory and algorithms. Attention is given to interpretation of results, equilibrium checks, convergence checks and judgment of output in relation to engineering design rules. Students are teached to critically approach or even distrust computer outputs, rather than naively show off exciting color plots. The specific content is: 1D, 1.5D, 2D, 2.5D and 3D modeling types and analysis methods, smeared cracking, discrete cracking, plasticity, bedding and interface models, geometrically nonlinear options, phased analysis of construction stages and special options like embedded reinforcements and prestress. The course is based on real-world engineering examples, augmented by small-scale test simulations and academic exercises. Application fields cover structures of concrete, steel, masonry and other quasi-brittle materials, and soil-structure interaction. CAD-FEM connections are addressed with a view to buildings of free-form geometry. Recent research on sequentially linear techniques for softening and structural optimization is touched upon.

DIANA multi-purpose finite element software, including pre- and postprocessors (available in the computer lecture room; download link available on blackboard; software licences will be distributed during the first lecture).

CT5315: Computational Hydraulics
Master Civiele Techniek
ECTS: 3
Prof.dr.ir. G.S. Stelling
Education period 4
Language: English

The course deals with the backgrounds of three-dimensional hydrostatic modelling. The course consists of a lecture once a week plus a practical session once a week. During the first practical session the flow model Delft3D-FLOW will be introduced in a tutorial manner. This model will be used in the following practicals. Matlab is employed for the post-processing of the model results. The content of the subsequent lectures and practicals are: the initial and (open) boundary conditions, the advection scheme, applying the Alternating Direction Implict (ADI) technique for efficient computations, calculation of the vertical structure of horizontal (stratified) flows and a sensitivity analysis for a case study.

Recommended other materials:
1. User Manual of Delft3D-Flow [Blackboard];

2. Concise Matlab tutorial [Blackboard];
3. Practical manual as hand-out on first practical session and on Blackboard;
4. Example matlab scripts on Blackboard.

CT5802-09: Advanced Transportation Modelling
Master Civiele Techniek
ECTS: 4
Dr.ir. R. van Nes
Education period 2
Language: English

The course elaborates on the basics of transportation modelling as studied in CT4801. Main themes are multi-user multi-modal network analysis and design, travel and driver behaviour, and the impact of ITS on transport networks. The framework used in CT5802-09 is based on route-based approaches in which choice sets are determined before modelling route choice and assignment. Topics dealt with are choice set generation, new developments in choice modelling, and assignment approaches as multi-user-class assignment, dynamic assignment and multimodal assignment. Furthermore attention is given to current research on transportation modelling, e.g. evacuation planning. Students have to make an exercise in teams to gain computational experience in modelling and transportation scenario analysis. Furthermore, they have to prepare individually a critical essay on a scientific article in the field of transportation modelling. Both the exercise and the essay have to be reported in writing and presented in class.

EMC-H/MM: Numerical Mine Modelling
Master Applied Earth Sciences
ECTS: 3
Ir. J.J. de Ruiter
Education period 1
Language: English

The course covers the cycle of mine modelling from exploration to design and production. The main topics are: management of investigation data, data analyses, visualization, geological and geotechnical modelling, rock mechanical analyses, open pit and underground mine design. The core includes both examples and practical work using rock mechanical software and geological and mine design software.

Elektrotechniek, Wiskunde en Informatica

WI2604: Numerical Methods 1
Bachelor Applied Mathematics
ECTS: 6
Dr. M.B. van Gijzen
Education period 3, 4

Language: Dutch

WI3097TU: Numerical Methods for Differential Equations
Bachelor Applied Mathematics
ECTS: 4
Dr. M.B. van Gijzen
Education period 1, 2, 4
Language: Dutch

WI4201: Scientific Computing
Master Applied Mathematics
ECTS: 6
Prof.dr.ir. C.Vuik, Dr. D.J.P. Lahaye
Education period 1, 2
Language: English

During the course, the important steps towards the solution of real-life applications dealing with partial differential equations will be outlined. Based on a well-known basic partial differential equation, which is representative for different application areas, we treat and discuss direct and iterative solution methods from numerical linear algebra in great detail. The discretization of the equation will result in a large system of discrete equations, which can be represented by a sparse matrix. After a discussion of direct solution methods, the iterative solution of such systems of equations is an important step during numerical simulation. Emphasis is laid upon the so-called Krylov subspace methods, like the Conjugate Gradient Methods. Finally, a concrete real life application will be presented.

Lecture notes, for further reading the book Matrix Computations, G.H. Golub and C.F. van Loan, the Johns Hopkins University, Baltimore, 1996, can be used.

WI4011: Computational Fluid Dynamics
Master Applied Mathematics
ECTS: 6
Dr.ir. D.R. van der Heul
Education period 1, 2
Language: English

Basic equations of fluid dynamics. Numerical methods for convection-diffusion equations: finite volume schemes; stability, consistency and convergence of numerical schemes; Fourier stability analysis, local grid refinement; singular perturbation theory; uniform accuracy and efficiency for vanishing viscosity. Numerical solution of the time-dependent and time-independent incompressible Navier-Stokes equations. Pressure-correction method. Colocated and staggered discretisation methods. Distributive iteration methods for the Navier-Stokes equations. Discretisation on curvilinear structured and unstructured triangular grids. Introduction to structured and unstructured grid generation in 2D.

Lecture notes "Elements of Computational Fluid Dynamics" by Prof. dr. ir. P. Wesseling, revised by Dr. ir. D.R. van der Heul

WI4017TU: Parallel Computing
Master Applied Mathematics
ECTS: 6
Dr.ir. H.X. Lin
Education period 3
Language: English

Principle and basic techniques of parallel computing. Concepts of the interplay between parallel algorithmic and architecture and programming of parallel computers. Parallel algorithms and parallel programming models (such as shared-variable, message-passing, etc.) are discussed. Basic concepts of problem decomposition, scheduling and mapping for parallel computation in large scale computational science&engineering problems are considered. The lab exercise comprises the solution of a problem on a parallel computer.

WI4204: Advanced Modeling
Master Applied Mathematics
ECTS: 6
Prof.dr.ir. A.W. Heemink
Education period 3, 4
Language: English

In this course the principles and practice of mathematical modeling are dealth with. An important part of the job is to recognize the essential mechanisms governing a phenomenon. These mechanisms have to be translated into mathematics and included into the model. This activity requires both a good understanding of the system under consideration and good mathematical shills. Although mathematical modeling may make use of all fields of mathematics, this course will concentrate on applications in science and therefore focus on models in terms of differential equations. The topics are: Basis Concepts of Mathematical Modeling; Non-dimensionalization, Scaling; Conservation Principles; Constitutive Relations; Stability and Robustness; Variational Methods; Inverse Modeling. The participants will work in small groups on the modeling of Bicycle Steering; Epidemics; Transport of Pollutants.

Continuum Modeling in the Physical Sciences, E. van Groesen and J. Molenaar, Mathematical Modeling and Computation, Vol. 13, SIAM, 2007 (ISBN 978-0-898716-25-2).

WI4055: Computational Aspects of Stochastic Differential Equations
Master Applied Mathematics
ECTS: 6
Prof.dr.ir. A.W. Heemink, Dr.ir. H.X. Lin

Education period 1
Language: English

Ito calculus for stochastic integrals, Stratonovitz calculus, stochastic differential equations, Fokker-Planck equations, Stochastic Taylor expansion, Euler schema, Milstein schema, strong order of convergence, weak order of convergence, Variance reduction. Applications in financial mathematics (option pricing) and environmental modelling (pollution transport).

WI4154: Computational Finance
Master Applied Mathematics
ECTS: 6
Dr.ir. C.W. Oosterlee
Education period 3, 4
Language: English

The course aims at improving the student's knowledge of computational methods in the area of finance. Numerical algorithms and partial differential equations, in particular in the field of modeling asset prices and in option pricing are presented. The student learns to apply methods in a computer project. For different mathematical models, for products from the financial industry, different numerical mathematics techniques are required. The students learn about the numerical techniques used in finance. Finite differences for PDEs, Monte Carlo techniques for complicated integrals and Fourier-based integration are taught for the numerical side; For the financial product modelling side, we discuss asset pricing processes, we discuss a variety of options, from basic European options to options with early-exercise opportunities and so-called exotic options. Furthermore, details about financial products are given.

Tools for Computational Finance (fourth edition or higher) required & by R. Seydel, Springer Verlag Berlin 2003, ISBN 3-540-40604-2.

WI4054: Environmental Simulation and Data Assimilation
Master Applied Mathematics
ECTS: 6
Dr. P. Wilders, Prof.dr.ir. A.W. Heemink
Education period 3, 4
Language: English

Transport models, diffusion and dispersion, chemical reactions, method of characteristics, Fourier analysis, finite volume Eulerian methods, monotonicity, Eulerian-Lagrangian methods, data assimilation via parameter estimation, uncertainty, Monte-Carlo method, recursive data assimilation by means of Kalman filtering.

WI4051TU: Introduction to Operation Research
Master Applied Mathematics
ECTS: 6

Dr. J.B.M. Melissen
Education period 1, 2
Language: Dutch (on request English)

History of Operations Research. Examples from practice. Linear Programming: LP Models, Simplex method, Sensitivity analysis, examples. Transport and assignment problems. Network optimization. Integer Programming: Computational complexity, examples, Branch-and-Bound procedure. Dynamical programming.

Hillier&Lieberman: Introduction to operations research. 8th Edition McGraw-Hill ISBN 007-123828-X

WI4218: Convex Optimization and Systems Theory
Master Applied Mathematics
ECTS: 6
Dr. F. Vallentin, Dr. J.W. van der Woude
Education period 3, 4
Language: English

In the last twenty years the following paradigm for dealing with problems in systems theory was established: A wide variety of problems arising in systems theory can be reduced to standard convex optimization problems that involve matrix inequalities. These standard problems can be solved efficiently; in theory and in practice. The aim of the course is to provide the theoretical background as well as to introduce the practical skills needed for solving problems in systems theory using this new paradigm. For establishing this goal the course is divided into five parts:
1. Convexity and efficient computation: We introduce basic notions from convexity and from computational complexity theory. Using this we can distinguish between easy and difficult computational problems.
2. Modelling of optimization problems as convex optimization problems: We study methods to show whether an optimization problem allows a convex model or not. We deal with several methods to get convex relaxations of non-convex models.
3. Solving convex optimization problems: We introduce efficient, interior-point methods for convex optimization in the case of conic optimization problems. Conic optimization problems are ubiquitous, they include: linear optimization, convex quadratic optimization, semidefinite optimization.
4. Several problems from systems theory: We introduce the notions of dissipativity, system norm, robustness and controller synthesis from systems theory. We discuss some common additional requirements that we want to impose on our system.
5. Using convex optimization in systems theory: We show how the problems described in 4 can be modelled using linear matrix inequalities. Then one can solve them by efficient methods from convex optimization.

S. Arora, B. Barak, Computational Complexity: A Modern Approach, Cambridge University Press, 2009

A. Barvinok, A Course in Convexity, AMS, 2002
A. Ben-Tal, A.Nemirovski, Lectures on Modern Convex Optimization. Analysis, Algorithms, and Engineering Applications, MPS-SIAM Series on Optimization, 2001.
S. Boyd, L. Vandenberghe, Convex Optimization, Cambridge University Press, 2004.
S. Boyd, L. El Ghaoui, E. Feron, V. Balakrishnan, Linear Matrix Inequalities in System and Control Theory, SIAM 1994
C. Scherer, S. Weiland, Linear Matrix Inequalities in Control, Delft Center for Systems and Control.

WI4219: Discrete Optimization
Master Applied Mathematics
ECTS: 6
Prof.dr.ir. K.I. Aardal
Education period 1, 2
Language: English

In Discrete Optimization, as opposed to Continuous Optimization, we deal with objects which are finite or at most countable. An archetypical problem is the notorious traveling salesman problem (find the shortest of a finite number of possible tours), but also linear programming can de seen as a discrete problem (find the best among a finite number of vertices of a polyhedron). The course introduces some of the most relevant problems from the area, as well as algorithms to solve them. The following topics will (most probably) be treated
• Introduction to Algorithms & Analysis
• Shortest Path Algorithms
• Minimum Spanning Trees & Matroids
• Maximum Flows & Minimum Cuts
• Minimum Cost Flows
• P, NP, coNP, NP-completeness
• Integer Linear Programming & Total Unimodularity
• Approximation Algorithms
• Primal-Dual Algorithms
• Inapproximability & Approximation Schemes

• W.J. Cook, W.H. Cunningham, W.R. Pulleyblank and A. Schrijver, Combinatorial Optimization, Wiley, 1998. ISBN 0-471-55894-X
• C.H. Papadimitriou and K. Steiglitz, Combinatorial Optimization; Algorithms and Complexity, Prentice-Hall, 1982. ISBN 0-13-152462-3
• Ahuja, R. K., T. L. Magnanti, and J. B. Orlin, Network Flows, Prentice Hall, 1993. ISBN 0-13-617-549.
• T. Cormen, C. Leiserson, R. Rivest and C. Stein, Introduction to Algorithms, 2nd ed., MIT Press, 2001. ISBN10 0262531968
• B. Korte and j. Vygen, Combinatorial Optimization - Theory and Algorithms, 4th ed., Springer, 2008. ISBN10 3-540-25684-9.

ET4107: Power Systems Analysis II
Master Electrical Engineering
ECTS: 4
Dr.ir. M. Popov
Education period 1
Language: English

The course is devoted to fault calculations in electrical power systems networks,the economic operation and control of power systems and an introduction to power system stability.
For network calculations and the description of symmetric and asymmetric faults the general method of power invariant symmetrical components is introduced.The economic operation involves the minimization of fuel costs, while the power system control deals with the primary and secondary control on the generating units to enable stable operation and maintaining a proper grid frequency. The stability of the power system after faults is studied through the method of the equal-area criterium.

Students will be introduced with methods for computation fault currents and load flows. For this, symetrical components will be studied. Power system components will be studied and adequate models for transformers, synchronous machines and transmission lines will be presented. Network calculations and short circuit analysis are studied by applying admittance and impedance matrices of the circuits. Symmetrical components and transformation from n-phase system into n separate 1-phase systems will be presented as an important tool to determine unsymmetrical fault currents (single-phase fault current, double-phase and double-phase-to-ground fault currents). Additionally, the course will be supported by computer exercises done with the commercially available software package Vision©.

John. J. Grainger and William D. Stevenson: Power System Analysis, ISBN 0-07035958

ET4162: Computational Electromagnetics A
Master Electrical Engineering
ECTS: 3
Dr. N.V. Budko
Education period 4
Language: English

The method of the volume integral equation is used to compute electromagnetic scattering on a large class of objects situated in free (unbounded) space. The following questions are studied: singularity of the Green tensor in 3-D; existence and uniqueness of the solution; spectrum of the scattering operator; iterative methods; discretization and numerical solution. The course is aimed at physicists and engineers and includes some practical numerical programming and simulation work.

Each participant is given a separate computational problem to solve. She/he has to: modify the provided MATLAB code, perform numerical experiments, write a little illustrated summary.

ET4163: Computational Electromagnetics B
Master Electrical Engineering
ECTS: 3
Dr.ir. R.F. Remis
Education period 4
Language: English

Being able to predict the electric behavior of a complex system is essential in many areas of electrical engineering and related fields such as microwave communications, high-speed microelectronics, chip design, radar, remote sensing, environmental sensing, electromagnetic compatibility, and bioengineering. To this end, Maxwell's equations need to be solved, since it is the electromagnetic field that determines this electric behavior. Practical systems are often so complex that only numerical solution techniques can be applied to obtain approximate solutions of Maxwell's equations. In this part of the computational electromagnetics series we discuss the essentials of a very popular numerical solution method, called the Finite-Difference Time-Domain method (FDTD method), which is used worldwide in industry and academia to solve all kinds of electromagnetic wave field problems. Computing the electromagnetic field scattered by an airplane, simulating fields in integrated circuits, field computations in the human body, and simulating a ground penetrating radar are just a few examples. In particular, what we discuss in this course is the spatial discretization of Maxwell's equations using a so-called nonuniform Yee grid, how to include piecewise constant media, the leap-frog time discretization scheme, stability of FDTD, and we also discuss how to simulate electromagnetic wave propagation in domains of infinite spatial extent (using perfectly matched layers). Moreover, certain symmetry properties of Maxwell's equations and their relation to energy conservation and reciprocity are discussed as well.

ET4255: Electronic Design Automation
Master Electrical Engineering
ECTS: 4
Dr.ir. N.P. van der Meijs
Education period 1
Language: English

State of the art IC design is difficult because of the complexity of scale (millions, and soon billions, of transistors on a single chip) and because of the non-ideal behaviour of the individual components (e.g. cross-talk), managed via advanced computer aids, which of course (but unfortunately) are non-ideal themselves. Thus, it is a goal of this course to teach prospective IC designers what to expect and not to expect from design tools, to enable better use of these tools for creation of better designs. A second goal is to provide an introduction to those students that want or need to develop such tools themselves. Many larger design sites have their own Design Automation department, working in close cooperation with their designers to solve unique problems for which a solution does not yet exist. Because of the ever-increasing integration density, constantly bringing about challenging new design automation problems, it is important for electrical engineers to have such skills. A third goal is to teach students how to use a computer to solve challenging technical problems in general. The field of Design Automation provides a rich source of examples of applying fundamental algorithms and data structures to real-world problems.

The course will consist of a number of introductory lectures and a hands-on programming assignment. In this assignment, students will develop a real computer program for a certain design problem.

The grade will be based for 50% on an oral examination and for 50% on the quality of the resulting program as judged from applying a number of test cases and a code review. In addition, a contest is set up for the fastest program with bonus points for the couple of best performers.

If, in an individual case, a programming assignment might be less appropriate, the assignment may be taken in the form of writing an essay on a chosen EDA topic and doing a presentation.

Gerez, S.H., Algorithms for VLSI Design Automation, John Wiley & Sons, 1999, ISBN 0471984892

ET4288: Applied Electromagnetic Analysis in Wireless, Microwave and Radar Engineering
Master Electrical Engineering
ECTS: 4
Prof.dr. O. Yarovyi
Education period 1
Language: English

The course contents consists of three major parts. In Part 1 the applied electormagnetics as a subject will be introduced, scope of the problems and typical approaches will be considered. Role of applied electromagnetics in wireless, microwave and radar engineering will be discussed. A general approach to solution of applied electromagnetics problems is presented and discussed in details. Part 2 of the course is dedicated to frequency domain simulations. Based on a simple problem of electromagnetic wave interaction with a thin wire all basics radiation phenomena will be analyzed and characterized. The problem will be treated via the method of moments. All essential features of the method of moments will be discussed in details. Simulation results will be verified against experimental ones. Following this, students will be introduced to the commercial program FEKO. Various structures will be modelled using FEKO, including simple 2D structures (microstrip filters and patch antennas) as well as more complex 3D scatteres (sphere). Specific issues for EM wave interaction with 2D and 3D structures will de discussed. Finally, computational limitations of frequency domain methods will be discussed. Advantages and disadvantages of time-domain and frequency domain methods will be compared. In part 3 wideband (time domain) simulations will be discussed.

On the example of one-dimensional transmission line basic time domain phenomena (such as dispersion, matching, stability) will be analyzed. Time-domain simulation will be performed using Finite Difference Time Domain (FDTD) method. The aim of this is to develop a basic appreciation of the FDTD method, as well as reinforce concepts of transforming between time and frequency domains. The use of time-domain simulation for ultra-wideband systems will be emphasized throughout. Finally, computational aspects of FDTD such as numerical dispersion, absorbing boundary conditions and numerical complexity will be discussed. The course will finish with overview of basic recommendation regarding choice of appropriate computational method for different problems of wireless, microwave and radar engineering. The lectures are supported by supervised laboratory work at which commercial simulation tools are used for simulation of five practical problems of wireless, microwave and radar engineering.

ET4356: Electromagnetics
Master Electrical Engineering
ECTS: 4
Dr. N.V. Budko, Dr.ir. M.D. Verweij
Education period 3
Language: English

This course consists of two parts. In the first part, three basic electromagnetic processes are considered, namely: radiation from arbitrary current-distributions; scattering of given incident fields by arbitrary inhomogeneous objects; imaging and inversion of objects using the scattered field data. We derive, and analyze in Matlab the full-vectorial three-dimensional electromagnetic radiation formulae in frequency and time domains. The following subjects are also discussed: numerical solution of the scattering problem, inverse source, and inverse scattering problems. The second part of the course is devoted to the guided waves, where the modal structure of the electromagnetic field in open and closed planar waveguides is analyzed.

WI3405TU: Waarderen van derivaten
EWI Keuzevakken Service-onderwijs
ECTS: 6
Dr.ir. R.J. Fokkink, Dr. J.A.M. van der Weide
Education period 1, 2
Language: Nederlands

In dit vak wordt ingegaan op de computational aspects van het prijzen van derivaten op basis van gegeven modellen. Hierbij komen zowel numerieke als simulatie technieken aan de orde. Een groot scala van opties passeeert de revu. Europese, Amerikaanse en Aziatische opties, Black-Scholes model, binomiaal modsel, PDE benadering, eindige differenties.