Module manual for
Computer Aided Conception and Production in Mechanical Engineering
MSCAME

SPO Version 2021
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Module manual for Computer Aided Conception and Production in Mechanical Engineering (Master (1-Subject))

Module manual for
Computer Aided Conception and Production in Mechanical Engineering
MSCAME

RWTH AACHEN UNIVERSITY

Examination Regulation Field

Module offer

Examination offer

Teaching offer

CONTENT
Module manual for
Computer Aided Conception and Production in Mechanical Engineering
MSCAME

RWTH AACHEN UNIVERSITY

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Examination Regulation Title & Version: Computer Aided Conception and Production in Mechanical Engineering (SPO Version / 2021)

Title	Computer Aided Conception and Production in Mechanical Engineering
Short title	MSCAME
Version	2021
Study/Qualification Objectives	The master's degree program Computer Aided Conception and Production in Mechanical Engineering (CAME) qualifies graduates to acquire advanced and specialized knowledge of methods, processes, and technologies in the field of computer-aided design of individual parts, assemblies, and computer-aided production in mechanical engineering. Graduates who have obtained this master's degree have the following qualifications: • Graduates acquired the ability to read and understand complex technical drawings and, on the basis of this, to independently design computer-aided constructions and can further develop existing ones according to the operational use. • Graduates are able to successfully apply the acquired and specialized engineering methods and knowledge to formulate and solve complex tasks in research and development in industry or in scientific research institutions. • Graduates are qualified to take on junior management tasks. This includes, in particular, presentation and communication techniques as well as the development of independent and autonomous actions, the ability to think abstractly, system-analytical thinking and the ability to work in a team. • Graduates have acquired various technical and social competencies (ability to abstract, system-analytical thinking, team and communication skills, international and intercultural experience, etc.) that prepare them for management tasks.
Qualification Profile	
Additionnal information	

Module titel	Nonlinear Structural Mechanics (Compulsory subject)
Identifier	4012290
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2010
Valid until	-
Module level	Master
Content	• Introduction and motivation: • Brief review of FE discretisation (solid vs. shell elements) • Brief review of linear statics and dynamics of structures • Structural nonlinearity: stress stiffening/softening, buckling, effect on nonlinear vibrations • Review of classical kinematical hypotheses (Bernoulli / Kirchhoff-Love), shortcomings, necessity of refined hypotheses • Index notation, Einstein summation convention • Kronecker symbol and associated rules • Scalar and vector product, matrix multiplication in index notation • Convected coordinates, parameter lines for a 3-D body • Co- and contravariant base vectors • Examples: cylindrical and spherical geometry • Co- and contravaiant metric tensor components • Co- and contravaiant vector and tensor components • Vector product of base vectors, permutation tensor, metric tensor determinant • Surface parameter lines • Co- and contravariant surface base vectors, normal vector • Surface metric and permutation tensor • Equations of Gauss and Weingarten • Christoffel symbols • Curvature tensor of a surface • Geometrical considerations (length, area and volume elements) in the shell space, at the reference surface, at the bounding surfaces, and at the lateral boundary • Deformed configuration • Base vectors of the deformed configuration • Covariant derivative • Shifter tensor, mean and Gaussian curvature • Principle of virtual displacements • Internal and external virtual work • Definition of stresses and strains • Strain tensor for von Kármán-type nonlinearity • Strain-displacement relations for tangential, transverse shear and transverse normal strains • First-order shear deformation hypothesis • Interpretation of the kinematical variables, rotations at the reference surface • Outlook: Refined hypotheses • Nonlinear strain-displacement relations for first-order shear deformation (Reissner-Mindlin) plate and shell theory • Transition to Kirchhoff-Love plate and shell theory / Bernoulli beam theory • Internal virtual work • Internal stress resultants • Theorem of Gauss • External virtual work (surface tractions, body forces, inertia forces) • Surface load couples, boundary load couples • Body couples, inertia couples • Nonlinear equilibrium equations • Static boundary conditions

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+ Nonlinear Structural Mechanics (4012290)

Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: <u>Knowledge / Understanding:</u> Students • shall know the important steps and features of consistent modeling of 2-D and 1-D structures for linear and nonlinear static and dynamic analysis. • shall be able to understand structural theories (e.g. in commercial FE-codes, in scientific publications etc.), to classify them, and to estimate the consequences of underlying hypotheses for the quality of obtainable simulation results. <u>Abilities / Skills:</u> Students • shall be able to analyse static and dynamic simulation results with respect to the quality of the adopted structural model. • are expected to transfer theoretical models to actual engineering problems of statically or dynamically loaded beam, plate and shell structures (e.g. arbitrary geometries, arbitrary boundary conditions, arbitrary material and ply lay-up). <u>Competencies:</u> Students • shall be able to critically assess the applicability, consistency and correctness of structural models. • shall be able to use their obtained knowledge in order to
(Study-Specific) Prerequisites	-
(recommended) Requirements	recommended: • Basic knowledge in mechanics (statics, strength of materials, dynamics)
References	A. H. Nayfeh, P. F. Pai: Linear and Nonlinear Structural Mechanics, Wiley-Interscience, 2004
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	apl. Prof. Dr.-Ing. Marcus Stoffel
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0
Self-study hours (h)	105,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Nonlinear Structural Mechanics (401229001)	2nd semester	no semester recommended	5	0

▲Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Vorlesung Nonlinear Structural Mechanics	2nd semester	no semester recommended	-	2
Übung Nonlinear Structural Mechanics	2nd semester	no semester recommended	-	1

Module titel	Failure of Structures and Structural Elements (Compulsory subject)
Identifier	4011486
Version	-
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2011
Valid until	-
Module level	Master
Content	The course is an introduction into the most important failure theories of structures. The content is summarized as: • Recall of fundamentals in continuum mechanics • Notion of “failure” in mechanical engineering. • Geometry and deformation: strain tensors • Mechanical and thermal loading: stress tensors • Conservation laws • Material behaviour: elasticity, elasto-plasticity, hardening, damage • Anisotropy • Yield-conditions and flow rules in plasticity and visco-plasticity • Direct methods: Lower and upper bound theorems of limit analysis • Examples of application of the theorems of limit analysis • Direct methods: Lower and upper bound theorems of shakedown analysis • Examples of application of shakedown theory • Notion and concepts of fracture mechanics • Linear elastic fracture mechanics • Elastic-plastic fracture mechanics • J-integral and other path-independent integrals • Kinematic criteria • Examples of application of fracture mechanics • Use of finite element methods • Software features, examples

Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following:
	
	<u>Knowledge / Understanding:</u>
	The students will understand:
	• the physical effects leading to failure of structures and mechanical systems. This includes:
	    • excessive elastic deformations,
	    • buckling of load carrying elements,
	    • permanent plastic deformations,
	    • material damage,
	    • initiation and propagation of cracks
	• limit and shakedown theories, failure of structures and mechanical systems under monotonic and cyclic loads and determination of corresponding load-carrying capacities
	• the phenomenon of fracture and determination of critical loads for crack propagation
	• the most important failure types and their numerical description
	
	<u>Abilities / Skills:</u>
	The students will be able to
	• a) determine limit loads for structures
	• b) model the phenomenon of fracture and determine critical loads for crack propagation
	• c) transfer theoretical and mathematical models to actual engineering problems and implementation into design codes

	• d) apply State-of-the-art numerical methods for the use of failure criteria in applied mechanical engineering The exercises are integrated in the lecture so that the students work individually or in groups on practical examples.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Lecture Notes • J. Lemaitre, J.-L. Chaboche: Mechanics of materials, Cambridge University Press, Cambridge, 1994 • J.A. König: Shakedown of elastic-plastic structures, Elsevier, Amsterdam, 1987
Language	English
Examination Terms	Written Examination
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Bernd Markert
ECTS Credits	5
Contact time (WSH)	2
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	30,0
Self-study hours (h)	120,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Failure of Structures and Structural Elements (401148601)	2nd semester	no semester recommended	5	0

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Failure of Structures and Structural Elements	2nd semester	no semester recommended	-	2

Module titel	Advanced Finite Element Methods for Engineers (Compulsory subject)
Identifier	4013866
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2018
Valid until	-
Module level	Master
Content	Content • General introduction, concept of the finite element method • Symbolic assembly procedure • Global and local coordinates • Stiffness matrix for trusses / coordinate transformation • Variational techniques • Solution of truss structures • Variational techniques, Euler-Lagrange equation • Natural and forced boundary conditions • Multiple integrals, Gauss-Theorem • Variations of elementary algebraic functions • Variational principle for linear self-adjoint diff. operators • Solution of some classical variational problems • Principle of virtual work as a weak form of the momentum balance, variational principles of mechanics (Lagrange, Hu-Washizu) • Differential equation of a linear elastic bar, analytic solution for various load cases • Rayleigh-Ritz method, weighted residual approximations, Point or subdomain collocation • Galerkin method, least-squares method, linear elastic bar approximated by a continuous shape function • Displacement formulation • Three-field (mixed) formulation • Examples to weighted residual approximations • Requirements to shape functions • Continuous shape functions, piecewise defined shape functions, approximation by piecewise defined shape functions. • 2-d problems of elasticity, triangular element, plain strain and plane stress problems, • Torsion of a prismatical bar • Examples for plain strain and plane stress problems discretized by linear triangular elements

	• Axisymmetric stress analysis, 3-d stress analysis • Construction of 2-d and 3-d finite elements (Lagrange and serendipity family) • Concept of hierarchical shape functions • Concept of mapping in iso-parametric finite elements • Application of numerical integration in 1-d, 2-d and 3-d finite element problems • Non-linear finite element problems (Newton-Raphson method) • Dynamic (time-dependent) finite element problems, time step size and mass scaling
Learning Objectives/ Learning Outcomes	The aim of the course is to impart the basic knowledge about finite element methods and their application to solid and structural mechanics. The students will • understand why the FE-Method and the other numerical methods behind are important for engineering practice • understand the basic concept of FEM • be able to find solutions for trusses with a variety of boundary conditions • understand the fundamental concept of variational calculus • be able to find solutions for mechanical problems by using weighted residual methods • be able to use finite element method for plane strain, plane stress and torsion problems • be able to construct finite elements with linear and non-linear shape functions • understand the application of numerical integration in finite element method • understand the concept of non-linear and time-dependent finite element problems In addition, voluntary programming exercise sessions are offered to deepen the theoretical understanding. A simple FEM solver is developed in Python, numerical integration schemes are discussed and the FEniCS programming package is introduced.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Advanced Finite Element Methods for Engineers (401386601)	1st semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Advanced Finite Element Methods for Engineers	1st semester	no semester recommended	-	2
Tutorial Advanced Finite Element Methods for Engineers	1st semester	no semester recommended	-	2

Module titel	Numerical Methods in Mechanical Engineering (Compulsory subject)
Identifier	4011449
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2014
Valid until	-
Module level	Master
Content	The content of the course is to provide a map to follow the long and winding road from intuitional perception to the mathematical formulation of engineering problems. The content is summarized as follows: • Selected assumptions and mathematical tools to formulate problems • An overview of several solution methods: analytical solutions, approximate solutions, direct approximation, approximate solution after transformation of the problem • An overview of selected types of physical problems: discrete systems, continuous systems, equilibrium problems, eigenvalue problems, propagation problems • Integral formulations • Weak formulation of problems • The Method of Weighted Residuals • Introduction to variational calculus • Functionals • Functionals associated with an integral form • The stationarity principle • Stationarity conditions • Examples from mechanics • The method of Lagrange multipliers • Mixed and complementary formulations • Catalogue of functionals used in continuum mechanics and their specific features • Discretisation of integral forms • Collocation by points • Collocation by subdomains • Galerkin’s method Least Squares Method Examples • Ritz' method • Examples • Numerical integration • Newton-Cotes method • Gauss method Examples: • The Finite Element Method, Shape functions, construction of finite elements • Matrix representation in the FEM, Stiffness matrix, Boundary conditions • Examples from structural engineering, Software packages in engineering
Learning Objectives/ Learning Outcomes	Overall goal: The students will gain theoretical background of numerical methods commonly used in mechanical engineering. In particular, the physical formulations are discussed based on which the corresponding mathematical formulations for large-scale numerical methods are presented. In this course, students shall acquire the following:

	Knowledge / Understanding The students will understand • the theoretical foundations of current numerical methods in engineering • the bridge between the physical formulation of a problem and the mathematical description suited to implement numerical approximation methods • the steps and transformations required to implement numerical methods Abilities / Skills The students are able to • apply approximation techniques and analyse the results obtained by various numerical methods • use their acquired knowledge to develop state-of-the-art approximation methods • critically judge the consistency and correctness of numerical methods • apply variational methods to obtain formulations of a problem of differential equations • construct basis functions compatible with the boundary conditions • construct and apply a variety of approximation methods based on the WRM (collocation by points, collocation by subdomains, Galerkin's method, least squares method, Ritz method) • solve constrained optimization problems by using the Lagrange Multipliers Method • construct the associated energy potential and to apply the stationary principle for a conservative mechanical problem • apply basic tools of numerical integration
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Lecture Notes • Dhatt, G., Touzot, G.: The Finite Element Method Displayed. Wiley, New York, 1984. • Finlayson, B.A.: The Method of Weighted Residuals and Variational Principles. Academic Press, New York, 1972. • Reddy, J.N.: Energy and Variational Methods in Applied Mechanics. Wiley, New York, 1984. • Lemaitre, J., Chaboche, J.-L.: Mechanics of Materials, Cambridge Univ. Press, Cambridge, 1994. • König, J.A.: Shakedown of Elastic-Plastic Structures. Elsevier, Amsterdam, 1987.
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Bernd Markert Dr. rer. nat. Michael Ban
ECTS Credits	7
Contact time (WSH)	5
Examination duration (min)	-
Total hours (h)	210,0
Contact hours (h)	75,0
Self-study hours (h)	135,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Numerical Methods in Mechanical Engineering (401144901)	1st semester	no semester recommended	7	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Numerical Methods in Mechanical Engineering	1st semester	no semester recommended	-	3
Tutorial Numerical Methods in Mechanical Engineering	1st semester	no semester recommended	-	2

Module titel	Continuum Mechanics (Compulsory subject)
Identifier	4013360
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2010
Valid until	-
Module level	Master
Content	• Material bodies, configuration, coordinates • Rigid body motion • Deformation gradient • Deformation of surface and volume elements • Strain, stretch and shear • Spectral decomposition of strain tensors • Strain invariants • Polar decomposition of the deformation gradient, stretch tensors • Strain measures • Velocity gradient • Cauchy stress tensor • Linear momentum balance • Scalar form of the linear momentum balance • Rotational momentum balance • Balance of mechanical energy • Work-conjugate stress-strain pairs • General principles of the constitutive theory, Noll axioms • Change of frame, objectivity • General constitutive relation, simple materials • Elastic materials • Material symmetry, isotropic materials • Hyperelastic materials • Mock-Examination
Learning Objectives/ Learning Outcomes	During the course, the students will obtain knowledge of the principles of continuum mechanics and exercise the subject matter by considering realistic problems. In particular, attending students will • learn how to describe the state of strain and stress in a material body that undergoes large elastic deformations • calculate the usual strain and stress tensors • understand and apply the principle of balance equations • understand the principles of the constitutive theory • learn to apply material laws • be able to read scientific literature on continuum mechanics. Throughout the course, the students will use and practice the nowadays usual absolute notation for tensors. Furthermore, examples based on Cartesian and curvilinear coordinates will be considered.
(Study-Specific) Prerequisites	-
(recommended) Requirements	recommended: • Module *Tensor Algebra and Tensor Analysis for Engineers I*
References	• Ogden, R.W. Non-linear Elastic Deformations, Ellis Harwood Ltd. (1984) • Basar, Y., Weichert D. Nonlinear Continuum Mechanics of Solids, Springer (2000)

+ Continuum Mechanics (4013360)

Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Continuum Mechanics (401336001)	2nd semester	no semester recommended	5	0
Exercise Continuum Mechanics (401336002)	2nd semester	no semester recommended	0	2

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Continuum Mechanics	2nd semester	no semester recommended	-	2

Module titel	Multibody Dynamics (Compulsory subject)
Identifier	4011462
Version	V1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2020
Valid until	-
Module level	Master
Content	• Introduction • Fundamentals • Fields of application • Model Building • Methods of Approach for Equivalent Models • Multi-body Systems • General mathematical description • Kinematics of Multi Body Systems • Position and Orientation of Bodies • Translational Kinematics • Rotational Kinematics • Equations of Motion • Lagrangian Equations of 2nd Kind • Newton-Euler equations • Lagrangian Equations of 1st Kind • Eigen Value Approach • Undamped non-gyroscopic systems • Damped gyroscopic systems • Eigen Value Stability Criteria Linear Systems with Harmonic Excitation • Real Frequency Matrix • Complex Frequency Matrix • State Equation • System Matrix • Eigen Value Approach • Fundamental Matrix • Modal Matrix • Theorem of Cayley-Hamilton • Analytical Solution • Numerical Solution • Step Excitation • Harmonic Excitation • Periodical Excitation Example • Modelling • Calculation • Evaluation
Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: Knowledge / Understanding: Students: • shall have a profound knowledge of theory of vibrations. • shall be capable of comprehending, describing and analyzing vibratory systems.

	• shall be familiar with the most important matrix based procedures for the calculation of eigenmotions and the behaviour of linear systems under forced excitations. Abilities / Skills: Students • shall have the ability of describing mathematically any mechanical system with its inherent physical effects like elasticity, damping and friction. • shall be able to properly interpret simulation results especially under consideration of simplifications within the model compared to the real system. Competencies: Students • shall be able to derive from their knowledge the necessary methods and proceedings for the analysis and synthesis of the systems in regard. • shall be capable to solve - accessing their acquired theoretical knowledge - complex problems concerning the choice and design of industrial vibratory systems.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Lecture Notes • Students also receive a list of relevant literature
Language	English
Examination Terms	Written/Oral Examination (Depending on registration numbers)
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Dr. h. c. Burkhard Corves
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Multibody Dynamics (401146201)	2nd semester	no semester recommended	5	0

▲Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Tutorial Multibody Dynamics	2nd semester	no semester recommended	-	2
Lecture Multibody Dynamics	2nd semester	no semester recommended	-	2

Module titel	Artificial Neural Networks in Structural Mechanics (Compulsory subject)
Identifier	4021387
Version	V1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2019
Valid until	-
Module level	Master
Content	Classical structural mechanics is based on continuum mechanics using tensor calculus, differential geometry, and modelling of inelastic material behaviour. This theoretical approach established in the 20th century is the basis for finite element programs widely used in industry and science. Innovative approaches by means of artificial neural networks are known to be very efficient to describe complex mathematical dependencies. This effect relies on the self-learning ability of neural networks to reproduce dependencies between mechanical quantities such as stresses, strains, or other state variables. However, the neural network is based on experience and has therefore tobe trained by experimental or numerical data. Once the neural network has been trained, it is able to predict structural deformations in shorter calculation times than by using classical numerical approaches. Also the accuracy does not suffer, even though that program codes of neural networks are shorter than classical finite element codes. In order to apply the new knowledge on practical examples, the students will learn how to develop a virtual copy of the engineering structure by means of a neural network. Here, a wide variety of components in the network with different layers, neurons, activation functions etc. is available and must be ordered for the application. Special attention is focused on the combination of artificial neural networks with the finite element method. Following this approach, advantages of mesh generation and equation solvers in finite element programs are used and parts of the classical mechanical models are replaced by neural networks. E.g. material models are substituted by trained neural networks leading to shorter simulation times. Due to the fact that artificial neural networks are becoming more widespread in engineering disciplines, students will be familiar with this new trend in simulation methods after visiting this course. They will gain the competences to support the development of neural network enhanced modelling and simulation in industrial and scientific applications.
Learning Objectives/ Learning Outcomes	The aim of the course is to enable students to work with artificial neural networks from the viewpoint of engineering science. This implies to understand different network topologies and their applications in structural mechanics. Classical structural models will be replaced by artificial neural networks partly or completely depending on the current problem. After successfully completing this course, the student will have acquired the following learning outcomes: Knowledge / Understanding: Students: • shall understand the topology of artificial neural networks • are to gain an overview and learn motivation of network architectures (weights, bias-terms, sensilivity analysis) • are to understand different network topologies and their applications in structural mechanics • shall describe mathematical models of artificial neural networks • are to describe possible applications of artificial neural networks in structural mechanics • shall model structures enhanced by neural networks • shall program artificial neural networks • are to find solutions for differential equations approximated by neural networks • shall develop intelligent elements and know the processes behind neural network enhanced finite element simulatios

	Abilities / Skills Students: • are expected to apply artificial neural networks for numerical predictions in structural mechanics • shall program neural networks and train them by data gained from experiments or simulations • shall train artificial neural networks by means of measurement and simulation data • shall model inelastic material behaviour with artificial neural networks • are expected to apply the enhancement of finite element simulation by neural networks Competencies: Students: • shall develop intelligent elements by combining neural networks with the finite element method • are to increase the efficiency of structural calculations towards faster simulations and new structural models without material parameters trained just by experimental or simulated data • are expected to choose, depending on the current problem, whether to replace classical structural models partly or completely by artificial neural networks • shall work with artificial neural networks from the viewpoint of engineering science
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: • Mechanik I-III • Nonlinear Structural Mechanics
References	• Lecture Notes • Empfohlene weiterführende Literatur: A. Engelbrecht, Computational lntelligence, An lntroduction, JohnWiley Literatur & Sens, Ltd, 2007.
Language	English
Examination Terms	An oral or a written exam
Miscellaneous	-
Module coordinator	Prof. Dr.-lng. Marcus Stoffel
ECTS Credits	6
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	180,0
Contact hours (h)	60,0
Self-study hours (h)	120,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Prüfung Artificial Neural Networks in Structural Mechanics (402138701)	3rd semester	no semester recommended	6	-

▲Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Artificial Neural Networks in Structural Mechanics	3rd semester	no semester recommended	-	2
Exercise Artificial Neural Networks in Structural Mechanics	3rd semester	no semester recommended	-	2

Module titel	Advanced Software Engineering (Compulsory subject)
Identifier	4011468
Version	V2_neu
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2022
Valid until	-
Module level	Master
Content	The aim of the course is to explain students for what purposes, under which conditions and with which consequences computer systems are used for the solution of problems related to Mechanical Engineering.Within the first part of the course the steps from problem description to the final software solution are illustrated. This covers the topics modelling, problem elicitation and analysis, program design and an introduction to UML (Unified Modelling Language) and implementation in C++ Java. Then the course goes on with a closer examination of the various aspects which comprise software development, concerning topics like design patterns, agile software processes and project management. Parallel to the lecture the students are given the chance to employ the theoretical input from the course in small software projects. After an introduction to Java and object-oriented programming, the students stepwise pass through the particular stages of a software development process.
Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: Knowledge / Understanding: Students • are to gain solid knowledge in the Software Development Life Cycle and also the main activities and core concepts in different software development phases. Abilities / Skills: Students • shall have the ability to transfer the acquired knowledge in object - oriented design to different engineering problems and understand the general structure and the functionality of software.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: • Basic knowledge in a programming language (e.g. C, C++, Java, Python)
References	• Bruegge, B.; Dutoit, A. (2009): Object-Oriented Software Engineering • Using UML, Patterns and Java. Boston: Pearson. • Sommerville, I. (2010): Software engineering. Boston: Pearson
Language	English
Examination Terms	Written or oral Examination (100 %)
Miscellaneous	-
Module coordinator	Dipl.-Inform Daniel Lütticke
ECTS Credits	5

Contact time (WSH)	-
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	-
Self-study hours (h)	-

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Advanced Software Engineering (401146801)	1st semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Advanced Software Engineering	1st semester	no semester recommended	-	2
Tutorial Advanced Software Engineering	1st semester	no semester recommended	-	2

Module titel	Computational Intelligence in Engineering (Compulsory elective subject)
Identifier	4021493
Version	V1_neu
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2022
Valid until	-
Module level	Master
Content	The elective course “Computational Intelligence in Engineering“ is available for students enrolled in the engineering Master programs of RWTH Aachen University. It provides an overview over recent applications of computational intelligence and deep learning that are relevant to engineering. The first half of the course content is a theoretical introduction into the topic of machine learning in engineering and programming fundamentals in Python. In the second half of the course, the students apply their gained knowledge in project-based learning. The course will be taught interactively, engaging the students using practical example projects. The following topics are covered: • Time-variant dynamic processes from simulations or experiments • Data acquisition and pre-processing • Machine learning algorithms and neural network models • Advanced neural networks architectures • Project-specific engineering problems • Programming fundamentals in Python for data-driven procedures
Learning Objectives/ Learning Outcomes	The course curriculum consists of interactive seminar lectures accompanied by semester project works. During the seminar lectures, the students will receive the necessary theoretical information and supervision to independently plan, advance and complete the projects in small groups. In addition, the seminars offer the opportunity to discuss challenges and problems arising during projects. Finally, the achievements and results obtained within the student projects will be presented by the students in the scope of the seminar lectures and the accompanying computer lab exercises. <u>Knowledge / Understanding</u> The students will understand • current trends in computational intelligence and their theoretical foundation in the context of engineering applications • the advantages of machine learning algorithms in engineering but also the limits of the methods and when better not to use them <u>Abilities / Skills:</u> The students will be able to • apply machine learning methods to a wide variety of engineering Problems • transfer their knowledge to new engineering applications in science and industry via the practical expertise gained • evaluate the merits and limitations of machine learning methods applied to computer aided engineering problems
(Study-Specific) Prerequisites	-
(recommended) Requirements	Programming experience is advantageous, preferably the language Python.
References	• Goodfellow, I., Bengio, Y., Courville, A., 2016. Deep Learning. MIT Press.

	• Keller, J.M., Liu, D., Fogel, D.B. , 2016. Fundamentals of Computational Intelligence. IEEE Press, Wiley.
Language	English
Examination Terms	Written Examination or Oral Examination (100 %)
Miscellaneous	-
Module coordinator	Univ.-Prof. Dr.-Ing. Bernd Markert
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0
Self-study hours (h)	105,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Computational Intelligence in Engineering (402149301)	3rd semester	no semester recommended	5	-

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture "Computational Intelligence in Engineering	3rd semester	no semester recommended	-	2
Exercise Computational Intelligence in Engineering	3rd semester	no semester recommended	-	1

Module titel	Computational Fluid Dynamics I (Compulsory elective subject)
Identifier	4012278
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2010
Valid until	-
Module level	Master
Content	• Introduction to CFD • Examples of flow simulatiaons • The basic PDE's of Fluid Mechanics • Different Notations • Physical meaning of characteristic lines • Determination of the type of PDE's • Characteristic form of PDE's • The basics of discretization of partial differentials • Truncation error and consistency • Solution schemes for scalar equations • Stability analysis of initial value problems • Discrete disturbance theory • von Neumann ananlysis • CFL-condition • Hirt's stability analysis • Introduction to the numerical solution of boundary value problems • Classical iterative solution methods, Jacobi, Gauß-Seidel methods • Convergence of iterative solution methods • ILU, Krylov subspace methods • Multigrid methods • Transformation of PDE's in curvlinear coordinates • Truncation error on curvelinear grids • Discretization on different unstructured meshes, solution adaptive methods • Triangle or tetrahedral based meshes • Hierarchical Cartesian meshes • Vectorization and parallelization of solution algorithms • Different applications and examples
Learning Objectives/ Learning Outcomes	• Knowledge of the partial differential equations (PDE'S) of fluid mechanics • Basics of the discretization of PDE's • Learn how to formulate numerical methods for the solution of PDE's • Ability to determine und understand the properties of truncation errors of numerical solution schemes • Understand stability and sonsistency of solution schemes • Solution of boundary value problems with iterative solution schemes • Discretization on different mesh types • Implementation of solution schemes on different computer architectures • The discussion of several examples of numerical flow simulation allows to understand different theoretical aspects in proactical mpplications
(Study-Specific) Prerequisites	-
(recommended) Requirements	recommended: • Basic knowledge in advanced mathematics • Basic knowledge in thermodynamics
References	• C.A. Fletcher: Computational Techniques for Fluid Dynamics Vol I+II, Springer Verlag, 1988

	• J.R. Anderson: Computational Fluid Dynamics, MacGraw-Hill, 1955 • C. Hirsch: Numerical Computation of Internal and External Flows, J. Wiley &; Sons, 1988 • P.J. Roache: Fundamentals of Computational Fluid Dynamics, hermosa publishers, Albuquerque
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Wolfgang Schröder
ECTS Credits	4
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	120,0
Contact hours (h)	45,0
Self-study hours (h)	75,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Computational Fluid Dynamics I (401227801)	2nd semester	no semester recommended	4	0

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exercise Computational Fluid Dynamics I	2nd semester	no semester recommended	-	1
Lecture Computational Fluid Dynamics I	2nd semester	no semester recommended	-	2

Module titel	Porous Media Mechanics (Compulsory elective subject)
Identifier	4013372
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2016
Valid until	-
Module level	Master
Content	Porous solids with a fluid pore content as well as real mixtures of liquids and gases belong both to the class of multi-phase materials. With a continuum theory for multiphasic media, the movement of flow of fluids in deformable porous solids can be describes for arbitrary deformation processes and arbitrary material properties of the solid matrix. Moreover, it is possible to consider phase transitions and electrochemical reactions within such a theory. In this regard, a theoretical tool is to provided that can be uses to mathematically describe and numerically analyse a manifold of distinct materials, ranging from geomaterials over polymer and metal foams to biological tissues. For the numerical application, a system of strangly coupled partial differential equations has to be solved. - Continuum-mechanical basics for the description of single- and multiphasic materials: state of motion, deformation measures, stress states - Balance relations for multi-phase materials: master balances, special balances for mass, momentum, moment of momentum, energy and entropy - Caloric state variables and energy potentials - Fundamentals of materials theory for multiphasic media: Thermodynamics and constitutive equations - The fluid-saturated, materially incompressible deformable porous solid - Hydraulics in porous materials, Darcy and Forchheimer filter law - Elastic and inelastic material properties of the solid skeleton
Learning Objectives/ Learning Outcomes	The students are able to apply continuum-mechanical methods to multiphasic and porous materials. They understand the character of strongly coupled equation systems for the description of complex phenomena in multi-component materials and mixtures.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Basic knowledge in Mathematics a. Successfully passed modul Biomechanics/Fluid Mechanics from the 1st semester. Recommended: - Continuum Mechanics (Prof. Itskov) - Selected topics of Inelasticity Theory (Prof. Markert)
References	- de Boer, R.: Theory of Porous Media, Springer Verlag, Berlin 2000 - Ehlers, W.: Grundlegende Konzepte in der Theorie Poröser Medien, Technische Mechanik 16 (1996), 63-76 - Ehlers, W.: Foundations of multiphasic and porous materials. In Ehlers, W. &; Bluhm, J (eds.): Porous Media: Theory, Experiments and Numerical Applications. Springer-Verlag, Berlin 2002, pp. 3-86 further reading: - Markert, B.: A biphasic continuum approach for viscoelastic high porosity foams: Comprehensive theory, numerics and application. Archives of Computational Methods in Engineering 15 (2008), 371-446 - Markert, B.: Coupled thermo- and electrodynamics of multiphasic continua. In Advances in Extended and Multifield Theories for Continua, Lecture Notes in Applied and Computational Mechanics, Markert, B., ed., Springer, Berlin 2011, vol.59, pp. 129-152
Language	English
Examination Terms	Written exam : Duration 120 Minutes or an Oral Exam: Duration 30 Minutes The mark of the module is equivalent to the mark of the exam.

+ Porous Media Mechanics (4013372)

Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Bernd Markert
ECTS Credits	4
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	120,0
Contact hours (h)	60,0
Self-study hours (h)	60,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Porous Media Mechanics (401337201)	2nd semester	no semester recommended	4	0
Exercise Porous Media Mechanics (401337202)	2nd semester	no semester recommended	0	2

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Porous Media Mechanics	2nd semester	no semester recommended	-	2

Module titel	Practical Introduction to FEM-Software I (Compulsory elective subject)
Identifier	4012292
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master
Content	• General introduction, development of FEM program, ANSYS (graphical interface) Modeling and calculation of frameworks with ANSYS Modeling of beam structures ANSYS commandos, Working with input data Post processing for beam elements • General introction in FEM program CALCULIX Modeling and calculation of beam structures with CALCULIX Data exchange between ANSYS - CAlCULIX • Introduction in 2D modeling with ANSYS (part 1) 2D element types, free networking, boundary conditions, network density, post processing Commandos for 2D modeling in CALCULIX boundary conditions, network density, post processing • Introduction in 2D modeling with ANSYS (part 2) Structured networking (mapped mesh), “bottom up”-/ “top down” – approach ANSYS commandos for heat transfer problems • APDL, Element types, boundary conditions, h- and p-method Post processing, estimation of errors • ANSYS 3D modeling (part 1), geometry creation, selection and grouping commands • 3D models (part 2), ANSYS- and CALCULIX commandos, 3D element types • 3D models (part 3), ANSYS- and CALCULIX commandos, extrusion of 2D models. • Project work, modeling • Project work, modeling, calculation, post processing • Project work, documentation, report • Revision course
Learning Objectives/ Learning Outcomes	Fachbezogene Lernziele: Providing an overview and introduction to Finite Element Software The students will: • Have sufficient practical and theoretical knowledge for the use of ANYSS and CALCULIX • be able to create smaller 2D and 3D FE models • be able to solve linear structural and heat transfer problems • Understand the concept of “Solid Modelling” and networking • Know the most important commands for creating input files • Know how to define boundary conditions and loading cases • Be able to test smaller FE models and to analyze possible errors • Be able to critically review the computing results in the post processor • Be able to deduce practical construction instructions from an FE calculation Nicht fachbezogene Lernziele: The students will • learn to work on a task in a team and to document and present the results in the form of a report • learn how to analyze problems • learn how to develop solutions and to evaluate them
(Study-Specific) Prerequisites	-
(recommended) Requirements	Empfohlene Voraussetzungen (z.B. andere Module, Fremdsprachenkenntnisse, …): • Command of English Voraussetzung für (z.B. andere Module, ...): • Practical Introduction to FEM-Software II
References	• Script • Online documentation, user handbooks
Language	English
Examination Terms	Practical Introduction to FEM-Software I

Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0
Self-study hours (h)	105,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Practical Introduction to FEM-Software I (401229201)	1st semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Vorlesung/Labor Practical Introduction to FEM-Software I	1st semester	no semester recommended	-	-

Module titel	Practical Introduction to FEM-Software II (Compulsory elective subject)
Identifier	4011498
Version	-
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2012
Valid until	-
Module level	Master
Content	• Time depending Problems, multi load steps, sub modeling. • Sub modeling • Non-linear Material, Plasticity • Non-linear Material, rubber-like materials, viscoelastic • Composite materials. • Solver for non-linear problems. • Contact problems part 1, coupling and constraint equations. • Contact problems part 2, CAD-Import. • Harmonic response • Modal analysis • Death and birth option, harmonic response. • Multiphysics problems 1, heat transfer, voltage. • Multiphysics problems 2, heat radiation. • Repetitorium
Learning Objectives/ Learning Outcomes	In part II of the course the considered examples are extended to nonlinear problems and applications. The students will • obtain an overview about various kinds of FE calculations. • obtain an understanding for the difficulties of nonlinear calculations. • be able to calculate nonlinear problems with ANSYS and CALCULIX.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: Practical Introduction to FEM-Software I
References	-
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0

+ Practical Introduction to FEM-Software II (4011498)

Contact hours (h)	45,0
Self-study hours (h)	105,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Practical Introduction to FEM-Software II (401149801)	2nd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Tutorial Practical Introduction to FEM-Software II	2nd semester	no semester recommended	-	2
Lecture Practical Introduction to FEM-Software II	2nd semester	no semester recommended	-	1

Module titel	Modeling, Model Reduction and Simulation in Laser Processing - Laser (Compulsory elective subject)
Identifier	4013863
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master
Content	• overview of contents, definition of the 10 learning targets • the constribution of the engineer to the interactive cooperation of scientific disciplines • main features of the theory of cognition (Karl Popper) • laser radiation, Helmholtz equation, reduced model: SVE-approximation • Learning target 1:gaussian beam, beam guiding and forming • reflection, transmission and absorption of light • Learning target 2:reduced model of the Fresnel Formulae for the limiting case of small discplacemant current, optical parameters • technical task and examples: cutting with laser radiation • Learning target 3:quality features of the high quality cut • physical task of cutting and identification of quality defined processing domains • Learning target 4:relation of physicl phenomena to built up of quality degradations • technical task and examples: drilling with laser radiation • physical task and 5 dominant phenomena • Learning target 5: quality features of the drilled hole • mathematical modelling Ia: time scales • degrees of freedom in phase space of dependent variables • separation of time scales in simple dynamical systems • Learning target 6a: separation of time scales • mathematical modelling Ib:length scales • thermal boundary layer in heat conduction with moving boundaries • Learning target 6b: separation of length scales • mathematical modelling IIa: Free Boundary Problems (FBP) for the solid phase • reduced model for the FBP: motion of the melting front, integral methods, variational formulation • Learning target 7: heating and melting phase of ablation • mathematical modelling IIb: FBP for the liquid phase • Navier-Stokes equations, material equations and boundary values • mathematical model reduction: melt flow • reduced model for thin film flow • Learning target 8: boundary character, integral and spectral methods • model reduction and solution with controlled error: melt flow at low Reynolds-number • structural stability of the reduced model: lubrication approximation, fingering and droplet formation • Learning target 9: creeping flow and expansion with respect to the Reynolds-number, exact solution of a model problem for arbitrary Reynolds-number • global properties of the solution of balance equations for mass, momentum and thermal energy • Learning target 10: scales for the choice of processing parameters in cutting and drilling • concluding discussion of the learning targets • actual research and development of laser processing
Learning Objectives/ Learning Outcomes	The students obtain scientific skills for the application of: 1. Free Boundary Problems and integral methods of solution, 2. non-linear stability analysis using spectral methods, 3. analysis of the structural stability of model equations and • know the least 3 types of laser systems, temporal and spatial distribution of laser radiation, Fresnel-number, invariant quantity of light propagation

	• understand the structure of solution for the Helmholtz-equation, diffraction, 5 parameter pairs of optical material equations, transmission, reflection, absorption, Fresnel Formulae, polarisation of matter and radiation • know and understand the 5 different, dominant phenomena of drilling, welding and cutting with laser radiation • know the physical meaning of the terms contained in the Navier-Stokes equations for mass, momentum and energy balance • know the main properties of the solution in the asymptotic case of thin film flow (boundary layer) and can explain the relation between dynamical properties of the solution and quality features of the product as well as productivity of the process for drilling and cutting • know the effect of dissipation in disctributed dynamical systems (inertial manifold) and know examples for the application of methods for the reduction of the dimension in dissipative systems, understand and perform the separation of length and time scales in simple systems The students get to know non-scientific tasks: • understand the interactive cooperation of scientists from engineering, physics and mathematics for application of model based methods for diagnosis in laser processing • Application of model based methods for solving practical tasks from discussion of project examples
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr. rer. nat. Wolfgang Schulz
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Modeling, Model Reduction and Simulation in Laser Processing - Laser (401386301)	2nd semester	no semester recommended	5	0

▲Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Modeling, Model Reduction and Simulation in Laser Processing - Laser	2nd semester	no semester recommended	-	2
Exercise Modeling, Model Reduction and Simulation in Laser Processing - Laser	2nd semester	no semester recommended	-	2

Module titel	Finite Element Methods in Lightweight Design (Compulsory elective subject)
Identifier	4011464
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2015
Valid until	-
Module level	Master
Content	1: Introduction • Energy methods • Ritz method • General procedure of FE analysis 2: Selection criteria in Finite Element Methods • Beam elements: Shear flexible beams • Element locking • Reduced integration 3: Stability analysis • Stability behaviour of lightweight structures • Linear stability 4: Introduction to nonlinear analysis • Types of nonlinearity • Degradation/damage models • Material nonlinearity • Composites 5: Dynamic problems • Fundamental equations for dynamic problems • Solution for free vibrations (eigenvalue problems) • Modal superposition 6: Implicit and Explicit analysis • Integration in the time domain • Crash and Impact • Iteration procedures

Learning Objectives/ Learning Outcomes	After successfully completing this course, the students will have acquired the following learning outcomes: <u>Knowledge / Understanding</u> Students a) know the mechanical and mathematical relations used in the Finite Element Method. b) understand the structural problems to be solved and the underlying fundamentals of the solution methods that are provided by commercial codes. <u>Skills and Competencies</u> Students a) are able to apply the Finite Element Method in structural mechanical applications properly in order to achieve reliable numerical results for problems of lightweight design. b) · are able to analyse the structural mechanics Finite Element models according to the desired field of application, taking the assumptions of solution methods into account. · have learned to work with FE codes and to find those solutions from the software handbook that are suited best for the investigated structural problem. · are able to interpret the achieved numerical results and evaluate their correctness.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: • Mechanics I, II, III • Numerical Mathematics
References	· Zienkiewicz, O.C.; Taylor, R.L.:The Finite Element Method Vol. 1+2+3 McGraw-Hill · Belytschko, T; Liu, W.K., Moran, B.: Nonlinear Finite Elements for continua and Structures John Wiley LtdCrisfield, M.A.:Non-linear Finite Element Analysis of Solids and Structures Vol. 1 John Wiley Ltd · Crisfield, M.A., Non-linear Finite Element Analysis of Solids and Structures Vol. 1 John Wiley Ltd
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Kai-Uwe Schröder
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0
Self-study hours (h)	105,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Finite Element Methods in Lightweight Design (401146401)	2nd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Tutorial Finite Element Methods in Lightweight Design	2nd semester	no semester recommended	-	1
Lecture Finite Element Methods in Lightweight Design	2nd semester	no semester recommended	-	2

Module titel	Modeling, Model Reduction and Simulation in Laser Processing - Applications (Compulsory elective subject)
Identifier	4013864
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master

Content	• overview of contents, definition of the learning targets
	• ecapitulation of the 10 learning targets from part I of the course
	• derivation and consolidation of the application of integral methods for treating heat conduction with Stefan-type boundary conditions
	• Learning target 1: variational formulation compared with direct integration for one space variable, spectral methods for error control of integral methods: spatial one-dimensional model problem, Eigenfunctions of differential operators, spectral decomposition of non-linear problems, discrete and continuous spectra
	• Learning target 2: separation of variables and relation to spectral methods, applications of spectral methods, asymptotic expansion of partial differential equations and their solution applied to a model problem of heat conduction
	• Learning target 3: identification of characteristic dynamical variables, degrees of freedom of an inertial manifold, determination of dimensionless groups, Buckingham's Pi-theorem, definition and physical meaning of Peclet-, Reynolds-, Marangoni- and Stefannumber.
	• Learning target 4: physical interpretation of dimensionless groups of system parameters and the dimension in phase space of processing parameters, optical modes in passive fibers, numerical aperture, total reflection, maximum mode-number, coupling of modes, optical excitation in active fibers and dissipation
	• Learning target 5: Slow surfaces in dynamical systems, Application of time scale separation
	• Learning target 6: thermal effects of large and small Peclet-number, model problems in thin film flow, applications of spectral methods:
	    • formation of pores in welding, closure of the drill hole
	• Learning target 7: relation of time scales and the onset of quality features, modelling evaporation and recondensation of metals I, comparison of models from Aden and Aoki &; Sone
	• Learning target 8: liquid-vapor phase transition in drilling and welding, modelling evaporation and recondensation of metals, Laplacepressure, evaporation and recondensation as driving forces for momentum of the liquid by pressure gradients
	• Learning target 9: boundary conditions for momentum at ideal surfaces,
	• technical examples:
	    • drilling with laser radiation, welding with laser radiation, concluding discussion of learning targets
	• actual research and development of laser processing

Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: <u>Knowledge / Understanding:</u> Students shall obtain understanding about the applications of: 1. Free Boundary Problems and integral methods of solution, 2. analysis of dynamical stability, non-linear stability analysis using spectral methods, 3. analysis of the structural stability of model equations. <u>Abilities / Skills:</u> Students

	• shall obtain scientific skills for the application of free Boundary Problems and integral methods of solution, non-linear stability analysis using spectral methods and for the analysis of the structural stability of model equations. • shall be able to determine the maximum number of dimensionsless groups of Boundary Value Problems. • shall understand the relation of boundary conditions, boundary values and the structure of solution for the Navier-Stokes equations. • shall know and understand the 5 different, dominant phenomena of drilling, welding and cutting with laser radiation. • shall know and be able to explain the physical meaning of the Navier-Stokes equations. • shall know the main properties of the solution in the asymptotic case of thin film flow (boundary layer) and shall be able to explain the relation between dynamical properties of the solution and quality features of the product as well as productivity of the process for drilling and cutting. • shall know the effect of dissipation in distributed dynamical systems (inertial manifold) and shall know examples for the application of methods for the reduction of the dimension in dissipative systems. • shall understand and perform the separation of length and time scales in simple systems. • shall understand the interactive cooperation of scientists from engineering, physics and mathematics for application of model based methods for diagnosis in laser processing.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: • Modeling, Model Reduction and Simulation in Laser Processing - Laser
References	• Lecture Notes • Students also receive a list of relevant literature
Language	English
Examination Terms	Oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr. rer. nat. Wolfgang Schulz
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Modeling, Model Reduction and Simulation in Laser Processing - Applications (401386401)	3rd semester	no semester recommended	5	0

▲Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exercise Modeling, Model Reduction and Simulation in Laser Processing - Applications	3rd semester	no semester recommended	-	2
Lecture Modeling, Model Reduction and Simulation in Laser Processing - Applications	3rd semester	no semester recommended	-	2

Module titel	Molecular Mechanics and Multiscale Modelling of Materials (Compulsory elective subject)
Identifier	4011511
Version	-
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master
Content	Lectures: Introduction to multi-scale modelling Molecular dynamics - Theoretical background of molecular dynamics - Force-probe molecular dynamics simulations - Compute mechanical properties at molecular level Phase field modelling (finite element modelling) - Theoretical background - Reproduce molecular mechanical properties - Validations Multi-scale modelling - Scale bridging - Bottom-up approach - Applications, e.g., spider silk, nacre Exercises: - Molecular dynamics simulations - Force-probe molecular dynamics simulations - Compute mechanical properties at molecular level, e.g., Young's modulus - Finite element simulations based on force-probe molecular dynamics simulations - Validations - Analysis of multi-phasic materials
Learning Objectives/ Learning Outcomes	Wissen und Verstehen: Molecular Mechanics and Multi-scale Modelling The need for multi-scale modelling comes usually from the fact that the available macro-scale models are not accurate enough, and the micro-scale models are not efficient enough and/or offer too much information. By combining both viewpoints, one hopes to arrive at a reasonable compromise between accuracy and efficiency. Multiscale models allow us to formulate models that couple together models at different scales. Overall goal: Students are able to bridge the wide range of time and length scales of methods that are inherent in a number of essential phenomena and processes in materials science and engineering. After successfully completing this course, the students will have acquired the following learning outcomes: Knowledge / Understanding - understand the theoretical background of both methods, molecular dynamics and continuum mechanics - are able to compute mechanical properties at molecular level - reproduce molecular material behaviour at macroscopic level - perform multi-scale modelling of hierarchical bio-materials - modelling of fracture at atomistic scale Fertigkeiten und Kompetenzen: Abilities / Skills: - able to deal with molecular dynamics simulations at nano-scale level - perform FEM simulations at macro-scale by using nano-scale mechanical properties - able to perform bottom-up approach in efficient way - knowledge of fracture at nano-scale as well as macro-scale Competence:

	- able to deal with interdisciplinary field problems, e. g., nano-scale MD simulations and macro-scale FEM simulations - use the knowledge to explore naturally available hierarchical materials, which outperform artificial materials in terms of mechanical properties - apply contents of the lecture to natural as well as artificial materials
(Study-Specific) Prerequisites	-
(recommended) Requirements	Empfohlene Voraussetzungen: Kontinuumsmechanik (Continuum Mechanics)
References	Rapaport, D. C. The art of molecular dynamics simulation Cambridge University Press, 2004 Frenkel, D. &; Smit., B. Understanding molecular simulation: from algorithms to applications Computational science. Academic Press, 2002 Haupt, P. Continuum Mechanics and Theory of Materials Springer-Verlag, Berlin, 2000 Empfohlene weiterführende Literatur: Allen, M. P. &; Tildesley, D. J. Computer simulation of liquids Clarendon Press, Oxford, 1987 Chadwick, P. Continuum mechanics: Concise theory and problems Courier Dover Publications, 1999
Language	English
Examination Terms	Eine schriftliche oder mündliche Prüfung (abhängig von der Teilnehmerzahl)
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Bernd Markert
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Molecular Mechanics and Multiscale Modelling of Materials (401151101)	3rd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Übung Molecular Mechanics and Multi-scale Modelling	3rd semester	no semester recommended	-	2
Vorlesung Molecular Mechanics and Multi-scale Modelling	3rd semester	no semester recommended	-	2

Module titel	Tensor Algebra and Tensor Analysis for Engineers I (Compulsory elective subject)
Identifier	4012288
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2009
Valid until	-
Module level	Master
Content	• Notion of the vector space • Geometrical illustration of vectors • Examples of vector spaces • Basis and dimension of the vector space • Components of a vector, summation convention • Scalar product of vectors, Euclidean space • Orthonormal basis • Dual basis • Second-order tensor as a linear mapping • Right and left mapping • Tensor product • Representation of a tensor with respect to a basis • Change of the basis, transformation rules • Special operations with second-order tensors • Tensor functions, exponential tensor function • Transposition, symmetric and skew-symmetric tensors • Inversion • Scalar product of tensors • Decomposition of second-order tensors • Vector and tensor valued functions, differential calculus • Coordinates in Euclidean space, tangent vectors • Coordinate transformation, covariant and contravariant components • Gradient, covariant derivative • Christoffel symbols, representation of the covariant derivative • Mock-Examination
Learning Objectives/ Learning Outcomes	Tensor algebra is the language of modern continuum mechanics and material theory. Due to the course the students will be able to read and understand modern scientific literature in this area, formulate and interpret tensor identities in absolute as well as index notation. The knowledge obtained within the course is also very helpful for the numerical implementation of finite element procedures.
(Study-Specific) Prerequisites	-
(recommended) Requirements	recommended: • Basic knowledge of mathematics and in particular matrix algebra
References	• Halmos, P.R. Finite-Dimensional Vector Spaces. Van Nostrand, New York, 1958. • Itskov, M. Tensor Algebra and Tensor Analysis for Engineers with Applications to Continuum Mechanics, Springer, 2007.
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov

– Track Conception
– Compulsory Elective Area II
+ Tensor Algebra and Tensor Analysis for Engineers I (4012288)

ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Examination Tensor Algebra and Tensor Analysis for Engineers I (401228801)	1st semester	no semester recommended	5	0
Exercise Tensor Algebra and Tensor Analysis for Engineers I (401228802)	1st semester	no semester recommended	0	-

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Vorlesung Tensor Algebra and Tensor Analysis for Engineers I	1st semester	no semester recommended	-	2

RWTH AACHEN UNIVERSITY

Module titel	Fundamentals of Lightweight Design (Compulsory elective subject)
Identifier	4011452
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2009
Valid until	-
Module level	Master

Content	1. Introduction to the Lightweight Design
	    1. Definition of lightweight design
	    2. General principles of lightweight design
	    3. Comparison of different materials
	2. Statically indeterminate systems
	    1. Polplan
	    2. Force method
	    3. Reduction method
	3. Beams under shear loading
	    1. Transverse shear in thin-walled closed cross-sections
	    2. St.-Venant‘s torsion
	    3. Warping torsion
	4. Physical nonlinearity: Plastic bending and plastic hinge theory
	5. Composite beam
	6. Beam theory under large deformations (Th. II. Order)
	7. Stability of beam structures and lateral torsional buckling
	8. Structures of lightweight design
	    1. Shear web theory
	    2. Plane shear webs (2 dimensional)
	    3. Stiffened shear webs with three flanges

Learning Objectives/ Learning Outcomes	**Knowledge and Understanding:** In this course, students shall acquire the following: • the basic principles in order to optimize structures in terms of lightweight design, • the calculation of cutting forces in statically indeterminate systems, • the shear stress calculation of thin-walled closed sections, • the structural mechanical treatment of physical nonlinearity, • the calculation of composite beams, • the structural mechanical treatment of geometric nonlinearity, • the computational treatment of stability phenomena, • the structural and mechanical properties and characteristics of structures of lightweight design **Skills and competences:** Students shall be able to perform • the analyses of structural behavior of truss structures, • the design of load carrying structures as lightweight structures, • the stress calculations of truss structures under all loads in the aspect of lightweight design, • the geometrically and physically nonlinear analyses of truss structures, • the weight optimization of structures, • the interpretation of correctness of numerical simulation software and check whether the numerical results are feasible or not, • identification of engineering applications of lightweight design, develop suggestions, evaluate the obtained results and present the issues.
(Study-Specific) Prerequisites	-

(recommended) Requirements	Recommended requirements (e.g...): • Mechanics I and II • Material Science I and II • Machine Design • Advanced mathematics
References	• Hertel, H.: Leichtbau, Springer Verlag, 1960 • Wiedemann, J.: Leichtbau, Band I: Elemente, Springer Verlag, 1986 • Wiedemann, J.: Leichtbau, Band II: Konstruktion, Springer Verlag, 1989 • Czerwenka, G., Schnell, W.: Einführung in die Rechenmethoden des Leichtbaus, Band 1 und 2, BI-Hochschultaschenbücher • Roark, R. J., Young, W. C.: Formulas for Stress and Strain, McGraw-Hill, 1975 • Jones, R. M.: Mechanics of Composite Materials, McGraw-Hill, 1975 • Bruhn, E. F.: Analysis and Design of Flight Vehicles Structures • Niu, M. C. Y.: Airframe Structural Design, Conmilit Press Ltd., 1988
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Kai-Uwe Schröder
ECTS Credits	4
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	120,0
Contact hours (h)	45,0
Self-study hours (h)	75,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Fundamentals of Lightweight Design (401145201)	1st semester	no semester recommended	4	0

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Tutorial Fundamentals of Lightweight Design	1st semester	no semester recommended	-	1
Lecture Fundamentals of Lightweight Design	1st semester	no semester recommended	-	2

Module titel	Tensor Algebra and Tensor Analysis for Engineers II (Compulsory elective subject)
Identifier	4012289
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2015
Valid until	-
Module level	Master
Content	• Three-dimensional vector fields • Divergence and curl • Eigenvalue problem for second-order tensors • Eigenvalues and eigenvectors • Characteristic polynomial • Principal invariants of a second-order tensor • Relationships between principal invariants, principal traces and eigenvalues • Spectral representation and eigenprojections • Spectral decomposition of symmetric tensors • Cayley-Hamilton theorem • Scalar-valued isotropic tensor functions • Representations of isotropic tensor functions • Scalar-valued anisotropic tensor functions • Rychlewski's theorem • Material symmetry • Isotropic, transversely isotropic and orthotropic materials • Derivatives of scalar-valued tensor functions • Tensor differentiation rules • Derivatives of principal invariants, principal traces and eigenvalues of a second-order tensor • Constitutive relations for hyperelastic materials • Tensor-valued isotropic tensor functions • Representation theorem • Example: constitutive relations for isotropic and anisotropic elastic materials • Mock-Examination
Learning Objectives/ Learning Outcomes	Additionally to the results of the first part of the course, the students obtain a basic knowledge of material symmetry. They will be able to formulate constitutive relations for isotropic and anisotropic materials like fiber-reinforced composites or soft biological tissues. Due to the lectures and exercises on the field theory and differential calculus they will also be able to formulate various balance equations for solids and fluids in absolute and index notation.
(Study-Specific) Prerequisites	Recommended: Tensor Algebra and Tensor Analysis for Engineers I
(recommended) Requirements	• Module Tensor Algebra and Tensor Analysis for Engineers I recommended: • Basic knowledge of mathematics and in particular matrix algebra
References	• Halmos, P.R. Finite-Dimensional Vector Spaces. Van Nostrand, New York, 1958. • Itskov, M. Tensor Algebra and Tensor Analysis for Engineers with Applications to Continuum Mechanics, Springer, 2007.
Language	English
Examination Terms	Eine schriftliche Prüfung

- Track Conception
- Compulsory Elective Area II
+ Tensor Algebra and Tensor Analysis for Engineers II (4012289)

Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Tensor Algebra and Tensor Analysis for Engineers II (401228901)	2nd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Übung Tensor Algebra and Tensor Analysis for Engineers II	2nd semester	no semester recommended	-	2
Vorlesung Tensor Algebra and Tensor Analysis for Engineers II	2nd semester	no semester recommended	-	2

Module titel	Machine Design Process (Compulsory elective subject)
Identifier	4012285
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2009
Valid until	-
Module level	Master
Content	Topic: Introduction Topic: Drawing Standards I • Projection drawing and axonometric views • Elements of technical drawings • Dimensioning Topic: Drawing Standards II • Section views • Broken views Topic: Joins and Connections • Connection types • Bolted connections • Shaft and hub connections Topic:Geometrical Irregularities and Tolerances • Dimension tolerances • Form and position tolerances • Technical surfaces Topic: Bearing of Shafts • Bearing principles • Bearing arrangements • Seals Topic: Power Transmission • Definitions and principles • Technical representation • Examples Topic: Engineering Design Process, Requirements List • Introduction to design methodology • General process of engineering design • Requirements list Topic: Conceptual Design I • Function structures and principle solutions • Design catalogues • Heuristic and analogy methods Topic: Conceptual Design II • Systematic variation, classification schemes • Overall solutions: morphological matrix Topic: Design Rules I - Basic Rules • Introduction to design rules • Basic rules “simple” and “clear” • Basic rule “safe” Topic: Design Rules II - Principles • Principles of fault-free design, force transmission, stability and bi-stability, self-help, division of tasks

	Topic: Design Rules III - Guidelines / DFX • Selected examples: design for assembly and production…
Learning Objectives/ Learning Outcomes	The studens • know the most common machine elements and applicable design rules. They are able to draft such solutions according to ISO drawing standards and understand production drawings including dimensions and tolerances. • know structured problem solving strategies, esp. the engineering design process acc. to VDI 2221. They are able to identify possible restrictions on a design task and to develop and select applicable concept solutions with a systematic approach. • know the body of design rules and are able to determine applicability depending on effective design restrictions. Basic rules of embodiment design, design principles and guidelines can be applied to draw up technical drafts.
(Study-Specific) Prerequisites	-
(recommended) Requirements	none
References	Pahl, G.;Beitz, W.; Feldhusen, J.; Grote, K. H.: Engineering Design - A Systematic Approach, Third Edition. Springer, 2007.
Language	English
Examination Terms	Written or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Georg Jacobs
ECTS Credits	5
Contact time (WSH)	5
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	75,0
Self-study hours (h)	75,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Machine Design Process (401228501)	1st semester	no semester recommended	5	0

▲Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Vorlesung Machine Design Process	1st semester	no semester recommended	-	2
Übung Machine Design Process	1st semester	no semester recommended	-	3

Module titel	Simulation of Discrete Event Systems (Compulsory elective subject)
Identifier	4011437
Version	V2
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2020
Valid until	-
Module level	Master

Content	• Definition of Discrete Event Systems and fundamentals of simulation, modelling and application
	• Deterministic approaches
	    • Languages, various kinds of automata, automata-generated languages
	    • Properties and relations of state charts
	    • Petri nets and coverability trees
	    • Timed models
	• Stochastic approaches
	    • Stochastic timed models
	    • Markov Chains and Variable Length
	    • Queuing models
	    • Bayesian Networks and Dynamic Bayesian Networks
	• Event scheduling schemes and output analysis with terminating and non-terminating simulations

Learning Objectives/ Learning Outcomes	After successfully completing this course, the students will have acquired the following learning outcomes: Knowledge / Understanding Students • shall know important theories and techniques for modelling discrete event systems; • shall understand the principles of simulation based on advance approaches. Abilities / Skills Students: • shall be able to analyse real systems and build quantitative models of these systems using the proposed methods for analysis and simulation; • shall be able to predict future states and properties of the modelled systems using the proposed methods for analysis and simulation; • shall be able to predict future states and properties of the modelled systems. Competencies Students: • shall learn to describe, analyse and evaluate event systems, apply their knowledge and skills to real-life engineering systems and come to well-founded conclusions; • are to understand how to model robust, effective and efficient systems which improve the satisfaction and the safety of the persons involved.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Lecture Notes • Students also receive a list of relevant literature

- Track Conception
- Compulsory Elective Area II
+ Simulation of Discrete Event Systems (4011437)

Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Univ.-Prof. Dr.-Ing. Verena Nitsch
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Simulation of Discrete Event Systems (401143701)	2nd semester	no semester recommended	5	0

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Simulation of Discrete Event Systems	2nd semester	no semester recommended	-	2
Exercise Simulation of Discrete Event Systems	2nd semester	no semester recommended	-	2

Module titel	Computational Fluid Dynamics II (Compulsory elective subject)
Identifier	4012279
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2009
Valid until	-
Module level	Master
Content	• Introduction to the solution of initial value problems • Heat conduction equation • Program example • Numerical solution of the boundary-layer equations • Linearization of the implicit solution scheme • Program example • Introduction to the solution of linear hyperbolic equations • Numerical solution of the potential flow equation • Program example • Upwind and central discretization • Transport properties of discretizations • Dissipative and dispersive truncation errors • Introduction to the solution of the Euler equations • Integral, differential, conservative, non-conservative, and characteristic forms • Discontinuous solutions of the Euler equations • Rankine-Hugoniot relations • Introduction to upwind discretizations for the Euler equations • Derivation of the Flux-Difference Splitting scheme • Flux-Vector Splitting schemes • High-order schemes • Explicit solution schemes for the Euler equations • MacCormack, Runge-Kutta methods etc. • Convergence acceleration methods • FAS Multigrid method, local time stepping etc. • Implicit solution schemes for the Euler equations • Linearization of the non-linear equations • Dual time stepping schemes • Discretization of the Euler equations on unstructured meshes • Formulation of upwind schemes • Numerical solution of the Euler equations for the shock tube problem • Program example
Learning Objectives/ Learning Outcomes	• Basics for the numerical solution of Boundary Layer, Euler and Navier-Stokes equations for compressible flows • Fundamental properties and different forms of Euler and Navier-Stokes equations • Understand central and upwind discretization schemes for Euler and Navier-Stokes equations • Formulatiaon of efficient explicit and implicit solution schemes for Euler and Navier-Stokes equations • Several program examples show how the theory is applied in the nuermical simulation of different flow problems
(Study-Specific) Prerequisites	-
(recommended) Requirements	recommended: • Module *Computational Fluid Dynamics I* • Basic knowledge in advanced mathematics • Basic knowledge in thermodynamics

References	• C.A. Fletcher: Computational Techniques for Fluid Dynamics Vol I+II, Springer Verlag, 1988 • J.R. Anderson: Computational Fluid Dynamics, MacGraw-Hill, 1955 • C. Hirsch: Numerical Computation of Internal and External Flows, J. Wiley &; Sons, 1988 • P.J. Roache: Fundamentals of Computational Fluid Dynamics, hermosa publishers, Albuquerque, 1998
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Wolfgang Schröder
ECTS Credits	3
Contact time (WSH)	2
Examination duration (min)	-
Total hours (h)	90,0
Contact hours (h)	30,0
Self-study hours (h)	60,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Computational Fluid Dynamics II (401227901)	3rd semester	no semester recommended	3	0

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Computational Fluid Dynamics II	3rd semester	no semester recommended	-	1
Exercise Computational Fluid Dynamics II	3rd semester	no semester recommended	-	1

Module titel	Intelligent Monitoring of Engineering Systems (Compulsory elective subject)
Identifier	4021494
Version	V1_neu
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2022
Valid until	-
Module level	Master
Content	The course curriculum consists of seminar lectures followed by a semester project. During the seminar lectures, the students will receive the necessary theoretical background to independently plan and execute the project in small groups. Consultation hours are offered to discuss challenges and problems arising during the course of the project. Finally, each group presents their achievements and results live and in form of a written report. The following topics are covered: • Sensing • Signal processing • Machine learning • Non-Destructive Testing (NDT) • Structural Health Monitoring (SHM) • Data pre- and postprocessing using MATLAB
Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: <u>Knowledge / Understanding</u> The students will understand • the theoretical foundations of structural health monitoring approaches in engineering • state-of-the-art and current trends in structural health monitoring • the fundamentals of sensors, filtering methods, and computational Intelligence <u>Abilities / Skills</u> The students are able to • describe and analyse mechanical engineering systems • extract and monitor relevant system parameters • apply fundamental methods of structural health monitoring • transfer their knowledge to new engineering applications in science and industry • independently plan, advance and complete projects
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: Programming experience, particularly in MATLAB (Python)
References	Farrar, C.R. and Worden, K., 2012. Structural Health Monitoring: A Machine Learning Perspective. Wiley.
Language	English
Examination Terms	Written or Oral Examination (100 %)
Miscellaneous	-

RWTH AACHEN UNIVERSITY

– Track Conception
– Compulsory Elective Area II
+ Intelligent Monitoring of Engineering Systems (4021494)

Module coordinator	Univ.-Prof. Dr.-Ing. Bernd Markert
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0
Self-study hours (h)	105,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Intelligent Monitoring of Engineering Sys-tems (402149401)	2nd semester	no semester recommended	5	-

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Intelligent Monitoring of Engineering Systems	2nd semester	no semester recommended	-	2
Exercise Intelligent Monitoring of Engineering Systems	2nd semester	no semester recommended	-	1

Module titel	Advanced Finite Element Methods for Engineers (Compulsory subject)
Identifier	4013866
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2018
Valid until	-
Module level	Master
Content	Content • General introduction, concept of the finite element method • Symbolic assembly procedure • Global and local coordinates • Stiffness matrix for trusses / coordinate transformation • Variational techniques • Solution of truss structures • Variational techniques, Euler-Lagrange equation • Natural and forced boundary conditions • Multiple integrals, Gauss-Theorem • Variations of elementary algebraic functions • Variational principle for linear self-adjoint diff. operators • Solution of some classical variational problems • Principle of virtual work as a weak form of the momentum balance, variational principles of mechanics (Lagrange, Hu-Washizu) • Differential equation of a linear elastic bar, analytic solution for various load cases • Rayleigh-Ritz method, weighted residual approximations, Point or subdomain collocation • Galerkin method, least-squares method, linear elastic bar approximated by a continuous shape function • Displacement formulation • Three-field (mixed) formulation • Examples to weighted residual approximations • Requirements to shape functions • Continuous shape functions, piecewise defined shape functions, approximation by piecewise defined shape functions. • 2-d problems of elasticity, triangular element, plain strain and plane stress problems, • Torsion of a prismatical bar • Examples for plain strain and plane stress problems discretized by linear triangular elements

	• Axisymmetric stress analysis, 3-d stress analysis • Construction of 2-d and 3-d finite elements (Lagrange and serendipity family) • Concept of hierarchical shape functions • Concept of mapping in iso-parametric finite elements • Application of numerical integration in 1-d, 2-d and 3-d finite element problems • Non-linear finite element problems (Newton-Raphson method) • Dynamic (time-dependent) finite element problems, time step size and mass scaling
Learning Objectives/ Learning Outcomes	The aim of the course is to impart the basic knowledge about finite element methods and their application to solid and structural mechanics. The students will • understand why the FE-Method and the other numerical methods behind are important for engineering practice • understand the basic concept of FEM • be able to find solutions for trusses with a variety of boundary conditions • understand the fundamental concept of variational calculus • be able to find solutions for mechanical problems by using weighted residual methods • be able to use finite element method for plane strain, plane stress and torsion problems • be able to construct finite elements with linear and non-linear shape functions • understand the application of numerical integration in finite element method • understand the concept of non-linear and time-dependent finite element problems In addition, voluntary programming exercise sessions are offered to deepen the theoretical understanding. A simple FEM solver is developed in Python, numerical integration schemes are discussed and the FEniCS programming package is introduced.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Advanced Finite Element Methods for Engineers (401386601)	1st semester	no semester recommended	5	0

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Advanced Finite Element Methods for Engineers	1st semester	no semester recommended	-	2
Tutorial Advanced Finite Element Methods for Engineers	1st semester	no semester recommended	-	2

Module titel	Numerical Methods in Mechanical Engineering (Compulsory subject)
Identifier	4011449
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2014
Valid until	-
Module level	Master
Content	The content of the course is to provide a map to follow the long and winding road from intuitional perception to the mathematical formulation of engineering problems. The content is summarized as follows: • Selected assumptions and mathematical tools to formulate problems • An overview of several solution methods: analytical solutions, approximate solutions, direct approximation, approximate solution after transformation of the problem • An overview of selected types of physical problems: discrete systems, continuous systems, equilibrium problems, eigenvalue problems, propagation problems • Integral formulations • Weak formulation of problems • The Method of Weighted Residuals • Introduction to variational calculus • Functionals • Functionals associated with an integral form • The stationarity principle • Stationarity conditions • Examples from mechanics • The method of Lagrange multipliers • Mixed and complementary formulations • Catalogue of functionals used in continuum mechanics and their specific features • Discretisation of integral forms • Collocation by points • Collocation by subdomains • Galerkin’s method Least Squares Method Examples • Ritz' method • Examples • Numerical integration • Newton-Cotes method • Gauss method Examples: • The Finite Element Method, Shape functions, construction of finite elements • Matrix representation in the FEM, Stiffness matrix, Boundary conditions • Examples from structural engineering, Software packages in engineering
Learning Objectives/ Learning Outcomes	Overall goal: The students will gain theoretical background of numerical methods commonly used in mechanical engineering. In particular, the physical formulations are discussed based on which the corresponding mathematical formulations for large-scale numerical methods are presented. In this course, students shall acquire the following:

	Knowledge / Understanding The students will understand • the theoretical foundations of current numerical methods in engineering • the bridge between the physical formulation of a problem and the mathematical description suited to implement numerical approximation methods • the steps and transformations required to implement numerical methods Abilities / Skills The students are able to • apply approximation techniques and analyse the results obtained by various numerical methods • use their acquired knowledge to develop state-of-the-art approximation methods • critically judge the consistency and correctness of numerical methods • apply variational methods to obtain formulations of a problem of differential equations • construct basis functions compatible with the boundary conditions • construct and apply a variety of approximation methods based on the WRM (collocation by points, collocation by subdomains, Galerkin's method, least squares method, Ritz method) • solve constrained optimization problems by using the Lagrange Multipliers Method • construct the associated energy potential and to apply the stationary principle for a conservative mechanical problem • apply basic tools of numerical integration
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Lecture Notes • Dhatt, G., Touzot, G.: The Finite Element Method Displayed. Wiley, New York, 1984. • Finlayson, B.A.: The Method of Weighted Residuals and Variational Principles. Academic Press, New York, 1972. • Reddy, J.N.: Energy and Variational Methods in Applied Mechanics. Wiley, New York, 1984. • Lemaitre, J., Chaboche, J.-L.: Mechanics of Materials, Cambridge Univ. Press, Cambridge, 1994. • König, J.A.: Shakedown of Elastic-Plastic Structures. Elsevier, Amsterdam, 1987.
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Bernd Markert Dr. rer. nat. Michael Ban
ECTS Credits	7
Contact time (WSH)	5
Examination duration (min)	-
Total hours (h)	210,0
Contact hours (h)	75,0
Self-study hours (h)	135,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Numerical Methods in Mechanical Engineering (401144901)	1st semester	no semester recommended	7	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Numerical Methods in Mechanical Engineering	1st semester	no semester recommended	-	3
Tutorial Numerical Methods in Mechanical Engineering	1st semester	no semester recommended	-	2

Module titel	Continuum Mechanics (Compulsory subject)
Identifier	4013360
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2014
Valid until	-
Module level	Master
Content	• Material bodies, configuration, coordinates • Rigid body motion • Deformation gradient • Deformation of surface and volume elements • Strain, stretch and shear • Spectral decomposition of strain tensors • Strain invariants • Polar decomposition of the deformation gradient, stretch tensors • Strain measures • Velocity gradient • Cauchy stress tensor • Linear momentum balance • Scalar form of the linear momentum balance • Rotational momentum balance • Balance of mechanical energy • Work-conjugate stress-strain pairs • General principles of the constitutive theory, Noll axioms • Change of frame, objectivity • General constitutive relation, simple materials • Elastic materials • Material symmetry, isotropic materials • Hyperelastic materials • Mock-Examination
Learning Objectives/ Learning Outcomes	During the course, the students will obtain knowledge of the principles of continuum mechanics and exercise the subject matter by considering realistic problems. In particular, attending students will • learn how to describe the state of strain and stress in a material body that undergoes large elastic deformations • calculate the usual strain and stress tensors • understand and apply the principle of balance equations • understand the principles of the constitutive theory • learn to apply material laws • be able to read scientific literature on continuum mechanics. Throughout the course, the students will use and practice the nowadays usual absolute notation for tensors. Furthermore, examples based on Cartesian and curvilinear coordinates will be considered.
(Study-Specific) Prerequisites	-
(recommended) Requirements	recommended: • Module *Tensor Algebra and Tensor Analysis for Engineers I*
References	• Ogden, R.W. Non-linear Elastic Deformations, Ellis Harwood Ltd. (1984) • Basar, Y., Weichert D. Nonlinear Continuum Mechanics of Solids, Springer (2000)

+ Continuum Mechanics (4013360)

Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Continuum Mechanics (401336001)	2nd semester	no semester recommended	5	0
Exercise Continuum Mechanics (401336002)	2nd semester	no semester recommended	0	2

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Continuum Mechanics	2nd semester	no semester recommended	-	2

Module titel	Production Management A (Compulsory subject)
Identifier	4011477
Version	-
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2015
Valid until	-
Module level	Master
Content	• From Taylorism to Industry 4.0 • Business Process Modelling • Production Optimization • Lean Production - Production Systems • Structured Innovation Process • Variant management • Product Planning and Engineering • Technology Planning • Manufacturing and Assembly Planning • Process Planning • Materials Management • Production Planning and Control • Global Production Networks • Factory Planning
Learning Objectives/ Learning Outcomes	Markets and manufacturing conditions are frequently changing. This imposes the necessity of long-range and intensive planning in enterprises of the manufacturing industry, as only early accommodation of actual conditions guarantees competitiveness. Students shall gain knowledge which topics have to be considered in this context and how this knowledge can be transferred to daily business of a company. For the purposes of manufacturing engineering, students are expected to know the following tasks that have to be carried out. In this course, students shall acquire the following: Knowledge / Understanding Students • shall elaborate and apply planning methods. • are to analyze problems in all enterprise domains which are involved in the manufacturing process. • shall be able to demonstrate possibilities for rationalisation and automation. • shall know elaboration of rationalisation methods and tools. • are expected to understand the problems of producing companies. These tasks are elucidated concerning the manufacturing domains design, operations planning and scheduling, production and assembly as well as the overall organization. • shall understand the problems of producing companies and find solutions best suited for the investigated subject. • shall understand the complex problems of producing companies and have the knowledge to identify critical parameters by considering performance indicators Abilities / Skills Students • shall apply this knowledge to elaborate possibilities for rationalization and automation issues; • shall analyse problems in all enterprise domains which are involved in the manufacturing process.

	Competencies Students • shall elaborate rationalization methods and tools; • shall find solutions best suited for the investigated subject in concerning the manufacturing domains design, operations planning and scheduling, production and assembly as well as the overall organization.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Kurbel, K. E. (Enterprise Resource Planning): Enterprise Resource • Planning and Supply Chain Management. Functions, Business Processes and Software for Manufacturing Companies, 2013 • Hans-Peter Wiendahl, Jürgen Reichardt, Peter Nyhuis, Handbook Factory Planning and Design, 2015 • Peter Nyhuis, Hans-Peter Wiendahl, Fundamentals of Production • Logistics: Theory, Tools and Applications, 2008 • Lecture Notes • Students also receive a list of relevant literature
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Dr.-Ing. Michael Riesener
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Production Management A (401147701)	3rd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exercise Production Management A	3rd semester	no semester recommended	-	2

Lecture Production Management A	3rd semester	no semester recommended	-	2

Module titel	Multibody Dynamics (Compulsory subject)
Identifier	4011462
Version	V1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2020
Valid until	-
Module level	Master
Content	• Introduction • Fundamentals • Fields of application • Model Building • Methods of Approach for Equivalent Models • Multi-body Systems • General mathematical description • Kinematics of Multi Body Systems • Position and Orientation of Bodies • Translational Kinematics • Rotational Kinematics • Equations of Motion • Lagrangian Equations of 2nd Kind • Newton-Euler equations • Lagrangian Equations of 1st Kind • Eigen Value Approach • Undamped non-gyroscopic systems • Damped gyroscopic systems • Eigen Value Stability Criteria Linear Systems with Harmonic Excitation • Real Frequency Matrix • Complex Frequency Matrix • State Equation • System Matrix • Eigen Value Approach • Fundamental Matrix • Modal Matrix • Theorem of Cayley-Hamilton • Analytical Solution • Numerical Solution • Step Excitation • Harmonic Excitation • Periodical Excitation Example • Modelling • Calculation • Evaluation
Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: Knowledge / Understanding: Students: • shall have a profound knowledge of theory of vibrations. • shall be capable of comprehending, describing and analyzing vibratory systems.

	• shall be familiar with the most important matrix based procedures for the calculation of eigenmotions and the behaviour of linear systems under forced excitations. Abilities / Skills: Students • shall have the ability of describing mathematically any mechanical system with its inherent physical effects like elasticity, damping and friction. • shall be able to properly interpret simulation results especially under consideration of simplifications within the model compared to the real system. Competencies: Students • shall be able to derive from their knowledge the necessary methods and proceedings for the analysis and synthesis of the systems in regard. • shall be capable to solve - accessing their acquired theoretical knowledge - complex problems concerning the choice and design of industrial vibratory systems.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Lecture Notes • Students also receive a list of relevant literature
Language	English
Examination Terms	Written/Oral Examination (Depending on registration numbers)
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Dr. h. c. Burkhard Corves
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Multibody Dynamics (401146201)	2nd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Tutorial Multibody Dynamics	2nd semester	no semester recommended	-	2
Lecture Multibody Dynamics	2nd semester	no semester recommended	-	2

Module titel	Simulation Techniques in Manufacturing Technology (STMT) (Compulsory subject)
Identifier	4012413
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2011
Valid until	-
Module level	Master
Content	1 - In der ersten Vorlesung wird eine Einführung in das Thema „Simulationsverfahren in der Fertigungstechnik“ gegeben. 2 - Die Inhalte der zweiten Vorlesung sind die grundlegenden Aspekte und Prozesse der Umformtechnik. 3 - Nachdem der Student die Grundlagen der Umformtechnik erlernt hat, konzentriert sich diese Vorlesung auf aktuelle Simulationsverfahren beim Umformen. 4 - Die vierte Vorlesung befasst sich mit grundlegenden Aspekten und der Simulation der Massivumformung. 5 - Die fünfte Vorlesung gibt eine Einführung in die Grundlagen und Simulationsverfahren bei Blechumformung und Trennen. 6 - Inhalt der sechsten Vorlesung sind die Grundsätze der Zerspanung. 7 - Vorlesung 7 gibt einen generellen Überblick der verschiedenen Zerpanprozesse. 8 - Eine Möglichkeit Zerspanprozesse ganzheitlich zu modellieren ist die Finite-Elemente-Methode (FEM). Diese Vorlesung vermittelt die Vorgehensweise und Modellierungsansätze der FE-Zerspansimulation sowie zeigt verschiedene und aktuelle Beispiele für die FE-Simulation von Zerspanprozessen. 9 - Die neunte Vorlesung gibt eine Einführung in das Zerspanen mit undefinierter Schneide. 10 - Vorlesung 10 stellt aktuelle Modellierungsmethoden beim Schleifen vor. 11 - In Vorlesung 11 wird besonders auf die Methoden der Validierungs- und Optimierungstechniken eingegangen. 12 - Inhalt der letzten Veranstaltung ist es, in kleinen Gruppen die Aufstellung und Auswertung von FE-Simulation mit den FE-Codes DEFORM und ABAQUS zu erlernen.
Learning Objectives/ Learning Outcomes	Fachbezogene Lernziele: - Einführung in die grundsätzlichen Methoden der Modellierung und Simulation von Fertigungsverfahren - Revision der Grundlagen der Werkstoffkunde und Fertigungstechnik - Darstellung des Potentials der Modellierung und Simulation: Erhöhung des Prozessverständnisses, Verbesserung der Prozesssicherheit und Optimierung des Arbeitsergebnisses - Vorgehensweise und Einsatz der Finite-Elemente-Methode zur Simulation von Fertigungsprozessen - Möglichkeiten und Grenzen der Modellierung und Simulation zeigen - Anwendung der Simulationssoftware DEFORM und ABAQUS zur Simulation unterschiedlicher Fertigungsverfahren Nicht fachbezogene Lernziele: - Im Rahmen von Forschung und Entwicklung eigenständig passende Simulationsverfahren für Fertigungsprozesse auswählen und wissenschaftlich fundiert begründen - Eigene Ansätze zur Modellierung der Fertigungsprozesse entwickeln und in Forschungsfragen formulieren sowie in Entwicklungstätigkeiten einfließen lassen
(Study-Specific) Prerequisites	-
(recommended) Requirements	Empfohlene Voraussetzungen: - Grundkenntnisse der Werkstoffkunde - Grundlagen der Vektor- und Tensorrechnung - EDV-Grundlagen

	Empfohlene Voraussetzungen - Englisch in Wort und Schrift - Fertigungstechnik I
References	S. Kobayashi, T. Altan, S. Kobayashi: Metal Forming and the Finite-Element Method, Oxford Series on Advanced Manufacturing, Oxford University Press, 1989 - T. Childs: Metal Machining (Theory and Applications), ISBN-13: 978-0340691595 - K. Cheng: Machining Dynamics (Fundamentals, Applications and Practices), ISBN: 978-1-84628-367-3
Language	English
Examination Terms	Eine mündliche oder eine schriftliche Prüfung
Miscellaneous	-
Module coordinator	Univ.-Prof. Dr.-Ing. Thomas Bergs
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam STMT (401241301)	3rd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exercise STMT	3rd semester	no semester recommended	-	2
Lecture STMT	3rd semester	no semester recommended	-	2

RWTH AACHEN UNIVERSITY

Module titel	Advanced Software Engineering (Compulsory subject)
Identifier	4011468
Version	V2_neu
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2022
Valid until	-
Module level	Master
Content	The aim of the course is to explain students for what purposes, under which conditions and with which consequences computer systems are used for the solution of problems related to Mechanical Engineering.Within the first part of the course the steps from problem description to the final software solution are illustrated. This covers the topics modelling, problem elicitation and analysis, program design and an introduction to UML (Unified Modelling Language) and implementation in C++ Java. Then the course goes on with a closer examination of the various aspects which comprise software development, concerning topics like design patterns, agile software processes and project management. Parallel to the lecture the students are given the chance to employ the theoretical input from the course in small software projects. After an introduction to Java and object-oriented programming, the students stepwise pass through the particular stages of a software development process.
Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: Knowledge / Understanding: Students • are to gain solid knowledge in the Software Development Life Cycle and also the main activities and core concepts in different software development phases. Abilities / Skills: Students • shall have the ability to transfer the acquired knowledge in object - oriented design to different engineering problems and understand the general structure and the functionality of software.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: • Basic knowledge in a programming language (e.g. C, C++, Java, Python)
References	• Bruegge, B.; Dutoit, A. (2009): Object-Oriented Software Engineering • Using UML, Patterns and Java. Boston: Pearson. • Sommerville, I. (2010): Software engineering. Boston: Pearson
Language	English
Examination Terms	Written or oral Examination (100 %)
Miscellaneous	-
Module coordinator	Dipl.-Inform Daniel Lütticke
ECTS Credits	5

Advanced Software Engineering (4011468)

Contact time (WSH)	-
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	-
Self-study hours (h)	-

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Advanced Software Engineering (401146801)	1st semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Advanced Software Engineering	1st semester	no semester recommended	-	2
Tutorial Advanced Software Engineering	1st semester	no semester recommended	-	2

RWTHAACHEN UNIVERSITY

Module titel	Quality Management (Compulsory subject)
Identifier	4011453
Version	V2
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2022
Valid until	-
Module level	Master
Content	The digitalization and networking of production increases the availability of data over the entire product life cycle and changes the role of quality management in relation to systems, processes and products. With the shift in focus of data analysis from reactive and corrective to proactive and predictive, the principles of quality management remain, but actors acting in quality management need new tools, e.g. from the domain of machine learning, to deal with increased complexity. The lecture deals with the interweaving of quality-related methods with the needs of a rapid situation clarification of possibly deviating processes along value chains or the associated industrial services. The orientation towards the structure of the "Internet of Production" first builds on the principles of quality management (e.g. important standards, clarification of the terms system, process and product quality). The identification of quality relevant data sources (incl. social media) along the product life cycle leads to the modelling of the data-information-knowledge pyramid. The statistical/stochastic basics serve as a fundamental basis to understand methods of data analytics and machine learning and are applied situationally to typical problem classes from different areas of quality management (e.g. process control, risk management, fault management), which are typified with regard to their structure and thus made accessible for rationalization. The goal is to increase the action competence of actors by decision support (e.g. by the use of smart devices). Contributions from practice give insight into the implementation of quality management in industry.
Learning Objectives/ Learning Outcomes	Knowledge Students shall know • Important standards and guidelines in the knowledge domain "quality management" • structure of standards (high-level structure) • System, process and product quality • Quality relevant data and data sources along the product life cycle • Statistical and methodical basics of "lndustrial lntelligence" as a core task of QM • Legal implications Understanding Students shall understand • The "Internet of Production" • The importance of quality and machine learning methods in networked adaptive production • Importance of quality and quality management in networked, adaptive production • The Classification of typical problems • basic data analytics and machine learning methods Students shall be able to apply: • Data collection (e.g. customer insights in the product development process and during product usage, data-driven procurement management) • selected data analytics and machine learning methods (e.g. for risk quantification and prediction, process control) • Quality management for services • Decision support of the "Smart Quality Expert" (e.g. predictive quality, predictive maintenance) Skills and Competencies Students

	• shall develop an understanding of the different forms of the quality concept that can be operationalized in the operational process and classify them in the sense of "Industrial Intelligence". • shall be able to identify and classify problems in the corporate context. • shall have basic knowledge in the field of machine learning, shall know corresponding advanced quality management methods and be able to describe their specific applicability and effectiveness. • shall be able to theoretically and practically penetrate applications in the quality management domain with the knowledge imparted to them as a 'tool'. • shall be able to build up the structure of an "lndustrial lntelllgence" by means of quality management methods in the corporate context, to evaluate it with regard to its effectiveness and to further develop and meaningfully link quality management methods based on an understanding of interrelationships and principles. • shall be able to intervene in value chains in an improving way based on their well-founded methodological and organizational knowledge. • shall be able to recognize and evaluate situations, strengths and weaknesses of an existing quality management system and to formulate suitable measures for a coherent further development. The contents are based on research of the Cluster of Excellence "Internet of Production". Considering this background, the participants should take the mental transformation from the application of tools (methodological competence) to the design of the underlying principles and cause-effect relationships in value chains (action competence).
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Lecture Notes • Students also receive a list of relevant literature
Language	English
Examination Terms	Written (100 %)
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Robert Schmitt
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Quality Managment (401145301)	3rd semester	no semester recommended	5	0

▲Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture/Tutorial Quality Management	3rd semester	no semester recommended	-	4

Module titel	Computational Intelligence in Engineering (Compulsory elective subject)
Identifier	4021493
Version	V1_neu
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2022
Valid until	-
Module level	Master
Content	The elective course “Computational Intelligence in Engineering“ is available for students enrolled in the engineering Master programs of RWTH Aachen University. It provides an overview over recent applications of computational intelligence and deep learning that are relevant to engineering. The first half of the course content is a theoretical introduction into the topic of machine learning in engineering and programming fundamentals in Python. In the second half of the course, the students apply their gained knowledge in project-based learning. The course will be taught interactively, engaging the students using practical example projects. The following topics are covered: • Time-variant dynamic processes from simulations or experiments • Data acquisition and pre-processing • Machine learning algorithms and neural network models • Advanced neural networks architectures • Project-specific engineering problems • Programming fundamentals in Python for data-driven procedures
Learning Objectives/ Learning Outcomes	The course curriculum consists of interactive seminar lectures accompanied by semester project works. During the seminar lectures, the students will receive the necessary theoretical information and supervision to independently plan, advance and complete the projects in small groups. In addition, the seminars offer the opportunity to discuss challenges and problems arising during projects. Finally, the achievements and results obtained within the student projects will be presented by the students in the scope of the seminar lectures and the accompanying computer lab exercises. <u>Knowledge / Understanding</u> The students will understand • current trends in computational intelligence and their theoretical foundation in the context of engineering applications • the advantages of machine learning algorithms in engineering but also the limits of the methods and when better not to use them <u>Abilities / Skills:</u> The students will be able to • apply machine learning methods to a wide variety of engineering Problems • transfer their knowledge to new engineering applications in science and industry via the practical expertise gained • evaluate the merits and limitations of machine learning methods applied to computer aided engineering problems
(Study-Specific) Prerequisites	-
(recommended) Requirements	Programming experience is advantageous, preferably the language Python.
References	• Goodfellow, I., Bengio, Y., Courville, A., 2016. Deep Learning. MIT Press.

	• Keller, J.M., Liu, D., Fogel, D.B. , 2016. Fundamentals of Computational Intelligence. IEEE Press, Wiley.
Language	English
Examination Terms	Written Examination or Oral Examination (100 %)
Miscellaneous	-
Module coordinator	Univ.-Prof. Dr.-Ing. Bernd Markert
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0
Self-study hours (h)	105,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Computational Intelligence in Engineering (402149301)	3rd semester	no semester recommended	5	-

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture "Computational Intelligence in Engineering	3rd semester	no semester recommended	-	2
Exercise Computational Intelligence in Engineering	3rd semester	no semester recommended	-	1

Practical Introduction to FEM-Software I (4012292)

Module titel	Practical Introduction to FEM-Software I (Compulsory elective subject)
Identifier	4012292
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master
Content	• General introduction, development of FEM program, ANSYS (graphical interface) Modeling and calculation of frameworks with ANSYS Modeling of beam structures ANSYS commandos, Working with input data Post processing for beam elements • General introction in FEM program CALCULIX Modeling and calculation of beam structures with CALCULIX Data exchange between ANSYS - CAlCULIX • Introduction in 2D modeling with ANSYS (part 1) 2D element types, free networking, boundary conditions, network density, post processing Commandos for 2D modeling in CALCULIX boundary conditions, network density, post processing • Introduction in 2D modeling with ANSYS (part 2) Structured networking (mapped mesh), “bottom up”-/ “top down” – approach ANSYS commandos for heat transfer problems • APDL, Element types, boundary conditions, h- and p-method Post processing, estimation of errors • ANSYS 3D modeling (part 1), geometry creation, selection and grouping commands • 3D models (part 2), ANSYS- and CALCULIX commandos, 3D element types • 3D models (part 3), ANSYS- and CALCULIX commandos, extrusion of 2D models. • Project work, modeling • Project work, modeling, calculation, post processing • Project work, documentation, report • Revision course
Learning Objectives/ Learning Outcomes	Fachbezogene Lernziele: Providing an overview and introduction to Finite Element Software The students will: • Have sufficient practical and theoretical knowledge for the use of ANYSS and CALCULIX • be able to create smaller 2D and 3D FE models • be able to solve linear structural and heat transfer problems • Understand the concept of “Solid Modelling” and networking • Know the most important commands for creating input files • Know how to define boundary conditions and loading cases • Be able to test smaller FE models and to analyze possible errors • Be able to critically review the computing results in the post processor • Be able to deduce practical construction instructions from an FE calculation Nicht fachbezogene Lernziele: The students will • learn to work on a task in a team and to document and present the results in the form of a report • learn how to analyze problems • learn how to develop solutions and to evaluate them
(Study-Specific) Prerequisites	-
(recommended) Requirements	Empfohlene Voraussetzungen (z.B. andere Module, Fremdsprachenkenntnisse, …): • Command of English Voraussetzung für (z.B. andere Module, ...): • Practical Introduction to FEM-Software II
References	• Script • Online documentation, user handbooks
Language	English
Examination Terms	Practical Introduction to FEM-Software I

Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0
Self-study hours (h)	105,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Practical Introduction to FEM-Software I (401229201)	1st semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Vorlesung/Labor Practical Introduction to FEM-Software I	1st semester	no semester recommended	-	-

RWTH AACHEN UNIVERSITY

– Track Production
– Compulsory Elective Area II
+ Practical Introduction to FEM-Software II (4011498)

Module titel	Practical Introduction to FEM-Software II (Compulsory elective subject)
Identifier	4011498
Version	-
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2012
Valid until	-
Module level	Master
Content	• Time depending Problems, multi load steps, sub modeling. • Sub modeling • Non-linear Material, Plasticity • Non-linear Material, rubber-like materials, viscoelastic • Composite materials. • Solver for non-linear problems. • Contact problems part 1, coupling and constraint equations. • Contact problems part 2, CAD-Import. • Harmonic response • Modal analysis • Death and birth option, harmonic response. • Multiphysics problems 1, heat transfer, voltage. • Multiphysics problems 2, heat radiation. • Repetitorium
Learning Objectives/ Learning Outcomes	In part II of the course the considered examples are extended to nonlinear problems and applications. The students will • obtain an overview about various kinds of FE calculations. • obtain an understanding for the difficulties of nonlinear calculations. • be able to calculate nonlinear problems with ANSYS and CALCULIX.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: Practical Introduction to FEM-Software I
References	-
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. (RUS) Mikhail Itskov
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0

Contact hours (h)	45,0
Self-study hours (h)	105,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Practical Introduction to FEM-Software II (401149801)	2nd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Tutorial Practical Introduction to FEM-Software II	2nd semester	no semester recommended	-	2
Lecture Practical Introduction to FEM-Software II	2nd semester	no semester recommended	-	1

Module titel	Modeling, Model Reduction and Simulation in Laser Processing - Laser (Compulsory elective subject)
Identifier	4013863
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master
Content	• overview of contents, definition of the 10 learning targets • the constribution of the engineer to the interactive cooperation of scientific disciplines • main features of the theory of cognition (Karl Popper) • laser radiation, Helmholtz equation, reduced model: SVE-approximation • Learning target 1:gaussian beam, beam guiding and forming • reflection, transmission and absorption of light • Learning target 2:reduced model of the Fresnel Formulae for the limiting case of small discplacemant current, optical parameters • technical task and examples: cutting with laser radiation • Learning target 3:quality features of the high quality cut • physical task of cutting and identification of quality defined processing domains • Learning target 4:relation of physicl phenomena to built up of quality degradations • technical task and examples: drilling with laser radiation • physical task and 5 dominant phenomena • Learning target 5: quality features of the drilled hole • mathematical modelling Ia: time scales • degrees of freedom in phase space of dependent variables • separation of time scales in simple dynamical systems • Learning target 6a: separation of time scales • mathematical modelling Ib:length scales • thermal boundary layer in heat conduction with moving boundaries • Learning target 6b: separation of length scales • mathematical modelling IIa: Free Boundary Problems (FBP) for the solid phase • reduced model for the FBP: motion of the melting front, integral methods, variational formulation • Learning target 7: heating and melting phase of ablation • mathematical modelling IIb: FBP for the liquid phase • Navier-Stokes equations, material equations and boundary values • mathematical model reduction: melt flow • reduced model for thin film flow • Learning target 8: boundary character, integral and spectral methods • model reduction and solution with controlled error: melt flow at low Reynolds-number • structural stability of the reduced model: lubrication approximation, fingering and droplet formation • Learning target 9: creeping flow and expansion with respect to the Reynolds-number, exact solution of a model problem for arbitrary Reynolds-number • global properties of the solution of balance equations for mass, momentum and thermal energy • Learning target 10: scales for the choice of processing parameters in cutting and drilling • concluding discussion of the learning targets • actual research and development of laser processing
Learning Objectives/ Learning Outcomes	The students obtain scientific skills for the application of: 1. Free Boundary Problems and integral methods of solution, 2. non-linear stability analysis using spectral methods, 3. analysis of the structural stability of model equations and • know the least 3 types of laser systems, temporal and spatial distribution of laser radiation, Fresnel-number, invariant quantity of light propagation

	• understand the structure of solution for the Helmholtz-equation, diffraction, 5 parameter pairs of optical material equations, transmission, reflection, absorption, Fresnel Formulae, polarisation of matter and radiation • know and understand the 5 different, dominant phenomena of drilling, welding and cutting with laser radiation • know the physical meaning of the terms contained in the Navier-Stokes equations for mass, momentum and energy balance • know the main properties of the solution in the asymptotic case of thin film flow (boundary layer) and can explain the relation between dynamical properties of the solution and quality features of the product as well as productivity of the process for drilling and cutting • know the effect of dissipation in disctributed dynamical systems (inertial manifold) and know examples for the application of methods for the reduction of the dimension in dissipative systems, understand and perform the separation of length and time scales in simple systems The students get to know non-scientific tasks: • understand the interactive cooperation of scientists from engineering, physics and mathematics for application of model based methods for diagnosis in laser processing • Application of model based methods for solving practical tasks from discussion of project examples
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr. rer. nat. Wolfgang Schulz
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Modeling, Model Reduction and Simulation in Laser Processing - Laser (401386301)	2nd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Modeling, Model Reduction and Simulation in Laser Processing - Laser	2nd semester	no semester recommended	-	2
Exercise Modeling, Model Reduction and Simulation in Laser Processing - Laser	2nd semester	no semester recommended	-	2

Module titel	Modeling, Model Reduction and Simulation in Laser Processing - Applications (Compulsory elective subject)
Identifier	4013864
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master

Content	• overview of contents, definition of the learning targets
	• ecapitulation of the 10 learning targets from part I of the course
	• derivation and consolidation of the application of integral methods for treating heat conduction with Stefan-type boundary conditions
	• Learning target 1: variational formulation compared with direct integration for one space variable, spectral methods for error control of integral methods: spatial one-dimensional model problem, Eigenfunctions of differential operators, spectral decomposition of non-linear problems, discrete and continuous spectra
	• Learning target 2: separation of variables and relation to spectral methods, applications of spectral methods, asymptotic expansion of partial differential equations and their solution applied to a model problem of heat conduction
	• Learning target 3: identification of characteristic dynamical variables, degrees of freedom of an inertial manifold, determination of dimensionless groups, Buckingham's Pi-theorem, definition and physical meaning of Peclet-, Reynolds-, Marangoni- and Stefannumber.
	• Learning target 4: physical interpretation of dimensionless groups of system parameters and the dimension in phase space of processing parameters, optical modes in passive fibers, numerical aperture, total reflection, maximum mode-number, coupling of modes, optical excitation in active fibers and dissipation
	• Learning target 5: Slow surfaces in dynamical systems, Application of time scale separation
	• Learning target 6: thermal effects of large and small Peclet-number, model problems in thin film flow, applications of spectral methods:
	    • formation of pores in welding, closure of the drill hole
	• Learning target 7: relation of time scales and the onset of quality features, modelling evaporation and recondensation of metals I, comparison of models from Aden and Aoki &; Sone
	• Learning target 8: liquid-vapor phase transition in drilling and welding, modelling evaporation and recondensation of metals, Laplacepressure, evaporation and recondensation as driving forces for momentum of the liquid by pressure gradients
	• Learning target 9: boundary conditions for momentum at ideal surfaces,
	• technical examples:
	    • drilling with laser radiation, welding with laser radiation, concluding discussion of learning targets
	• actual research and development of laser processing

Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: <u>Knowledge / Understanding:</u> Students shall obtain understanding about the applications of: 1. Free Boundary Problems and integral methods of solution, 2. analysis of dynamical stability, non-linear stability analysis using spectral methods, 3. analysis of the structural stability of model equations. <u>Abilities / Skills:</u> Students

	• shall obtain scientific skills for the application of free Boundary Problems and integral methods of solution, non-linear stability analysis using spectral methods and for the analysis of the structural stability of model equations. • shall be able to determine the maximum number of dimensionsless groups of Boundary Value Problems. • shall understand the relation of boundary conditions, boundary values and the structure of solution for the Navier-Stokes equations. • shall know and understand the 5 different, dominant phenomena of drilling, welding and cutting with laser radiation. • shall know and be able to explain the physical meaning of the Navier-Stokes equations. • shall know the main properties of the solution in the asymptotic case of thin film flow (boundary layer) and shall be able to explain the relation between dynamical properties of the solution and quality features of the product as well as productivity of the process for drilling and cutting. • shall know the effect of dissipation in distributed dynamical systems (inertial manifold) and shall know examples for the application of methods for the reduction of the dimension in dissipative systems. • shall understand and perform the separation of length and time scales in simple systems. • shall understand the interactive cooperation of scientists from engineering, physics and mathematics for application of model based methods for diagnosis in laser processing.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: • Modeling, Model Reduction and Simulation in Laser Processing - Laser
References	• Lecture Notes • Students also receive a list of relevant literature
Language	English
Examination Terms	Oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr. rer. nat. Wolfgang Schulz
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Modeling, Model Reduction and Simulation in Laser Processing - Applications (401386401)	3rd semester	no semester recommended	5	0

▲Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exercise Modeling, Model Reduction and Simulation in Laser Processing - Applications	3rd semester	no semester recommended	-	2
Lecture Modeling, Model Reduction and Simulation in Laser Processing - Applications	3rd semester	no semester recommended	-	2

Module titel	Molecular Mechanics and Multiscale Modelling of Materials (Compulsory elective subject)
Identifier	4011511
Version	-
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master
Content	Lectures: Introduction to multi-scale modelling Molecular dynamics - Theoretical background of molecular dynamics - Force-probe molecular dynamics simulations - Compute mechanical properties at molecular level Phase field modelling (finite element modelling) - Theoretical background - Reproduce molecular mechanical properties - Validations Multi-scale modelling - Scale bridging - Bottom-up approach - Applications, e.g., spider silk, nacre Exercises: - Molecular dynamics simulations - Force-probe molecular dynamics simulations - Compute mechanical properties at molecular level, e.g., Young's modulus - Finite element simulations based on force-probe molecular dynamics simulations - Validations - Analysis of multi-phasic materials
Learning Objectives/ Learning Outcomes	Wissen und Verstehen: Molecular Mechanics and Multi-scale Modelling The need for multi-scale modelling comes usually from the fact that the available macro-scale models are not accurate enough, and the micro-scale models are not efficient enough and/or offer too much information. By combining both viewpoints, one hopes to arrive at a reasonable compromise between accuracy and efficiency. Multiscale models allow us to formulate models that couple together models at different scales. Overall goal: Students are able to bridge the wide range of time and length scales of methods that are inherent in a number of essential phenomena and processes in materials science and engineering. After successfully completing this course, the students will have acquired the following learning outcomes: Knowledge / Understanding - understand the theoretical background of both methods, molecular dynamics and continuum mechanics - are able to compute mechanical properties at molecular level - reproduce molecular material behaviour at macroscopic level - perform multi-scale modelling of hierarchical bio-materials - modelling of fracture at atomistic scale Fertigkeiten und Kompetenzen: Abilities / Skills: - able to deal with molecular dynamics simulations at nano-scale level - perform FEM simulations at macro-scale by using nano-scale mechanical properties - able to perform bottom-up approach in efficient way - knowledge of fracture at nano-scale as well as macro-scale Competence:

	- able to deal with interdisciplinary field problems, e. g., nano-scale MD simulations and macro-scale FEM simulations - use the knowledge to explore naturally available hierarchical materials, which outperform artificial materials in terms of mechanical properties - apply contents of the lecture to natural as well as artificial materials
(Study-Specific) Prerequisites	-
(recommended) Requirements	Empfohlene Voraussetzungen: Kontinuumsmechanik (Continuum Mechanics)
References	Rapaport, D. C. The art of molecular dynamics simulation Cambridge University Press, 2004 Frenkel, D. &; Smit., B. Understanding molecular simulation: from algorithms to applications Computational science. Academic Press, 2002 Haupt, P. Continuum Mechanics and Theory of Materials Springer-Verlag, Berlin, 2000 Empfohlene weiterführende Literatur: Allen, M. P. &; Tildesley, D. J. Computer simulation of liquids Clarendon Press, Oxford, 1987 Chadwick, P. Continuum mechanics: Concise theory and problems Courier Dover Publications, 1999
Language	English
Examination Terms	Eine schriftliche oder mündliche Prüfung (abhängig von der Teilnehmerzahl)
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Bernd Markert
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Molecular Mechanics and Multiscale Modelling of Materials (401151101)	3rd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Übung Molecular Mechanics and Multi-scale Modelling	3rd semester	no semester recommended	-	2
Vorlesung Molecular Mechanics and Multi-scale Modelling	3rd semester	no semester recommended	-	2

Module titel	Manufacturing Technology I (Compulsory elective subject)
Identifier	4011458
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2014
Valid until	-
Module level	Master
Content	- Introduction in manufacturing technology - Machining with geometrically defined cutting edge - Machining with geometrically undefined cutting edge I - Material removal manufacturing processes EDM - Material removal manufacturing processes ECM - Bulk forming - Sheet metal forming - Casting/Powder metallurgy - Additive manufacturing - Laser material processing and high-pressure water jet machining - Technology chain design and manufacturing-induced part characteristics - Closing-off lecture with contributions from the students
Learning Objectives/ Learning Outcomes	Overall goal: Extend prior knowledge about manufacturing technologies with scientific approaches, methods and models After successfully completing this course, the students will have acquired the following learning outcomes: Knowledge / Understanding Students: • know and understand the working principles of relevant manufacturing technologies. • know and understand the process parameters and the main effects on the part's quality, tool wear and processing time. • know and understand tool wear mechanisms and resulting errors. Abilities / Skills Students: • are able to assess manufacturing processes, machine tools and metrology methods with regard to workpiece characteristics. • Are able to evaluate the effects of parameter changes on thermo-mechanical loads, wear behaviour and risks. • are able to analyse, optimize and to question established manufacturing processes from a scientific point of view. Competencies

	Students: • critically analyse company decisions with a broad technological background and can communicate the assessments to non-specialist audiences. • elaborate manufacturing strategies for higher quality, more output and lower costs. • present alternatives for the production. At the end of the lecture series, students are given the opportunity to design a closing-off lecture. A few weeks before, topics will be offered, to which students can research independently, prepare a presentation and give a short lecture. The presentations can be done individually or in a small group and their contents can also be used for the exam. As an incentive, the chair offers the option to receive a letter of recommendation. The chair is enabled to do so by the personal commitment, the special interest in the subject, the cooperation during the preparation and by an impression of the quality of the presentation.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Dr.-Ing. E. h. Dr. h. c. Dr. h. c. Fritz Klocke
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Manufacturing Technology I (401145801)	1st semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Manufacturing Technology I	1st semester	no semester recommended	-	2

Tutorial Manufacturing Technology I	1st semester	no semester recommended	-	2

Module titel	Industrial Engineering and Ergonomics (Compulsory elective subject)
Identifier	4014442
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2016
Valid until	-
Module level	Master
Content	Work as a Scientific Field of Research • Fundamentals of industrial engineering • Trends and challenges in the field of industrial engineering Industrial Organization and Work Organization • Basics and classification of industrial organization and work organization in modern industries • Basics and modelling options of structure organization and process organization • Principles of function and object oriented order processing • traditional industrial organizations and trends • Methods for activity planning and scheduling Work Organization within Direct and Indirect Departments • The phenomenon “organization” • Characteristics of direct and indirect departments • Types of work organization in direct and indirect departments Work and Time Study I • The operational purpose of time data • REFA types of activities and REFA types of times • Methods for the determination of time data • The REFA Stop Watch Time Study method and the work sampling method Work and Time Study II • The basic principles of the sequence-analytic time modelling (predetermined motion-time systems) • Basics and application of MTM („Methods Time Measurement“) Ergonomic Design and Usability Engineering • Design criteria and requirements of ergonomic design • Anthropometric design • Methods for the analysis of movement-, sight- and reaching-areas • Computer aided design and evaluation aids Computer and Office Work • Conventional and modern components of a computer workstation • Overview of display technologies • Aspects of work psychology • Risk assessment for computer work stations • Office concepts Ergonomic Work Place Design in Production Areas • Different types of physical and muscular work • Factors influencing spine damage • Methods for assessing the danger of spine damage at work places • Physiological principles of work place design Occupational Risk Prevention (ORP) • Effects of occupational safety for the company and national economy • Terms of safety science • Technical, organizational and personal measures of occupational risk prevention Work Ecology - Noise and Hazardous Substances • Physical and psychological measurement categories of sound • Noise induced hearing damages • Organizational and personal noise control • Taxonomy and effects of hazardous substances Work Ecology II - Illumination • Physical and physiological basics of illumination • Effects of lighting on work performance and health • Measurement of lightRelevance of illumination for workplace design. Remuneration and Motivation • Forms of remuneration • Relationship between remuneration and motivation • Forms of organizations and conditions suitable for the use of network technology

+ Industrial Engineering and Ergonomics (4014442)

Learning Objectives/ Learning Outcomes	The students know the essentials of work science covering technical, organizational and personnel aspects. Based on this knowledge the students are able to interpret respective work situations, predict consequences and future work system states. The students are able to independently scrutinize and discuss the proposed methods and theories and judge their applicability. By using the methods students are able to analyse work systems according to various practical problems. Furthermore, the students are able to apply the theoretical models, methodologies and practical techniques to problem solution and work system design in modern enterprises.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Univ.-Prof. Dr.-Ing. Nitsch Verena
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Industrial Engineering (401444201)	1st semester	no semester recommended	5	0

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture/Tutorial Industrial Engineering	1st semester	no semester recommended	-	4

Module titel	Production Metrology (Compulsory elective subject)
Identifier	4011467
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2015
Valid until	-
Module level	Master
Content	Introduction • Relevance of metrology for quality assurance and its integration in production processes. Metrological Basics • Metrological concepts and definitions (Calibration, Uncertainty etc.) Tolerancing • Form and positional tolerances, tolerancing principles and basics Inspection Planning • Tasks and workflow of inspection planning, Procedure for creation of inspection plans Shop floor measuring devices/ Measuring sensors • Commonly used manual inspection devices for the shop floor, Function and application of inductive, capacitive and pneumatical sensors Optoelectronic inspection devices • Optical inspection systems for geometry testing and applications Form and surface inspection devices • Tactile and optical system for the characterisation of forms and surfaces, surfaces parameters Coordinate measurement technology • Principles, types and applications of coordinate measuring machines Gauging inspection • Form and positional gauging, Gauging Procedures Statistical basics • Statistical parameters for the description of production and measuring processes, tests on normal distribution SPC, Process Capability • Statistical analysis and control of processes, Process capability indices Inspection device management • Tasks and procedures of inspection device management, Calculation of measuring device capability, Calibration chain
Learning Objectives/ Learning Outcomes	First of all, the elements of the application of the means of measurement concerning the production are pointed out. The theoretical fundamentals which have to be taken into consideration while the measuring process is planned, controlled, analysed, are discussed. Thereby, current measuring principles and devices in the field of industrial production will be considered and new measuring techniques and trends will be presented In this context the characteristics of the measured quantities and their fringe conditions are explained. A further subject of the lecture will be the statistical analysis of the measured values.

	The aim of this lecture is to create the awareness, that “measuring” comprehends a lot more than plain data acquisition and metrology is a vital part of modern production processes.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	Written exam or oral exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Robert Schmitt
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Production Metrology (401146701)	2nd semester	no semester recommended	5	0

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture/Exercise Production Metrology	2nd semester	no semester recommended	-	4

Module titel	Computational Modeling of Membranes and Shells (Compulsory elective subject)
Identifier	4012293
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2015
Valid until	-
Module level	Master
Content	1. General mathematical principles 2. Basic principles of differential geometry 3. Short summary of continuum mechanics 4. Membrane kinematics considering large deformations 5. Constitutive equations for membranes 6. High and low membrane equilibrium 7. Summary of isogeometric finite element methods 8. Numeric discretisation techniques for membranes 9. Extension to shells 10. Rotation free discretisation techniques for Kirchhoff-Love shells 11. Practical realization of 8. and 9.
Learning Objectives/ Learning Outcomes	**Knowledge and understandig:** The students are able to identify the elements of numerical models for membranes and shells and to justify their mathematical and physical origin. The students can derive from this the discussed numerical discretization techniques. **Skills and competences:** The students may transfer the membrane and shell formulation to other constitutive laws, and may implement these formulations in existing software programs. They can evaluate the numerical results of such programs with respect to their accuracy.
(Study-Specific) Prerequisites	Empfohlene Voraussetzungen Kontinuumsmechanik; Grudlagen der Finite Element Methode
(recommended) Requirements	**Recommended requirements** Continuum mechanics Principles of finite element methods
References	-
Language	English
Examination Terms	The final grade is 100% of the oral exam.
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Bernd Markert
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0

Self-study hours (h)	105,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Oral Exam Computational Modeling of Membranes and Shells (401229301)	2nd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Computational Modeling of Membranes and Shells	2nd semester	no semester recommended	-	2
Exercise Computational Modeling of Membranes and Shells	2nd semester	no semester recommended	-	1

Artificial Neural Networks in Structural Mechanics (4021387)

Module titel	Artificial Neural Networks in Structural Mechanics (Compulsory elective subject)
Identifier	4021387
Version	V1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2019
Valid until	-
Module level	Master
Content	Classical structural mechanics is based on continuum mechanics using tensor calculus, differential geometry, and modelling of inelastic material behaviour. This theoretical approach established in the 20th century is the basis for finite element programs widely used in industry and science. Innovative approaches by means of artificial neural networks are known to be very efficient to describe complex mathematical dependencies. This effect relies on the self-learning ability of neural networks to reproduce dependencies between mechanical quantities such as stresses, strains, or other state variables. However, the neural network is based on experience and has therefore tobe trained by experimental or numerical data. Once the neural network has been trained, it is able to predict structural deformations in shorter calculation times than by using classical numerical approaches. Also the accuracy does not suffer, even though that program codes of neural networks are shorter than classical finite element codes. In order to apply the new knowledge on practical examples, the students will learn how to develop a virtual copy of the engineering structure by means of a neural network. Here, a wide variety of components in the network with different layers, neurons, activation functions etc. is available and must be ordered for the application. Special attention is focused on the combination of artificial neural networks with the finite element method. Following this approach, advantages of mesh generation and equation solvers in finite element programs are used and parts of the classical mechanical models are replaced by neural networks. E.g. material models are substituted by trained neural networks leading to shorter simulation times. Due to the fact that artificial neural networks are becoming more widespread in engineering disciplines, students will be familiar with this new trend in simulation methods after visiting this course. They will gain the competences to support the development of neural network enhanced modelling and simulation in industrial and scientific applications.
Learning Objectives/ Learning Outcomes	The aim of the course is to enable students to work with artificial neural networks from the viewpoint of engineering science. This implies to understand different network topologies and their applications in structural mechanics. Classical structural models will be replaced by artificial neural networks partly or completely depending on the current problem. After successfully completing this course, the student will have acquired the following learning outcomes: <u>Knowledge / Understanding:</u> Students: • shall understand the topology of artificial neural networks • are to gain an overview and learn motivation of network architectures (weights, bias-terms, sensilivity analysis) • are to understand different network topologies and their applications in structural mechanics • shall describe mathematical models of artificial neural networks • are to describe possible applications of artificial neural networks in structural mechanics • shall model structures enhanced by neural networks • shall program artificial neural networks • are to find solutions for differential equations approximated by neural networks • shall develop intelligent elements and know the processes behind neural network enhanced finite element simulatios

	<u>Abilities / Skills</u> Students: • are expected to apply artificial neural networks for numerical predictions in structural mechanics • shall program neural networks and train them by data gained from experiments or simulations • shall train artificial neural networks by means of measurement and simulation data • shall model inelastic material behaviour with artificial neural networks • are expected to apply the enhancement of finite element simulation by neural networks <u>Competencies:</u> Students: • shall develop intelligent elements by combining neural networks with the finite element method • are to increase the efficiency of structural calculations towards faster simulations and new structural models without material parameters trained just by experimental or simulated data • are expected to choose, depending on the current problem, whether to replace classical structural models partly or completely by artificial neural networks • shall work with artificial neural networks from the viewpoint of engineering science
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: • Mechanik I-III • Nonlinear Structural Mechanics
References	• Lecture Notes • Empfohlene weiterführende Literatur: A. Engelbrecht, Computational lntelligence, An lntroduction, JohnWiley Literatur & Sens, Ltd, 2007.
Language	English
Examination Terms	An oral or a written exam
Miscellaneous	-
Module coordinator	Prof. Dr.-lng. Marcus Stoffel
ECTS Credits	6
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	180,0
Contact hours (h)	60,0
Self-study hours (h)	120,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Prüfung Artificial Neural Networks in Structural Mechanics (402138701)	3rd semester	no semester recommended	6	-

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Artificial Neural Networks in Structural Mechanics	3rd semester	no semester recommended	-	2
Exercise Artificial Neural Networks in Structural Mechanics	3rd semester	no semester recommended	-	2

Module titel	Simulation of Discrete Event Systems (Compulsory elective subject)
Identifier	4011437
Version	V2
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2020
Valid until	-
Module level	Master

Content	• Definition of Discrete Event Systems and fundamentals of simulation, modelling and application
	• Deterministic approaches
	  ◦ Languages, various kinds of automata, automata-generated languages
	  ◦ Properties and relations of state charts
	  ◦ Petri nets and coverability trees
	  ◦ Timed models
	• Stochastic approaches
	  ◦ Stochastic timed models
	  ◦ Markov Chains and Variable Length
	  ◦ Queuing models
	  ◦ Bayesian Networks and Dynamic Bayesian Networks
	• Event scheduling schemes and output analysis with terminating and non-terminating simulations

Learning Objectives/ Learning Outcomes	After successfully completing this course, the students will have acquired the following learning outcomes: <u>Knowledge / Understanding</u> Students • shall know important theories and techniques for modelling discrete event systems; • shall understand the principles of simulation based on advance approaches. <u>Abilities / Skills</u> Students: • shall be able to analyse real systems and build quantitative models of these systems using the proposed methods for analysis and simulation; • shall be able to predict future states and properties of the modelled systems using the proposed methods for analysis and simulation; • shall be able to predict future states and properties of the modelled systems. <u>Competencies</u> Students: • shall learn to describe, analyse and evaluate event systems, apply their knowledge and skills to real-life engineering systems and come to well-founded conclusions; • are to understand how to model robust, effective and efficient systems which improve the satisfaction and the safety of the persons involved.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-none-
References	• Lecture Notes • Students also receive a list of relevant literature

Track Production
Compulsory Elective Area II
Simulation of Discrete Event Systems (4011437)

Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Univ.-Prof. Dr.-Ing. Verena Nitsch
ECTS Credits	5
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	60,0
Self-study hours (h)	90,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Simulation of Discrete Event Systems (401143701)	2nd semester	no semester recommended	5	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Simulation of Discrete Event Systems	2nd semester	no semester recommended	-	2
Exercise Simulation of Discrete Event Systems	2nd semester	no semester recommended	-	2

Module titel	Computational Fluid Dynamics II (Compulsory elective subject)
Identifier	4012279
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2009
Valid until	-
Module level	Master
Content	• Introduction to the solution of initial value problems • Heat conduction equation • Program example • Numerical solution of the boundary-layer equations • Linearization of the implicit solution scheme • Program example • Introduction to the solution of linear hyperbolic equations • Numerical solution of the potential flow equation • Program example • Upwind and central discretization • Transport properties of discretizations • Dissipative and dispersive truncation errors • Introduction to the solution of the Euler equations • Integral, differential, conservative, non-conservative, and characteristic forms • Discontinuous solutions of the Euler equations • Rankine-Hugoniot relations • Introduction to upwind discretizations for the Euler equations • Derivation of the Flux-Difference Splitting scheme • Flux-Vector Splitting schemes • High-order schemes • Explicit solution schemes for the Euler equations • MacCormack, Runge-Kutta methods etc. • Convergence acceleration methods • FAS Multigrid method, local time stepping etc. • Implicit solution schemes for the Euler equations • Linearization of the non-linear equations • Dual time stepping schemes • Discretization of the Euler equations on unstructured meshes • Formulation of upwind schemes • Numerical solution of the Euler equations for the shock tube problem • Program example
Learning Objectives/ Learning Outcomes	• Basics for the numerical solution of Boundary Layer, Euler and Navier-Stokes equations for compressible flows • Fundamental properties and different forms of Euler and Navier-Stokes equations • Understand central and upwind discretization schemes for Euler and Navier-Stokes equations • Formulatiaon of efficient explicit and implicit solution schemes for Euler and Navier-Stokes equations • Several program examples show how the theory is applied in the nuermical simulation of different flow problems
(Study-Specific) Prerequisites	-
(recommended) Requirements	recommended: • Module *Computational Fluid Dynamics I* • Basic knowledge in advanced mathematics • Basic knowledge in thermodynamics

Computational Fluid Dynamics II (4012279)

References	• C.A. Fletcher: Computational Techniques for Fluid Dynamics Vol I+II, Springer Verlag, 1988 • J.R. Anderson: Computational Fluid Dynamics, MacGraw-Hill, 1955 • C. Hirsch: Numerical Computation of Internal and External Flows, J. Wiley &; Sons, 1988 • P.J. Roache: Fundamentals of Computational Fluid Dynamics, hermosa publishers, Albuquerque, 1998
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Wolfgang Schröder
ECTS Credits	3
Contact time (WSH)	2
Examination duration (min)	-
Total hours (h)	90,0
Contact hours (h)	30,0
Self-study hours (h)	60,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Computational Fluid Dynamics II (401227901)	3rd semester	no semester recommended	3	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Computational Fluid Dynamics II	3rd semester	no semester recommended	-	1
Exercise Computational Fluid Dynamics II	3rd semester	no semester recommended	-	1

RWTH AACHEN UNIVERSITY

Module titel	Intelligent Monitoring of Engineering Systems (Compulsory elective subject)
Identifier	4021494
Version	V1_neu
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2022
Valid until	-
Module level	Master
Content	The course curriculum consists of seminar lectures followed by a semester project. During the seminar lectures, the students will receive the necessary theoretical background to independently plan and execute the project in small groups. Consultation hours are offered to discuss challenges and problems arising during the course of the project. Finally, each group presents their achievements and results live and in form of a written report. The following topics are covered: • Sensing • Signal processing • Machine learning • Non-Destructive Testing (NDT) • Structural Health Monitoring (SHM) • Data pre- and postprocessing using MATLAB
Learning Objectives/ Learning Outcomes	In this course, students shall acquire the following: <u>Knowledge / Understanding</u> The students will understand • the theoretical foundations of structural health monitoring approaches in engineering • state-of-the-art and current trends in structural health monitoring • the fundamentals of sensors, filtering methods, and computational Intelligence <u>Abilities / Skills</u> The students are able to • describe and analyse mechanical engineering systems • extract and monitor relevant system parameters • apply fundamental methods of structural health monitoring • transfer their knowledge to new engineering applications in science and industry • independently plan, advance and complete projects
(Study-Specific) Prerequisites	-
(recommended) Requirements	Recommended: Programming experience, particularly in MATLAB (Python)
References	Farrar, C.R. and Worden, K., 2012. Structural Health Monitoring: A Machine Learning Perspective. Wiley.
Language	English
Examination Terms	Written or Oral Examination (100 %)
Miscellaneous	-

– Track Production
– Compulsory Elective Area II
+ Intelligent Monitoring of Engineering Systems (4021494)

Module coordinator	Univ.-Prof. Dr.-Ing. Bernd Markert
ECTS Credits	5
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	150,0
Contact hours (h)	45,0
Self-study hours (h)	105,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Intelligent Monitoring of Engineering Sys-tems (402149401)	2nd semester	no semester recommended	5	-

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Intelligent Monitoring of Engineering Systems	2nd semester	no semester recommended	-	2
Exercise Intelligent Monitoring of Engineering Systems	2nd semester	no semester recommended	-	1

Module titel	Linear Control Systems (Compulsory elective subject)
Identifier	4011476
Version	Angelegt über RWTH API als 1_neu
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2022
Valid until	-
Module level	Master
Content	Significance of control theory, examples of biological and biomedical control loops, functional diagrams, linearization, set up and solving of differential equations, stability, features in time domain of dynamical systems, Laplace transform, transfer function, frequency response, functional diagram algebra, features in frequency domain of dynamical systems, bode diagram, Nyquist plot, Linear control loop elements, principle and goals of controller design, algebraic stability criteria, steady state analysis and transient performance of a control loop, controller setting rules, Nyquist stability criterion, phase margin, gain margin, controller design in bode diagram.
Learning Objectives/ Learning Outcomes	After successfully completing this course, the student will have acquired the following learning outcomes: Knowledge / Understanding: • know, recognize and classify the most common linear control loop elements • the effects of feedback and apply different methods to set up feedback elements (controllers) such that predefined control goals are met Abilities / Skills: • to analyze dynamical, biological and biomedical systems and identify the relevant causalities • to employ different mathematical descriptions of dynamical systems • solve differential equations by means of Laplace transform • assess of the stability of dynamical systems using different methods • obtain, interpret and employ the frequency response of dynamical systems
(Study-Specific) Prerequisites	-
(recommended) Requirements	Basic knowledge in mathematics as defined in the examination regulations.
References	-
Language	English
Examination Terms	The module grading is weighted according to the CP-allocation • Written Exam (schriftliche Prüfung) or • Oral Exam (mündliche Prüfung)
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Dirk Abel
ECTS Credits	3
Contact time (WSH)	2

Examination duration (min)	-
Total hours (h)	90,0
Contact hours (h)	30,0
Self-study hours (h)	60,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Linear Control Systems (401147601)	1st semester	no semester recommended	4	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Linear Control Systems	1st semester	no semester recommended	-	1
Tutorial Linear Control Systems	1st semester	no semester recommended	-	1

RWTH AACHEN UNIVERSITY

Module titel	Computational Fluid Dynamics I (Compulsory elective subject)
Identifier	4012278
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2010
Valid until	-
Module level	Master
Content	• Introduction to CFD • Examples of flow simulatiaons • The basic PDE's of Fluid Mechanics • Different Notations • Physical meaning of characteristic lines • Determination of the type of PDE's • Characteristic form of PDE's • The basics of discretization of partial differentials • Truncation error and consistency • Solution schemes for scalar equations • Stability analysis of initial value problems • Discrete disturbance theory • von Neumann ananlysis • CFL-condition • Hirt's stability analysis • Introduction to the numerical solution of boundary value problems • Classical iterative solution methods, Jacobi, Gauß-Seidel methods • Convergence of iterative solution methods • ILU, Krylov subspace methods • Multigrid methods • Transformation of PDE's in curvlinear coordinates • Truncation error on curvelinear grids • Discretization on different unstructured meshes, solution adaptive methods • Triangle or tetrahedral based meshes • Hierarchical Cartesian meshes • Vectorization and parallelization of solution algorithms • Different applications and examples
Learning Objectives/ Learning Outcomes	• Knowledge of the partial differential equations (PDE'S) of fluid mechanics • Basics of the discretization of PDE's • Learn how to formulate numerical methods for the solution of PDE's • Ability to determine und understand the properties of truncation errors of numerical solution schemes • Understand stability and sonsistency of solution schemes • Solution of boundary value problems with iterative solution schemes • Discretization on different mesh types • Implementation of solution schemes on different computer architectures • The discussion of several examples of numerical flow simulation allows to understand different theoretical aspects in proactical mpplications
(Study-Specific) Prerequisites	-
(recommended) Requirements	recommended: • Basic knowledge in advanced mathematics • Basic knowledge in thermodynamics
References	• C.A. Fletcher: Computational Techniques for Fluid Dynamics Vol I+II, Springer Verlag, 1988

	• J.R. Anderson: Computational Fluid Dynamics, MacGraw-Hill, 1955 • C. Hirsch: Numerical Computation of Internal and External Flows, J. Wiley &; Sons, 1988 • P.J. Roache: Fundamentals of Computational Fluid Dynamics, hermosa publishers, Albuquerque
Language	English
Examination Terms	Written exam
Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Wolfgang Schröder
ECTS Credits	4
Contact time (WSH)	3
Examination duration (min)	-
Total hours (h)	120,0
Contact hours (h)	45,0
Self-study hours (h)	75,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Computational Fluid Dynamics I (401227801)	2nd semester	no semester recommended	4	0

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exercise Computational Fluid Dynamics I	2nd semester	no semester recommended	-	1
Lecture Computational Fluid Dynamics I	2nd semester	no semester recommended	-	2

Module titel	Porous Media Mechanics (Compulsory elective subject)
Identifier	4013372
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Summer semester 2016
Valid until	-
Module level	Master
Content	Porous solids with a fluid pore content as well as real mixtures of liquids and gases belong both to the class of multi-phase materials. With a continuum theory for multiphasic media, the movement of flow of fluids in deformable porous solids can be describes for arbitrary deformation processes and arbitrary material properties of the solid matrix. Moreover, it is possible to consider phase transitions and electrochemical reactions within such a theory. In this regard, a theoretical tool is to provided that can be uses to mathematically describe and numerically analyse a manifold of distinct materials, ranging from geomaterials over polymer and metal foams to biological tissues. For the numerical application, a system of strangly coupled partial differential equations has to be solved. - Continuum-mechanical basics for the description of single- and multiphasic materials: state of motion, deformation measures, stress states - Balance relations for multi-phase materials: master balances, special balances for mass, momentum, moment of momentum, energy and entropy - Caloric state variables and energy potentials - Fundamentals of materials theory for multiphasic media: Thermodynamics and constitutive equations - The fluid-saturated, materially incompressible deformable porous solid - Hydraulics in porous materials, Darcy and Forchheimer filter law - Elastic and inelastic material properties of the solid skeleton
Learning Objectives/ Learning Outcomes	The students are able to apply continuum-mechanical methods to multiphasic and porous materials. They understand the character of strongly coupled equation systems for the description of complex phenomena in multi-component materials and mixtures.
(Study-Specific) Prerequisites	-
(recommended) Requirements	Basic knowledge in Mathematics a. Successfully passed modul Biomechanics/Fluid Mechanics from the 1st semester. Recommended: - Continuum Mechanics (Prof. Itskov) - Selected topics of Inelasticity Theory (Prof. Markert)
References	- de Boer, R.: Theory of Porous Media, Springer Verlag, Berlin 2000 - Ehlers, W.: Grundlegende Konzepte in der Theorie Poröser Medien, Technische Mechanik 16 (1996), 63-76 - Ehlers, W.: Foundations of multiphasic and porous materials. In Ehlers, W. &; Bluhm, J (eds.): Porous Media: Theory, Experiments and Numerical Applications. Springer-Verlag, Berlin 2002, pp. 3-86 further reading: - Markert, B.: A biphasic continuum approach for viscoelastic high porosity foams: Comprehensive theory, numerics and application. Archives of Computational Methods in Engineering 15 (2008), 371-446 - Markert, B.: Coupled thermo- and electrodynamics of multiphasic continua. In Advances in Extended and Multifield Theories for Continua, Lecture Notes in Applied and Computational Mechanics, Markert, B., ed., Springer, Berlin 2011, vol.59, pp. 129-152
Language	English
Examination Terms	Written exam : Duration 120 Minutes or an Oral Exam: Duration 30 Minutes The mark of the module is equivalent to the mark of the exam.

+ Porous Media Mechanics (4013372)

Miscellaneous	-
Module coordinator	Universitätsprofessor Dr.-Ing. Bernd Markert
ECTS Credits	4
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	120,0
Contact hours (h)	60,0
Self-study hours (h)	60,0

● Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Exam Porous Media Mechanics (401337201)	2nd semester	no semester recommended	4	0
Exercise Porous Media Mechanics (401337202)	2nd semester	no semester recommended	0	2

▲ Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Porous Media Mechanics	2nd semester	no semester recommended	-	2

RWTH AACHEN UNIVERSITY

+ Industrial Internship (4014343)

Module titel	Industrial Internship (Compulsory elective subject)
Identifier	4014343
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter/summer semester
Valid from	Summer semester 2013
Valid until	-
Module level	Master
Content	See 'Guidelines for Practical Work Experience'
Learning Objectives/ Learning Outcomes	See 'Guidelines for Practical Work Experience'
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	- none -
Miscellaneous	-
Module coordinator	Unbekannt
ECTS Credits	9
Contact time (WSH)	-
Examination duration (min)	0
Total hours (h)	270,0
Contact hours (h)	-
Self-study hours (h)	-

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Industrial Internship (401434301)	3rd semester	no semester recommended	9	0

+ Mini Thesis (4014344)

Module titel	Mini Thesis (Compulsory elective subject)
Identifier	4014344
Version	Angelegt über RWTH API als 1
Duration (Semester)	one semester
Cycle (Semester)	winter/summer semester
Valid from	Winter semester 2012
Valid until	-
Module level	Master
Content	Completed academic paper, which is written under supervision. The students work out an outline with their tutors, determine partial tasks and aids and the required amount of time necessary for fulfilling the task.
Learning Objectives/ Learning Outcomes	The students learn the approach and processing of academic themes, their documentation and written interpretation under intensive supervision. They aquire the methodology of systematic academic research.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	English
Examination Terms	Mini Thesis (Written paper, 40-70 pages)
Miscellaneous	-
Module coordinator	-
ECTS Credits	9
Contact time (WSH)	-
Examination duration (min)	-
Total hours (h)	270,0
Contact hours (h)	-
Self-study hours (h)	-

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Mini Thesis (401434401)	3rd semester	no semester recommended	9	0

+ Mini Thesis (4014344)

+ Language Course II (4021267)

Module titel	Language Course II (Compulsory subject)
Identifier	4021267
Version	V1
Duration (Semester)	one semester
Cycle (Semester)	summer semester
Valid from	Winter semester 2019
Valid until	-
Module level	Master
Content	The course is aimed at students who are looking for a university-specific foreign lan-guage education, who need a foreign language for their studies and/or are planning a stay abroad (study, internship, project). Depending on the level, the range of foreign languages on offer takes into account the training of language skills specific to the profession. In the course you will learn the essential elements of grammar and vocabulary of the respective language, depending on your level, so that you can assert yourself both in writing and orally in everyday communication situations. In addition, you will learn to extract the essential information from authentic and university-specific reading and lis-tening texts as well as from various types of texts such as: Write e-mails, letters, messages and notes.
Learning Objectives/ Learning Outcomes	To learn the basics of the respective language or to deepen and expand already existing skills for active participation in everyday and working life.
(Study-Specific) Prerequisites	-
(recommended) Requirements	none
References	-
Language	German/English
Examination Terms	100% written examination in reading, listening, writing and grammar
Miscellaneous	-
Module coordinator	-
ECTS Credits	2
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	60,0
Contact hours (h)	60,0
Self-study hours (h)	,0

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+ Language Course II (4021267)

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Examination Language Course II (402126701)	2nd semester	no semester recommended	2	-

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Language Course II	2nd semester	no semester recommended	-	2
Exercise Language Course II	2nd semester	no semester recommended	-	2

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+ Language Course I (4021266)

Module titel	Language Course I (Compulsory subject)
Identifier	4021266
Version	V1
Duration (Semester)	one semester
Cycle (Semester)	winter semester
Valid from	Winter semester 2019
Valid until	-
Module level	Master
Content	The course is aimed at students who are looking for a university-specific foreign lan-guage education, who need a foreign language for their studies and/or are planning a stay abroad (study, internship, project). Depending on the level, the range of foreign languages on offer takes into account the training of language skills specific to the profession. In the course you will learn the essential elements of grammar and vocabulary of the respective language, depending on your level, so that you can assert yourself both in writing and orally in everyday communication situations. In addition, you will learn to extract the essential information from authentic and university-specific reading and lis-tening texts as well as from various types of texts such as: Write e-mails, letters, messages and notes.
Learning Objectives/ Learning Outcomes	To learn the basics of the respective language or to deepen and expand already existing skills for active participation in everyday and working life.
(Study-Specific) Prerequisites	-
(recommended) Requirements	none
References	-
Language	German/English
Examination Terms	100% written examination in reading, listening, writing and grammar
Miscellaneous	-
Module coordinator	-
ECTS Credits	2
Contact time (WSH)	4
Examination duration (min)	-
Total hours (h)	60,0
Contact hours (h)	60,0
Self-study hours (h)	,0

Language Course I (4021266)

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Examination Language Course I (402126601)	1st semester	no semester recommended	2	-

Offer node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Lecture Language Course I	1st semester	no semester recommended	-	2
Exercise Language Course I	1st semester	no semester recommended	-	2

RWTH AACHEN UNIVERSITY

+ Linguistic Elective (4024418)

Module titel	Linguistic Elective (Compulsory subject)
Identifier	4024418
Version	V1
Duration (Semester)	one semester
Cycle (Semester)	winter/summer semester
Valid from	Winter semester 2021
Valid until	-
Module level	Master
Content	The course is aimed at students who are looking for a university-specific foreign lan-guage education, who need a foreign language for their studies and/or are planning a stay abroad (study, internship, project). Depending on the level, the range of foreign languages on offer takes into account the training of language skills specific to the profession. In the course you will learn the essential elements of grammar and vocabulary of the respective language, depending on your level, so that you can assert yourself both in writing and orally in everyday communication situations. In addition, you will learn to extract the essential information from authentic and university-specific reading and listening texts as well as from various types of texts such as: Write e-mails, letters, messages and notes. *Recommended language: Technical English*
Learning Objectives/ Learning Outcomes	To learn the basics of the respective language or to deepen and expand already existing skills for active participation in everyday and working life.
(Study-Specific) Prerequisites	-
(recommended) Requirements	-
References	-
Language	-
Examination Terms	100% written examination
Miscellaneous	-
Module coordinator	-
ECTS Credits	2
Contact time (WSH)	2
Examination duration (min)	-
Total hours (h)	60,0
Contact hours (h)	30,0
Self-study hours (h)	30,0

+ Linguistic Elective (4024418)

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Examination Linguistic Elective (402441801)	3rd semester	no semester recommended	2	2

+ Master Thesis (4024783)

Module titel	Master Thesis (Compulsory subject)
Identifier	4024783
Version	-
Duration (Semester)	-
Cycle (Semester)	-
Valid from	Winter semester 2021
Valid until	-
Module level	Master
Content	The students learn the independent approach and processing of academic themes, their documentation and written interpretation within a set deadline. They acquire systematic academic research.
Learning Objectives/ Learning Outcomes	Completed academic paper which shall show that the students are capable of independently processing a problem related to their subject according to academic methods within a set deadline.
(Study-Specific) Prerequisites	The topic of the Master's thesis cannot be assigned until 80 CPs have been achieved.
(recommended) Requirements	-
References	-
Language	English
Examination Terms	100% Master Thesis, to pass the Master Thesis, the participation at the colloquium is mandatory
Miscellaneous	-
Module coordinator	-
ECTS Credits	30
Contact time (WSH)	1
Examination duration (min)	-
Total hours (h)	900,0
Contact hours (h)	15,0
Self-study hours (h)	885,0

Exam node

Title	Recommended Semester (Study start winter)	Recommended Semester (Study start summer)	ECTS Credits	Contact time (WSH)
Master Thesis (402478301)	4th semester	no semester recommended	30	-