Module Handbook

Career-Integrated Master's Program
Simulation Based Engineering

Degree: Master of Engineering (M. Eng.)

Technische Hochschule Ingolstadt
Institut für Akademische Weiterbildung
Status

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Quality Assurance

In its present version, the study course Master of Engineering Simulation Based Engineering has

- successfully undergone the internal approval procedure of Technische Hochschule Ingolstadt and
- been subjected to an external inspection by the Bayerisches Staatsministerium für Bildung und Kultus, Wissenschaft und Kunst (Bavarian Ministry for Education and Cultural Affairs, Science and Art) within the scope of granting a consensus for the establishment or for a significant change of study courses according to Art. 57(3) BayHSchG (Bavarian Colleges and Universities Law).

The study course is continually evaluated and further developed within the scope of the internal quality assurance system for academic further education of Technische Hochschule Ingolstadt. The regulations of the QM manual and the guidelines for the aptitude requirements and the approval procedures of practice partners are applied.

The module handbook has been approved in its present version by the IAW Academic Dean.

The IAW Quality Officer is available for further questions and suggestions regarding the quality management system for academic further education.

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For reasons of improved legibility, the male form will be used throughout the remainder of this document. The female form is hereby included. This procedure exclusively serves the purposes of simplification.

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1 Overview

Master of Engineering Simulation Based Engineering

Type of study	Career-integrated master's program
Academic degree	Master of Engineering (M.Eng.)
Type of qualification	Double Degree with HAW Landshut
Initial start date	19.09.2005
Normal study period	5 semesters
Study duration	4 semesters - The number of semesters can usually be reduced to four semesters as students may receive credit for previously acquired knowledge and competencies.
ECTS credit points	90 ECTS credit points
Elective module/s	none
Compulsory elective module/s	- Fatigue and Fracture - Scientific Programming - Optimization and Robust Design - Modeling Techniques - Acoustics - Multibody Systems - Product Development and Manufacturing Processes - Experimental Validation - Mechatronics - Computational Fluid Dynamics and Heat Transfer - Computational Fluid Dynamics in Practice - Simulation: State-of-the-Art in Industry and Sciences
Mandatory module/s	- Applied Methods in Simulation-Based Engineering - Specific Methodological Competencies - Self-Competence and Social Competence at the Workplace - Mathematics and Computational Methods - Solid Mechanics - Finite Element Method - Materials and Material Models - Computational Dynamics

	- Project - Geometrically Nonlinear and Contact Analysis
Target group	Graduates with a first academic degree in the field of engineering or natural sciences as well as graduates of other related subjects with at least 210 ECTS credit points or equivalent study volume. We address graduates with qualified work experience (at least 1 year) in the field of engineering or natural sciences acquired after the first academic degree. The study program is taught in English. Therefore, candidates need sufficient English skills (level B2 according to the Common European Framework of Reference) as well as German (level A1).
Study location	TH Ingolstadt, HAW Landshut
Language of Instruction	English

2 Introduction

Simulation-based engineering technologies contribute to shorter and optimized product development cycles in many fields of industry and research.

Computer-aided analysis and simulation allow a deep understanding of products and improve development processes in costs and time to market. Engineers can assess and test the behavior of future components, products, and processes by subjecting them to a range of computer simulated physical conditions. Time and money can be saved without loss in product quality, which otherwise would have been spent on cost-intensive test runs. Quite the contrary: safety, comfort, and durability of the products are improving. As digitalization and the use of Simulation-based engineering continue to expand within companies, the demand for professionals with further expertise in this field expands accordingly.

Due to these facts the master's program Simulation Based Engineering was established. A strong public-private partnership consisting of the Universities of Applied Sciences in Ingolstadt and Landshut and CADFEM GmbH forms the basis and the driving force of this career-integrated study program. It puts a strong focus on simulation-based engineering and imparts relevant basics as well as up-to-date expert knowledge.

2.1 Objectives

The study program is designed with the objective to deepen qualified and practice-oriented knowledge in the area of computer-aided simulation technologies. Based on scientific knowledge and methods, graduates will be prepared to take over new tasks in their field of expertise as well as more management-oriented tasks.

Furthermore, students will improve their personal skills such as intercultural competencies and conflict- and self-management by obtaining methodical expertise and highly developed processual thinking. Graduates will be able to participate in new complex projects or to take over project leadership positions.

2.2 Approval prerequisites

To gain admission to the master's program Simulation Based Engineering, a first academic degree in the field of engineering sciences or natural sciences is mandatory. This degree should contain 210 ECTS credit points. For candidates with a first academic degree with at least 180 ECTS credit points, missing ECTS credit points can be accredited due to previous occupational experience on a case-by-case review basis.

Additionally, qualified professional work experience in the field of engineering or natural sciences of at least one year is required. Furthermore, applicants need proof of their proficiency in English (level B2 according to the Common European Framework of Reference or TOEFL iBT min. 80 Pt.) as well as German (level A1).

Generally, the admission requirements of the BayHSchG (Bavarian Colleges and Universities Law) apply.

2.3 Target group

The master's program prepares its students for specific tasks in the field of simulation-based engineering. It addresses young professionals with work experience in engineering, natural sciences or in a related field, who would like to enter the rapidly growing area of Computer-Aided Engineering, as well as experienced engineers, who are already working in the field and would like to improve their knowledge. Graduates improve their career opportunities remarkably through theoretically based and application-oriented lectures and seminars. Taught in English, the master's program addresses international students, too.

2.4 Study course design

2.4.1 Study course, if applicable with information on field of specialization

The study program is organized as a career-integrated program. Graduates will receive 90 ECTS credit points. The normal study period is five semesters. The number of semesters can usually be reduced to four semesters, as students may receive up to 15 credit points for previously acquired knowledge and competencies to substitute the modules of the first semester. Applications for recognition of these competencies are checked individually by the director of studies and the Board of Examiners.

Starting with the second semester, the program contains seven mandatory modules and two compulsory elective modules in the fourth semester.

In the first semester, the module "Applied Methods in Simulation-Based Engineering" lays a solid foundation for the following study program and builds uniform knowledge about methods of simulation-based engineering. The modules "Specific Methodological Competencies" and "Self-Competence and Social Competence at the Workplace" support the students' personal and professional development.

At the beginning of the second semester, the students' previously acquired knowledge from their bachelor's studies will be built upon and essential mathematical and numerical concepts will be conveyed in the module "Mathematics and Computational Methods". The module "Solid

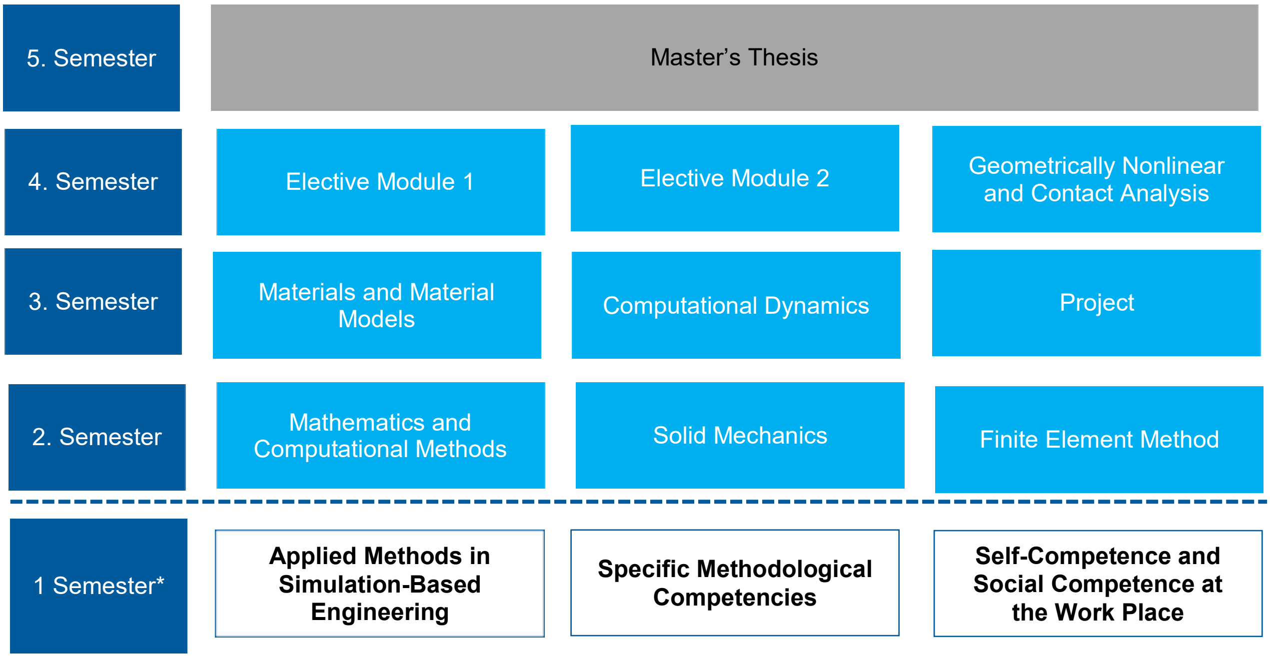
Mechanics" shares thorough mechanical problem descriptions. During the module "Finite Element Methods" detailed numerical methods for solving such problems will be examined.

In the third semester, the students will further deepen their understanding of various topics concerning the description and solution of structural mechanics tasks, for example in the field of nonlinear problems or dynamics in the modules "Material and Material Models" and "Computational Dynamics". They will also learn to solve realistic problems and improve their team-working skills in the module "Project".

During the fourth semester, the students refine their analytical skills in the mandatory module "Geometrically Nonlinear and Contact Analysis" and develop their own academic focus by choosing two compulsory elective modules out of a catalogue of various modules like "Fatigue and Fracture" and "Experimental Validation". They may also take the opportunity to supplement their coursework through additional courses in complementary physics like "Mechatronics", "Acoustics", or "Computational Fluid Dynamics and Heat Transfer".

2.4.2 Graphic representation of the study course

The following picture shows the study course in graphical form.



** The modules of the first semester stated in the Appendix of the SPO can be credited under consideration of the basic principle of Art. 63 BayHSchG.*

2.5 Prerequisites for advancement

none

2.6 Conception/Advisory Board

The master’s program Simulation Based Engineering (M.Eng.) was designed by Technische Hochschule Ingolstadt (THI), Hochschule für Angewandte Wissenschaften (HAW) Landshut, and CADFEM GmbH in 2005 as the first career-integrated master’s degree program in Germany in Simulation-Based Engineering. At that time, only full-time university courses were available in the field of numerical simulation, which were mostly theoretically oriented. However, industry requires engineers with application-based knowledge and the capability of effectively solving complex problems. Enquiries and personal interviews showed a lack of experience in the application of Simulation-Based Engineering among graduates as well as a need for management and quality assurance skills – a need, which can optimally be addressed by a career-integrated master’s program while maintaining business life. The European Commission, which offered funding from 2004 until 2006 through the European Union’s Leonardo da Vinci grant program, voted the study program “to be an innovative, original and daring project, on the pulse of time”. Independent referees evaluated the achievements of the program with a total score of 9.75 out of 10 (excellent).

Since 2005, the master’s program has started with a new study group each year. The Universities of Applied Sciences in Ingolstadt and Landshut are very active in the field of career-integrated studies and they continue to gain experience over the years. A consequent quality management ensures the course to stay up-to-date with the latest developments in didactics. The program received its first accreditation by ASIIN in 2007. The evaluators especially highlighted the practical link and the regular inclusion of projects of the students’ employers as particularly positive as they prepare students for their real-life tasks. The accreditation was confirmed in 2017.

Within the program’s public-private partnership CADFEM, one of Europe’s largest providers of simulation technology, directly contributes to the study contents. Their expert knowledge together with external lecturers from different sectors of industry, who bring in the latest practical simulation know-how, allows keeping the program up-to-date so it serves the needs of companies and employee alike.

The master’s program Simulation Based Engineering has an international orientation. All lectures are taught in English. Apart from German students, participants from Brazil, China, India, Italy, Luxembourg, Norway, Vietnam, Switzerland and the USA have completed the course. The program proved to be especially interesting for employees of foreign companies with German headquarters. These candidates combine their professional stay in Germany with academic further education. Since 2016 students can also participate in modules on Computational Fluid Dynamics at HSR Rapperswil in Switzerland.

3 Qualification profile

3.1 Qualification profile IAW

The IAW has defined a qualification profile for further education study programs, which targets the personal and professional development of students. As a result, students attain knowledge and skills, which enable them to be successful both professionally and socially.

Each study program therefore conveys specialist competencies, methodological competencies, and social and self-competencies, which are specified in the respective study courses.

Students lay the foundation for their further personal and professional development with the Institute of Further Education. They acquire knowledge and skills in order to be successful and also to act in a socially responsible manner.

Specialist competencies: *Fundamental theories, concepts and methods, which endure beyond trends, are shared based on practical experiences. The students strengthen their knowledge in topical subject areas. They gain the ability to recognize, analyze and solve new problems. The acquired knowledge can be transferred to future developments and successfully implemented into professional development.*

Self-competencies: *The students are open to innovation and persistently and resolutely pursue their objectives. They are able to set priorities, delegate tasks, and make and implement courageous decisions even under high work pressure. The students critically question issues and reflect their own actions with a view to their social responsibility.*

Social competencies: *In small groups, the students not only strengthen their communication and team skills, but also their ability to deal with conflicts. They work jointly on complex topics and problems not only during the residential phases, but also throughout the module regardless of time and location. They are accustomed to giving and receiving constructive feedback. The students introduce their professional knowledge into an interdisciplinary context and furthermore develop an extensive network from which they will also benefit after their study course.*

Methodological competencies: *Selected case studies from the students' everyday professional life expand their methodological repertoire. Amongst other things, they learn to present skillfully, to structure processes and to successfully implement projects. They also receive the ability to autonomously acquire new knowledge.*

3.2 Study course objectives

3.2.1 Specialist competencies of the study course

The graduates are capable of

- developing innovative products and technologies with modern simulation-based engineering methods and tools.
- describing and applying scientific fundamentals in the fields of
    a. mathematics and computational methods,
    b. linear and nonlinear structural mechanics,
    c. dynamics, and
    d. further simulation topics of chosen mandatory elective modules.
- understanding and designing development processes in a complex environment.

- deriving and analyzing simulation models for engineering challenges, determining the most suitable simulation method for a given problem.
- interpreting simulation results and identifying possible improvements.
- designing experiments for validation of simulation results.

3.2.2 Interdisciplinary competencies of the study course

The following generic competencies are of particular significance for the study course.

Methodological competencies:

The graduates are capable of

- applying methods of scientific work with confidence.
- choosing appropriate project management methods and implementing these methods in practice.
- applying suitable search strategies to get information.
- abstracting and expressing complex issues.

Social competencies:

The graduates are capable of

- discussing, communicating, and moderating with colleagues of all qualification levels.
- taking over lead or expert positions in R&D projects.
- integrating all relevant stakeholders into operational procedures.
- working in intercultural teams.

Self-competencies:

The graduates are capable of

- judging autonomously.
- acquiring advanced knowledge on their own and applying it.
- working systematically and efficiently to solve even complex problems.

3.2.3 Examination concept of the study course

In the second semester theoretical basics will be taught in the following modules: “Mathematics and Computational Methods”, “Solid Mechanics”, and “Finite Element Methods”. For these modules a written exam is especially suitable to examine theoretical knowledge and the ability for solving application issues.

Besides the written exams of the theoretical modules “Materials and Material Models” and “Computational Dynamics”, a project work will be offered in the module “Project” in the third semester. Therein, a real-life problem will be solved in a team applying learned competencies from the field of simulation.

Complementing the theoretical module “Geometrically Nonlinear and Contact Analysis” with a written exam two compulsory elective modules must be chosen out of a catalogue of elective modules in the fourth semester. The examination forms are presented in the table below and include oral exams, student research/seminar papers, a practical examination and written exams.

Serial number acc. Appendix 1 Studien- und Prüfungsordnung (Study and Examination Regulations) (SPO)	Modules	Examinations
1	**Applied Methods in Simulation-Based Engineering**	Oral examination
2	**Specific Methodological Competencies**	Student research paper
3	**Self-Competence and Social Competence at the Workplace**	Student research paper
4	**Mathematics and Computational Methods**	Written examination
5	**Solid Mechanics**	Written examination
6	**Finite Element Method**	Written examination
7	**Materials and Material Models**	Written examination
8	**Computational Dynamics**	Written examination
9	**Project**	Project thesis
10/11.1	**Compulsory Elective Module: Fatigue and Fracture**	Written examination
10/11.2	**Compulsory Elective Module: Scientific Programming**	Student research paper
10/11.3	**Compulsory Elective Module: Optimization and Robust Design**	Oral examination
10/11.4	**Compulsory Elective Module: Modeling Techniques**	Oral examination
10/11.5	**Compulsory Elective Module: Acoustics**	Oral examination
10/11.6	**Compulsory Elective Module: Multibody Systems**	Written examination

10/11.7	**Compulsory Elective Module: Product Development and Management Processes**	Seminar paper
10/11.8	**Compulsory Elective Module: Experimental Validation**	Practical examination
10/11.9	**Compulsory Elective Module: Mechatronics**	Written examination
10/11.10	**Compulsory Elective Module: Fluid Dynamics and Heat Transfer**	Written examination
10/11.11	**Compulsory Elective Module: Simulation: State-of-the-Art in Industry and Science**	Student research paper
10/11.12	**Compulsory Elective Module: Computational Fluid Dynamics in Practice**	Project thesis
12	**Geometrically Nonlinear and Contact Analysis**	Written examination
13.1	**Masterarbeit**	Master thesis
13.2	**Kolloquium**	Thesis defense

3.2.4 Application-orientation of the study course

Choice of lecturers:

The faculty of the master's program Simulation Based Engineering has extraordinary expertise in the field of simulation-based engineering and their education concepts are both scientifically based and practice-oriented. To provide a wide range of specialized knowledge, professors from TH Ingolstadt and HAW Landshut as well as experts from other universities and from industry teach in this study program.

Generally, all professors of the program possess at least five years of working experience; at least three years were conducted in the industrial sector. All associate lecturers show at least three years of working experience outside a university. Additionally, lecturers ideally provide some international experience to support students with their preparations for global engineering challenges.

Definition and address of the target group:

The master's program Simulation Based Engineering specifically addresses graduates with a first academic degree in the field of engineering or natural sciences as well as graduates of other related subjects. Their work experience may be taken into account by accreditation of up to one semester of theoretical studies.

Concept of the lectures:

The study course is organized extra-occupationally, i.e., the learning contents match the students' range of occupational responsibilities. During the self-learning phases students prepare themselves for the subsequent residential phases and deepen their knowledge. The students transfer the newly adopted expertise to their current or future area of responsibility at their workplace.

Project works and seminar papers are usually based on real-life questions and problems at their places of employment. Thus, solutions developed by students in these examination forms can be used directly in their companies. A direct transfer from theory into practice is therefore guaranteed as well as the utility of the subject matter.

The objectives of group and project work are not only the acquisition of new expertise, but also improving soft skills like team work, project management, and self-management, which are indispensable in every working environment today.

Normally, the students choose a topic for their master's thesis out of their occupational context, so the preparation for the thesis can be partially integrated into the work at their company.

3.3 Future professional fields

Graduates of the study program are particularly prepared for specialist and management tasks in the following areas:

- Development and optimization of new technologies, products and processes
- Applied research
- Virtual testing
- Quality management
- Technical control

As a result, the focus is placed on the following branches:

- Research and development departments of large and medium-sized companies in the areas mechanical, plant, and tool engineering
- With additional expertise also in civil engineering, electronics, biomedical or aerospace engineering
- Medium-sized engineering offices which provide simulation services within simulation projects of large companies
- OEM and system suppliers for OEM
- Higher services
- PhD study programs

4 Module descriptions

4.1 Applied Methods in Simulation-Based Engineering

(Serial no. Acc. Appendix to SPO: **1**)

Module Director	**Prof. Dr. Jiří Horák, Prof. Dr.-Ing. Detlev Maurer**
Lecturer (s)	N.N.
Semester according to study schedule	1
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Definition of simulation objectives with employers and clients - Choice of adequate simulation processes - Simulation with a computation software - Evaluation and documentation of results
Learning results	Following participation in the module events, the participants are capable of, - developing products and technologies with simulation-based engineering methods - deriving and analyzing simulation models for engineering challenges - determining an appropriate simulation method for a given problem. - interpreting simulation results and identifying possible improvements. - handling a professional simulation software
Materials, methodology	Beamer, slides, blackboard, computer lab with simulation software

Prerequisite for participation	None Expected prior knowledge: content related work experience for at least one year
Usability for other study courses	none
ECTS-credit points	5
	Hours total: 125

Workload and distribution in hours	Hours in attendance: 40	
	Hours self-study: 62	
	Hours examination preparation: 23	
Semester hours per week	4	
Examination prerequisites	None	
Type of examination	Oral examination	
- ***Weighting in the overall grade (%)***	4%	
Literature	Basic literature: - J.S. Rao, Simulation Based Engineering in Solid Mechanics, 1st edition, Springer International Publishing, Berlin, Heidelberg, 2017.	
	Further literature: - will be announced during the course.	

4.2 Specific Methodological Competencies

(Serial no. Acc. Appendix to SPO: **2**)

Module Director	**Prof. Dr. Jiří Horák, Prof. Dr.-Ing. Detlev Maurer**
Lecturer (s)	N.N.
Semester according to study schedule	1
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Project management - Process management - Communication techniques - Coordination - Presentation and moderating skills - Scientific methods - Analytical and problem solving skills
Learning results	Following participation in the module events, the participants are capable of - actively participating in project teams or of taking over lead positions in smaller projects - structuring processes and of observing set rules - successfully coordinating technical work with internal or external stakeholders and of professionally communicating results - integrating relevant stakeholders into operational procedures while considering time and effort - professionally presenting results in a well-adjusted form to specific target groups - analyzing complex problems, of constructively solving them and of finding alternative solutions if necessary - evaluating the suitability of a given method and of improving methods to specific situations
Materials, methodology	Beamer, slides, blackboard

Prerequisite for participation	None Expected prior knowledge: content related work experience for at least one year

Usability for other study courses	all study programs at Institute of Further Education at THI
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 23
	Hours examination preparation: 62
Semester hours per week	4
Examination prerequisites	None
Type of examination	Student research paper (assignment without oral presentation)
Weighting in the overall grade (%)	4%
Literature	Basic literature: - O. Zwikael, J.R. Smyrk, Project Management, A Benefit Realization Approach, Springer International Publishing, Berlin, Heidelberg, 2019
	Further literature: - will be announced during the course

4.3 Self-Competence and Social Competence at the Workplace

(Serial no. Acc. Appendix to SPO: **3**)

Module Director	**Prof. Dr. Jiří Horák, Prof. Dr.-Ing. Detlev Maurer**
Lecturer (s)	N.N.
Semester according to study schedule	1
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 semester
Language of instruction	English

Form of teaching and learning	Seminar / practise
Content	- Supervision of teams - Self-driven knowledge acquisition - Priority and time management - Stress management - Self-competence - Cooperation skills - Intercultural competencies
Learning results	Following participation in the module events, the participants are capable of, - managing teams functionally or person related. - acquiring independently relevant knowledge and letting it flow systematically into one's own work. - designing the way, oneself works systematically and efficiently, setting priorities and delegating thematic areas. - achieving good results even with high workloads, changing tasks or deadlines. - recognizing weaknesses and strengths of one's own professional style and modifying it. - performing together in a team and proactively contributing to groups. - working in an intercultural environment and deal with cultural differences.
Materials, methodology	Beamer, slides, blackboard

Prerequisite for participation	None Expected prior knowledge: content related work experience for at least one year
Usability for other study courses	all study programs at Institute of Further Education at THI

ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 23
	Hours examination preparation: 62
Semester hours per week	4
Examination prerequisite	None
Type of examination	Student research paper (assignment without oral presentation)
Weighting in the overall grade (%)	4%
Literature	Basic literature: - D.Bourn, Understanding Global Skills for 21st Century Professions, Palgrave Macmillan, London, 2018
	Further literature: - will be announced during the course

4.4 Mathematics and Computational Methods

(Serial no. Acc. Appendix to SPO: **4**)

Module Director	**Prof. Dr. Jiří Horák**
Lecturer (s)	Prof. Dr. Jiří Horák
Semester according to study schedule	2
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Numerical solution of large systems of linear algebraic equations, round-off error - Numerical solution of nonlinear equation systems - Numerical approximation of derivatives and integrals - Surface integrals, integral theorems and their applications - Linear and tensor algebra - Fourier series - Differential equations: initial and boundary value problems, numerical solution
Learning results	Following participation in the module events, the participants are capable of - understanding the influence of the round-off error and conditioning on the numerical solution of large systems of linear algebraic equations and assessing which direct or iterative methods are suitable for the given purpose. - applying a suitable iterative method to approximately solve a nonlinear equation or a nonlinear system, predicting the expected order of convergence. - estimating the error of a numerical approximation of derivatives and integrals and using a suitable order of approximation for the given application. - stating the concept and methods of computation of surface integrals, understanding their relationship to line and volume integrals via integral theorems, being aware of their physical meaning in basic engineering applications. - conducting a linear transformation of coordinates, understanding the notion of orthogonality in function spaces. - understanding the concept of tensors and are familiar with some applications in engineering. - decomposing a given function into a Fourier or related series, understanding the principle of superposition of harmonic signals.

	- using a catalog of basic numerical methods for initial and boundary value problems, assessing the impact of the choice of the method's type, order and step size on the behavior of the numerical solution and the cost of the computation. - simple implementations of the discussed numerical methods in some widely used computer algebra system or programming language.
Materials, methodology	All: Lecture notes, Matlab/Octave scripts, Moodle Lecturer: Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None <u>Expected prior knowledge:</u> The knowledge of undergraduate calculus and algebra is assumed. This includes in particular - Sequences, convergence, limits - Functions of one real variable, derivative, integral and their applications, Taylor polynomial - Series, convergence, power series, Taylor series - Complex numbers, polar coordinates, trigonometric and exponential functions, logarithms - Ordinary differential equations, separation of variables, linear equations, exponential growth and decay, harmonic oscillations - Number vectors and matrices, inverse matrix, determinant, Gaussian elimination, eigenvalues and eigenvectors, basis and dimension of a linear vector space, linear dependence and independence, dot and cross products - Scalar and vector-valued functions of several real variables, partial and total derivative and their applications, gradient, divergence and curl, planar and volume integrals Basic programming knowledge is also expected.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	none
Type of examination	Written examination (90 minutes)

Weighting in the overall grade (%)	7%
Literature	Basic literature: - Larry Turyn: Advanced Engineering Mathematics, CRC Press, 2014 - Dennis G. Zill and Warren S. Wright: Advanced Engineering Mathematics, 5th edition, Jones & Barlett Learning, 2014
	Further literature: - will be announced during the course

4.5 Solid Mechanics

(Serial no. Acc. Appendix to SPO: **5**)

Module Director	**Prof. Dr. Otto Huber**
Lecturer (s)	Prof. Dr. Otto Huber
Semester according to study schedule	2
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Stress state: Definition of stress vector and stress tensor; index notation; coordinate transformation; principal stresses; invariants; hydrostatic stress state; stress deviator; equations of equilibrium; boundary conditions - Deformation and strain state: Definition and notation; Lagrange and Euler description; small displacements and small strains; linear strain tensor; principal strains; compatibility equations - Constitutive equations: Linear elasticity; isotropic and anisotropic materials; homogenization; thermoelasticity; applications - Plane problems: Plane stress; plane strain; stress differential equations; stress functions - Torsion problems: Classification, torsion of bars with solid sections - Plate problems: Displacement differential equations - Energy principles: Strain energy and complementary energy; principle of virtual work; total potential energy; method of Ritz; applications.
Learning results	Following participation in the module events, the participants are capable of - acquiring a solid comprehension of the fundamentals of solid mechanics. - applying mathematical concepts on engineering problems. - reducing complex technical problems into simplified models with enough validity for the early phase of the design process and review FEM results. - getting the comprehension of the description of problems in the field of linear elasticity and its solution methods. - grasping the stress and strain state and the constitutive equations for linear problems. - stating different homogenization methods. - getting a good comprehension of energy principles.

	- solving problems in the field of elastostatics (e.g. torsion, plane and plate problems). - checking FEM solutions and to interpret results in the field of elasticity. - grasping the potential and limitations of analytical methods within solid mechanics.
Materials, methodology	Handout, Presentation slides, Blackboard or whiteboard, Lab presentation, Moodle, Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None <u>Expected prior knowledge:</u> The knowledge of undergraduate mathematics, statics and strength of materials is assumed. This includes in particular: - *Mathematics*: Functions of one real variable, derivative, integral and their applications; Taylor and Fourier series; Polar coordinates, trigonometric and exponential functions, logarithms; Ordinary differential equations; Vectors and matrices, determinants, eigenvalues and eigenvectors, systems of equations, inverse matrix, dot and cross products; Scalar and vector-valued functions of several real variables, partial and total derivative, gradient, divergence, planar integrals. - *Statics*: Equivalence and Equilibrium; Coplanar force systems; Center of Gravity; Resultants in beams; Moments of Inertia; area moments of first and second order; Truss and frame structures - *Strength of Materials*: Tension and compression; Bending and transverse shear; Torsion (circular and thin-walled non-circular cross sections); Superposition, combined loading, equivalent stresses; Statically indeterminate systems From the module „Mathematics and Computational Methods" - Line integrals, surface integrals, Gauss' and Stokes' theorems and applications - Linear algebra: coordinates with respect to a basis, change of bases, Euclidean vector spaces (inner product), orthonormal bases, orthogonal projection, Fourier coefficients - Tensor algebra: introduction to Cartesian tensors with basic examples - Fourier/cosine/sine series	
Usability for other study courses	none	
ECTS-credit points	5	
Workload and distribution in hours	Hours total: 125	
	Hours in attendance: 40	
	Hours self-study: 62	
	Hours examination preparation: 23	
Semester hours per week	4	
Examination prerequisites	None	

Type of examination	Written examination (90 minutes)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - R. G. Budynas: Advanced Strength and Applied Stress Analysis, McGraw-Hill, 1999 - G. T. Mase, G. E. Mase: Continuum Mechanics for Engineers, CRC PRESS, 2010 - S. P. Timoshenko, J. N. Goodier: Theory of Elasticity, McGRAW-HILL, 2001 - W. C. Young, R. G. Budynas: Roark´s Formulas for Stress and Strain, McGraw-Hill 2002 - J. R. Vinson: Plate and Panel Structures of Isotropic, Composite and Piezoelectric Materials, Including Sandwich Construction, Springer 2005
	Further literature: - D. Gross, W. Hauger, W. Schnell, P. Wriggers: Technische Mechanik 4, Springer, 2007 - H. Göldner: Lehrbuch Höhere Festigkeitslehre, Band 1, Grundlagen der Elastizitätstheorie, Fachbuchverlag Leipzig, 1991

4.6 Finite Element Method

(Serial no. Acc. Appendix to SPO: **6**)

Module Director	**Prof. Dr.-Ing. Detlev Maurer**
Lecturer (s)	Prof. Dr.-Ing. Detlev Maurer
Semester according to study schedule	2
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 Semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- 1) Introduction: Outline of the basic concept of FEM; Steps of a FEA in stress analysis; Typical Finite Elements,overview over typical fields of application; significance of the FEM - 2) The principle of virtual work; Finite Element formulation for elastodynamic problems - 3) Solid isoparametric elements: General concept, shape functions, Gauss' quadrature, choice of quadrature rule, reduced integration, stress calculation - 4) Modeling in linear stress analysis: Modeling in general, mesh generation, material properties, boundary conditions (single point constraints, multi point constraints, mechanical loads, thermal loads), model checking, postprocessing, checking the results, documentation and presentation, Selected topics like stress concentrations, modeling of welds and bolts, adaptive meshing - 5) Bars and beams, plates and shells; variational formulation, weighted residual method, mixed formulations - 6) Heat transfer: Finite element formulation for heat transfer problems; heat conduction in solids, convection and radiation boundary conditions; practical examples of steady state and transient heat transfer problemsSelected topics: Finite Difference Method for heat transfer problems; introduction to optimizationpractical exercises with commercial software in the fields of stress analysis and heat transfer
Learning results	Following participation in the module events, the participants are capable of

	- acquiring a deepened knowledge and understanding of the Finite Element Method (FEM) and of modeling techniques in numerical simulations. - explaining the theoretical background of FEM. - applying mathematical concepts in the context of numerical simulations to engineering problems. - understanding the formulation of different types of Finite Elements and with their performance and application in numerical simulations. - applying FEM to engineering problems, especially linear stress analysis and heat transfer problems and have exercised this with practical examples using commercial software tools. - performing a Finite Element Analysis based on the understanding of the simulation method and its modeling techniques, including correct modeling of the real physical problem, selection of appropriate Finite Elements, checking, presenting and discussion of results. - realizing the potential and the limits of FEM. -
Materials, methodology	Lecture notes; FEM lab with software ANSYS (PC lab) Exercises with results, Moodle, Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None <u>Expected prior knowledge:</u> The knowledge of undergraduate mathematics, solid mechanics and stress analysis is assumed. From the module „Mathematics and Computational Methods” the knowledge about - Line integrals, surface integrals, Gauss' and Stokes' theorems and applications - Tensor algebra: introduction to Cartesian tensors with basic examples is helpful. A basic knowledge of FEM is also recommended.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Written examination (90 minutes)
Weighting in the overall grade (%)	7%

Literature	Basic literature: - K.-J. Bathe: Finite Element Procedures, Prentice Hall, 2007 - R.D. Cook, Malkus, Plesha, Witt: Concepts and Applications of Finite Element Analysis, John Wiley & Sons, 2001 - N.S. Gokhale, S.S. Deshpande, S.V. Bedekar, A.N. Thite: Practical Finite Element Analysis, Finite to Infinite, Pune, 2008
	Further literature: - will be announced during the course

4.7 Materials and Material Models

(Serial no. Acc. Appendix to SPO: **7**)

Module Director	**Prof. Dr. Armin Fritsch**
Lecturer (s)	Prof. Dr. Armin Fritsch; Prof. Dr. Christian Hühne
Semester according to study schedule	3
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 Semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	Part I: Constitutive modeling of materials: - Introduction to material classification (examples) - The four categories of material behavior and modeling - Tensor calculus within a mechanical context - General considerations and mechanical principles - Plasticity: Experimental observations and constitutive assumptions - Derivation of J_2-(von Mises) Plasticity, constitutive equations - Viscoelasticity: Theory of linear viscoelasticity - Rheological models: Maxwell, Kelvin-Voigt, generalized Maxwell model - Boltzmann's superposition principle - Temperature dependency of viscous materials, shift functions - Computational aspects: Implementation of material models - Newton-Raphson algorithm, stress algorithm - Tangent modulus Part II: Composites: - Materials - Processes - Classical Laminate Theory - Hardening and pseudo-plasticity - Failure criteria - Intralaminar Damage: Progressive failure analysis,Mechanics and basics for fracture mechanics,Determination of required critical energy release rates - VTP example

Learning results	Following participation in the module events, the participants are capable of Part I: - distinguishing and classify different material behaviors based on experimental observations. They know about the test specifications to account for time dependent effects. - evaluating tensor equations and to calculate the derivative of scalar functions with respect to 2nd-order tensors. - stating the mechanical principles used in material modelling, e.g. “The principle of distortional energy” and “The principle of the equivalence of plastic work”. - understanding and interpreting the representation of the yield surface in the principal stress space using deviatoric and hydrostatic stress vectors. - understanding the stress algorithm applied to the constitutive algebra-differential equations (predictor-corrector method, Euler-backward algorithm). They know about the need to calculate the tangent modulus according the Newton-Raphson procedure. - possessing the ability to derive the differential equations of simple rheological models based on an operator notation and solving these equations for a relaxation and creep test. - understanding the meaning of a relaxation- and creep-function, relaxation time and strength. - recognizing a thermo-rheological simple material behavior based on experimental observations and understanding the use of “shift-functions” to account for temperature-dependency. Part II: - knowing the materials used for composite structures. - understanding manufacturing processes. - using the skills to size a composite structure by use of classical laminate theory. - understanding the failure modes and criteria of composites. - recognizing the numerical approaches to consider progressive intralaminar damage. - being aware of numerical approaches to determine interlaminar failure and material degradation.
Materials, methodology	Lecture notes, Black-/Whiteboard, Moodle, LCD-projector, PC, Lab-exercises with ANSYS

Prerequisite for participation	None <u>Expected prior knowledge:</u> The knowledge of undergraduate mechanics and mathematics is assumed. This includes in particular - Definition of stress and strain tensors, deviatoric – hydrostatic split - Theory of linear Elasticity From module “Mathematics and Computational Methods” - Tensor algebra From module “Finite Element Methods” - Gauss' quadrature, stress calculation and material properties From module “Solid Mechanics” - Stress state, deformation and strain state, constitutive

	equations, principle of virtual work Furthermore, extended knowledge of the Finite Element method as well as comprehension of numerical approximation of derivatives and integrals and numerical solution of equations systems is recommended.
Usability for other study courses	None
ECTS-credit points	5

Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Written examination (90 minutes)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - Baker, Dutton, Kelly: Composite Materials for Aircraft Structures, 2nd edition, 2004. - Bergmann, H.W.: Konstruktionsgrundlagen für Faserverbundbauteile, Springer-Verlag, 1992. - Chen, W.F.; Han, D.J.: Plasticity for Structural Engineers, Springer-Verlag, 1988. - Jones: Mechanics of Composite Material, 2nd edition, 1999. - Kojic, M. and Bathe, K. J.: Inelastic Analysis of Solids and Structures. Springer-Verlag, Berlin, 2005. - Lemaitre, J.; Chaboche, J.L.: Mechanics of solid materials, Cambridge University Press, 1994. - Schürmann, H.: Konstruieren mit Faser-Kunststoff-Verbunden, 2. Auflage, Springer-Verlag, 2007. - Schwarzl, F.R.: Polymermechanik, Springer-Verlag, 1990. - VDI 2014: Entwicklung von Bauteilen aus Faser-Kunststoff-Verbund (Blatt 1: Grundlagen, Juli 1989, Blatt 2: Konzeption und Gestaltung, September 1993, Blatt 3: Analysis, September 2006).
	Further literature: - will be announced during the course

4.8 Computational Dynamics

(Serial no. Acc. Appendix to SPO: **8**)

Module Director	**Prof. Dr. Jörg Bienert**
Lecturer (s)	Prof. Dr. Jörg Bienert, Dr. Ulrich Stelzmann
Semester according to study schedule	3
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 Semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Introduction: repetition of the theory of SDOF-systems (Single Degree of Freedom) - General equation of motion with multiple degrees of freedom, derivation of system matrices, especially mass and damping matrices - Numerical simulation, characterization of dynamic analysis types: Modal analysis, transient dynamic analysis, harmonic response analysis, spectrum analysis - Reduction methods in dynamic simulation: Guyan Reduction, Craigh-Bampton method, mode superposition - Modal analysis: Compute natural frequencies and mode shapes; basic equation of the eigenvalue problem; numerical methods for the solution of large systems; eigenvalues of pre-stressed structures; unsymmetric system matrices; quadratic eigenvalue problem with damping; guidelines for modeling and comparison with experimental data - Harmonic response analysis: Compute the response under harmonic loads; derivation of the general equation; characteristics and restrictions; numerical methods for the solution of large systems; guidelines for modeling and result interpretation - Transient dynamic analysis: Compute the response under arbitrary load; numerical methods to solve the differential equation of motion with implicit and explicit time integration; characteristics, restrictions and advantages; step size in time integration, stability and accuracy; solution of linear and nonlinear problems; guidelines for model set up - Response Spectrum Analysis: Theoretical background, characteristics and restrictions of the method; guidelines for application - Transfer of equations of motions into state space - Frequency Response Functions (FRFs) for linear systems

	- Experimental acquisition of FRFs with different excitation signals and excitation devices - general vibration testing - modal parameter extraction for linear systems; Operational Modal Analysis (OMA) and Experimental Modal Analysis (EMA)
Learning results	Following participation in the module events, the participants are capable of - showing a deep understanding in the field of structural dynamics of large systems. - commanding the corresponding mathematical and technological knowledge and are able to transfer theoretical concepts into practical application like numerical simulation of dynamic systems. - solving dynamic problems with numerical methods, especially with FEM, including the selection of the appropriate simulation method, correct modeling, checking and discussion of results. - estimating the potentials and limits of numerical simulation of dynamic systems. - understanding the basic concepts for solving practical exercises using standard software tools.
Materials, methodology	All: Lecture notes, ANSYS Workbench Projects, Moodle Lecturer: Blackboard or whiteboard, LCD-projector, PC, tablet, Lab exercise with professional vibration analysis system

Prerequisite for participation	None Expected prior knowledge: The knowledge of undergraduate calculus and algebra as well as undergraduate solid mechanics and dynamics is assumed. This includes in particular: - Dynamics of single degrees of freedom systems From the module “Mathematics and Computational Methods” - Numerical solution of ordinary differential equations and initial value problems - Fourier/cosine/sine series and complex Fourier series From the module “Finite Element Methods” - Finite Element formulation for elastodynamic problems A basic knowledge of MATLAB is also recommended. Knowledge of direct (Gauss algorithm) and iterative (Jacobi, OR) methods for numerical solution of systems of linear equations is helpful.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4

Examination prerequisites	None
Type of examination	Written examination (90 minutes)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - K.-J. Bathe: Finite Element Procedures, Prentice Hall, 1996 - R. W. Clough, J. Penzien: Dynamics of Structures. McGraw- Hill, New York, 1993 - U. Stelzmann, C. Groth, G. Müller: FEM für Praktiker – Band 2: Strukturdynamik, Expert Verlag, 2002 - D. J. Ewins: Modal Testing: Theory, Practice and Application, Research Studies Press, 2000 - N. Maia, J. M. Silva: Theoretical and Experimental Modal Analysis, Research Studies Press, 1997 - A. Brandt: Noise and Vibration Analysis: Signal Analysis and Experimental Procedures, John Wiley & Sons, 2011 - R. Brincker, C. Ventura: Introduction to Operational Modal Analysis, John Wiley & Sons, 2015 - D. J. Inman: Engineering Vibration, Pearson, 2014 - R. Gasch, K. Knothe, R. Liebich: Strukturdynamik: Diskrete Systeme und Kontinua, Springer, 2012 - R. Markert: Strukturdynamik, Shaker, 2013
	Further literature: - will be announced during the course

4.9 Project

Serial no. Acc. Appendix to SPO: **9**)

Module Director	**Prof. Dr.-Ing. Detlev Maurer**
Lecturer (s)	Prof. Dr.-Ing. Detlev Maurer
Semester according to study schedule	3
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 Semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Self organized solution of a predefined task by a team based project work - Definition and selection of the project task - Development of a team structure - Definition of the project phases incl. gate review meetings - Methods for a team based solution process (i.e. brain storming, etc.) - Creation of a solution report. - Team based presentation of the results
Learning results	Following participation in the module events, the participants are capable of - acquiring the knowledge of the fundamentals of project management and development processes. - understanding project structures and the project environment. - defining and implement success factors of project management. - designing and organize projects with special focus on managing information technologies and CAE methods. - interacting creatively within a team. - acquiring process orientation, social and communication skills - solving complex and interdisciplinary problems in a team.
Materials, methodology	All: Lecture notes, Team work, PC Pool rooms Lecturer: Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None <u>Expected prior knowledge:</u>

	From the module "Applied Methods in Simulation-Based Engineering": - Definition of simulation objectives with stakeholders - Choice of adequate simulation processes - Simulation with a professional computation software - Evaluation and documentation of results From the module "Specific Methodological Competencies", especially: - structuring processes and successfully coordinating technical work with internal or external stakeholders - analyzing complex problems, constructively solving them and finding alternative solutions if necessary - professionally presenting results in a well-adjusted form The knowledge of basics in numerical methods and physics is assumed.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Project thesis (group paper + presentation)
Weighting in the overall grade (%)	7%
Literature	Basic literature: Pahl, G., Beitz, W., Feldhusen, J., Grote, K.H., Engineering Design, Springer Verlag, Berlin, 2007
	Further literature: - will be announced during the course

4.10 Compulsory Elective Module: Fatigue and Fracture

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr. Michael Vormwald**
Lecturer (s)	Prof. Dr. Michael Vormwald, Prof. Dr Ing. Sergej Diel
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of instruction	English

Form of teaching and learning	Seminar / practise
Content	- Service history determination and measurement, cycle counting methods - Cyclic behavior of materials, stress and strain life curves - Fatigue tests, statistical evaluation and description of fatigue data - Effects on fatigue life (notches and stress raisers, stress gradients, surface roughness, etc.) - Lifetime evaluation based on fatigue - Basics of the Theory of Elasticity, near crack tip solutions, stress intensity factors - Numerical methods based on the Finite Element technology and on weight functions - Energy release rates, J-integral, strip-yield and cohesive-zone models, crack tip opening displacement - Proof of strength based on Failure-Assessment and Crack-Driving-Force diagrams - Fatigue crack growth including load sequence and short crack effects
Learning results	Following participation in the module events, the participants are capable of - handling of service loads and preparing them for fatigue estimations. - understanding material behavior in fatigue problems. - recognizing typical influencing factors on fatigue life. - predicting fatigue life using the FKM Guideline. - using the local strain approach for fatigue estimations. - deciding which numerical method provides stress intensity factors with an optimum with respect to accuracy and effort. - calculating stress intensity factors, J-integrals, and crack tip opening displacements. - evaluating the strength of structures with defects. - calculating fatigue crack growth lives.

Materials, methodology	Lecture notes, Moodle, Blackboard, LCD-projector, PC

Prerequisite for participation	None <u>Expected prior knowledge:</u> The knowledge of undergraduate mechanics and material science as well as basic knowledge in fatigue is assumed. From module “Mathematics and Computational Methods”: - Numerical approximation of integrals and derivatives (one variable) - Numerical solution of ordinary differential equations (single and systems) – initial value problems (explicit and implicit methods, Runge-Kutta family of methods, multistep methods) - Line integrals, surface integrals, Gauss’ and Stokes’ theorems and applications From module “Solid Mechanics”: - Stress state, deformation and strain state - Plate problems: Displacement differential equations From module “Finite Element Method”: - Finite Element formulation for elastodynamic problems - Solid isoparametric elements - Modeling in linear stress analysis Furthermore, comprehension of complex calculus and handling of professional FEM software is recommended.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Written examination (90 minutes)
Weighting in the overall grade (%)	7%

Literature	Basic literature: Fatigue: - J. Schijve: Fatigue of structures and materials, 2n ed. Springer, 2010 - Y. Lee, M.E. Barkey, H.-T. Kang: Metal fatigue analysis handbook. Elsevier, 2012 - FKM Guideline: Analytical Strength Assessment, VDMA Verlag, Frankfurt/Main, 6th edition, 2013 - Hobbacher A.: Recommendations for fatigue design of welded joints and components, Springer International Publishing, 2nd edition, 2016 - Köhler, M., Jenne, S., Pötter, K., Zenner, H.: Load Assumption for Fatigue Design of Structures and Components, Springer, 2017 Fracture Mechanics: - Kuna, M.: Finite Elements in Fracture Mechanics; Theory - Numerics – Applications - Series: Solid Mechanics and its Applications, Vol. 201 - Springer (2013) Hardcover and eBook - ISBN 978-94-007-6680-8 - Zerbst, U., Schödel, M., Webster, S., Ainsworth, R.: Fitness-for-Service Fracture Assessment of Structures Containing Cracks. Elsevier Science, ISBN 978-0-08055283-5, 2007	
	Further literature: - will be announced during the course	

4.11 Compulsory Elective Module: Scientific Programming

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr. Bernhard Gubanka**
Lecturer (s)	Prof. Dr. Bernhard Gubanka
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	Each student group
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Programming basics - From a real world problem to a computer simulation - Numerical solutions of ordinary differential equations - Text book implementations vs professional production code - Realistic projectile motion - Oscillatory motion and chaos - Random systems: random numbers, Monte Carlo methods, random walks - Monte Carlo simulation of a non-technical system - Waves: solving the wave equation, spectral methods
Learning results	Following participation in the module events, the participants are capable of - implementing numerical methods as working computer programs. - assessing the limitations of numerical methods and recognizing numerical artifacts. - recognizing the difference between a text book implementation and professional production code. - translating a real-world problem into a realistic computer simulation. - understanding various simulation methods. - displaying the simulation results. - applying simulation techniques to various kinds of real-world problems.
Materials, methodology	All: Lecture notes, PC with Matlab or Octave, Moodle Lecturer: Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None

	<u>Expected prior knowledge:</u> - Knowledge of undergraduate calculus and algebra. - Ordinary differential equations. - Basic knowledge of partial differential equation. - Basic knowledge of numerical methods. - Basic programming skills
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 23
	Hours examination preparation: 62
Semester hours per week	4
Examination prerequisites	None
Type of examination	Student research paper (assignment without oral presentation)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - Matlab Documentation and Tutorials: http://www.mathworks.com - Press et al.: Numerical Recipes 3rd Edition: The Art of Scientific Computing, Cambridge University Press, 2007
	Further literature: - will be announced during the course

4.12 Compulsory Elective Module: Optimization and Robust Design

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Christian Bucher**
Lecturer (s)	Prof. Christian Bucher, Dr. Johannes Will, Prof. Thomas Binder
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	Each student group
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Minima of functions of many variables - Mathematical formulation of objective function and constraints in engineering problems - Gradient-based optimization methods including constraint handling - Evolutionary strategies and genetic algorithms - Multi-objective optimization - Robustness measures and stochastic analysis - Meta-modeling and response surface techniques - Practical exercises with commercial RDO software - Topology optimization
Learning results	Following participation in the module events, the participants are capable of - applying fundamental concepts of mathematical optimization to engineering problems. - formulating optimization tasks in engineering applications such as structural mechanics. - choosing appropriate optimization methods and analysis tools most suitable for the task under investigation. - understanding and anticipate potential difficulties of certain optimization methods in specific applications. - assessing the robustness and imperfection sensitivity of optimized solutions and develop strategies to improve robustness. - utilizing meta-modeling techniques to substantially reduce computational effort and improve robustness. - applying commercial software tools to achieve robust optimal solutions with moderate effort. - treating topology optimization problems for structures.
Materials, methodology	All: Lecture notes, slangTNG/optiSLang, Ansys Topology, Moodle

	Lecturer: Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None <u>Expected prior knowledge:</u> The knowledge of undergraduate calculus and algebra is assumed. This includes in particular - Functions of one real variable, derivative, integral and their applications, Taylor polynomial. - Functions of several real variables, partial derivatives, gradient, Hessian matrix. - Vectors and matrices, inverse matrix, determinant, Gaussian elimination, eigenvalues and eigenvectors. - Elementary probability concepts, mean value, variance, correlation. From module "Mathematics and Computational Methods" - Numerical approximation of derivatives (one variable) Basic knowledge of structural mechanics is also expected.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Oral examination
Weighting in the overall grade (%)	7%
Literature	Basic literature: - Kirsch, U.: Fundamentals and Applications of Structural Optimization, Springer, 1993 - Bucher, C.: Computational Analysis of Randomness in Structural Mechanics, Taylor& Francis, 2009. - Goldberg, D. E.: Genetic algorithms in search, optimization, and machine learning., Addison Wesley Longman, Inc., 1953 - Myers, R. H.: Response Surface Methodology., Boston, USA: Allyn and Bacon Inc., 1971 - Rechenberg, I.: Evolutionsstrategie: Optimierung technischer Systeme nach Prinzipien der biologischen Evolution., Stuttgart: Frommann-Holzboog, 1973
	Further literature: - will be announced during the course

4.13 Compulsory Elective Module: Modeling Techniques

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Dr. Martin Hanke**
Lecturer (s)	Dr. Martin Hanke
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- FEM and Analysis - Mesh morphing methods - Vector space description of FEM results - Projection as a tool to extract data from FEM results - Increasing Numerical Effectivity - Submodel - Concentrated elements - Superelements - High performance computing - Reduced Order Modeling - ROM concept - Generation methods: State Space Model, Look up table… - Application in system simulation - Constraint Equations - Force distribution from CE's - Material homogenization from periodic structures - Symmetry and Boundary Conditions
Learning results	Following participation in the module events, the participants are capable of - comprehending various advanced modeling techniques. - stating knowledge about vector space as an advanced tool in engineering. - using a catalog of different methods to reduce complexity of their simulation problems, like submodels, superelements, reduced order models, appropriate symmetry conditions. - handling large scaled simulation problems by high performance computing. - choosing an appropriate approach depending on the physics of the problem. - setting up models with different description techniques. - explaining concepts of systems simulation.

	- investigating and discussing complex and interdisciplinary problems in this context.
Materials, methodology	All: Lecture notes, Moodle, Excel/ANSYS Lecturer: Blackboard or whiteboard, Video projector, PC

Prerequisite for participation	None Expected prior knowledge: The knowledge of vector analysis is assumed as well as undergraduate knowledge in physics. Knowledge of terms likes vector space, basis, norm is essential.	
Usability for other study courses	none	
ECTS-credit points	5	
Workload and distribution in hours	Hours total: 125	
	Hours in attendance: 40	
	Hours self-study: 62	
	Hours examination preparation: 23	
Semester hours per week	4	
Examination prerequisites	None	
Type of examination	Oral examination	
Weighting in the overall grade (%)	7%	
Literature	Basic literature: - K.-J. Bathe: Finite Element Procedures, Prentice Hall, 2007 - R.D. Cook, Malkus, Plesha, Witt: Concepts and Applications of Finite Element Analysis, John Wiley & Sons, 2001 - N.S. Gokhale, S.S. Deshpande, S.V. Bedekar, A.N. Thite: Practical Finite Element Analysis, Finite to Infinite, Pune, 2008	
	Further literature: - will be announced during the course	

4.14 Compulsory Elective Module: Acoustics

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Dr.-Ing. Marold Moosrainer**
Lecturer (s)	Dr.-Ing. Marold Moosrainer
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Langauge of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Specific Acoustics Nomenclature - Signal Analysis - Structure-Borne Sound I – Analytics for Plate-like Structural Components - Structure-Borne Sound II: FE computation for arbitrary structures - Air-Borne Sound I – Fundamental Equation of Linear Acoustics - Air-Borne Sound II – Analytical Solutions of the Acoustic Wave Equation - Air-Borne Sound III – Analytical Description of Sound Radiation - Air-Borne Sound IV – Simulation of Sound Radiation by FEM - Air-Borne Sound IV – Room Acoustics - Fluid-Structure-Interaction (FSI) - Sound Radiation of Electric Drives - Psychoacoustics - Vibro-acoustics – Overview - Vibro-Acoustics – Class Room Training FEM - Flow-Acoustics (Lecturer B) - Measurement Techniques in Acoustics
Learning results	Following participation in the module events, the participants are capable of - stating the fundamental terminology and solution concepts of technical acoustics. - comprehending the relevant parameters for the sound radiation of vibrating structures. - understanding the vibroacoustics solution process: signal analysis, structure-borne sound, air-borne sound, psychoacoustic postprocessing. - deciding how to modify the vibration and sound radiation of structures by constructive means, e.g. mass, stiffness, damping, insulation, radiation efficiency.

	- using modern numerical techniques to simulate acoustic problems and select the proper one for specific tasks.
Materials, methodology	- PPT material presented in a class room training - derivations on the blackboard - analytical examples allowing simple hand calculations - some engineering simulation exercises demonstrated by the lecturer - practical session of simulation training for students

Prerequisite for participation	None Expected prior knowledge: - complex calculus - linear dynamics of structures - numerical concept of Finite Element Method	
Usability for other study courses	none	
ECTS-credit points	5	
Workload and distribution in hours	Hours total: 125	
	Hours in attendance: 40	
	Hours self-study: 62	
	Hours examination preparation: 23	
Semester hours per week	4	
Examination prerequisites	None	
Type of examination	Oral examination	
Weighting in the overall grade (%)	7%	
Literature	Basic literature: - Cremer, L.; Heckl, M. and Ungar, E.E.: *Structure-Borne Sound*. Springer Verlag, Berlin, 2nd ed. (1988). - Fahy, F.: *Sound and Structural Vibration*. Academic Press, London (1985). - Kuttruff, Heinrich: *Akustik*. Hirzel, Stuttgart (2004). - Pierce, A. D.: *Acoustics*. Acoustical Society of America, New York (1991).	
	Further literature: - will be announced during the course	

4.15 Compulsory Elective Module: Multibody Systems

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr.-Ing. Martin Förg**
Lecturer (s)	Prof. Dr.-Ing. Martin Förg
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Introduction: Outline of the basic concept of MBS - Spatial kinematics: Coordinate systems, coordinate transformation, relative kinematics - Spatial Kinetics: Inertias of rigid bodies, principle of linear momentum, - principle of angular momentum - Equations of motion of MBS: Structural set up, coordinates, constraints, force laws, Newton-Euler equations, Lagrange's equations, non-smooth dynamics, linearization - Numerical simulation: Set up of the numerical problem, implementation, solver strategies - Practical exercises in modelling and simulation of MBS
Learning results	Following participation in the module events, the participants are capable of - comprehending the fundamentals of Multi Body Dynamics. - transferring the acquired theoretical knowledge in this field to practical problems in engineering. - distinguishing when to apply MBS and when FEM techniques. - comprehending and solving problems in this field, including correct modeling, selection of appropriate modeling elements (joints, forces, etc), checking and discussion of results and practicing this in exercises using commercial software. - realizing the potential and the limits of Multi Body Dynamics.
Materials, methodology	All: Lecture notes, Matlab/Octave scripts, MBSim models, Moodle Lecturer: Blackboard or whiteboard, LCD-projector, Laptop, Visualizer

Prerequisite for participation	None <u>Expected prior knowledge:</u>

	Basic knowledge of mathematics is assumed, in particular: - Linear algebra - Differential and integral calculus - Ordinary differential equations Basic knowledge of dynamics is assumed, in particular: - Planar rigid body kinematics - Planar rigid body kinetics Basic programming knowledge is also expected.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Written examination
Weighting in the overall grade (%)	7%
Literature	Basic literature: - F. Pfeiffer: Mechanical System Dynamics, Springer Verlag, 2008 - Ahmed A. Shabana: Dynamics of Multibody Systems, Cambridge University Press, 2005 - E. Eich-Soellner, C. Führer: Numerical Methods in Multibody Dynamics, Teubner Verlag, 1998 - R. von Schwerin: Multibody System Simulation – Numerical Methods, Algorithms and Software, Springer-Verlag, 1999
	Further literature: - F. Pfeiffer: Einführung in die Dynamik, Springer Verlag, 2014 - Ch. Woernle, Mehrkörpersysteme, Springer, 2011 - E. Hairer, S.P. Norsett, G. Wanner: Solving Ordinary Differential Equations I, Nonstiff Problems, Springer Verlag, 1993 - E. Hairer, G. Wanner: Solving Ordinary Differential Equations II, Stiff and Differential Algebraic Problems, Springer Verlag, 1996 - K.E. Brenan, S.L. Campbell, L.R. Petzold: Numerical solution of initial-value problems in differential-algebraic equations, SIAM, 1996

4.16 Compulsory Elective Module: Product Development and Manufacturing Processes

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr. Jiří Horák, Prof. Dr. Bernhard Gubanka**
Lecturer (s)	N.N.
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Characterization of manufacturing processes: Outlining of the main paths of manufacturing processes; Examples from automotive and aerospace industry; interface definition to the CAE process. - Collaborative engineering: Main principles of collaborative engineering; the CAE process embedded in collaborative engineering - Simultaneous Engineering: The main way of simultaneous engineering and its applications; CAE process in simultaneous engineering with interface to manufacturing processes; - Product data management: Explanation of the mostly used interface data formats; CAE and CAD interface study on practical examples; - Embedding of CAE in the virtual development and manufacturing process: Virtual engineering with no prototype philosophy; - Methods of Industrial Engineering: advantages, examples - Production Systems: Classification and chaining alternatives: characteristics, advantages, examples - Advance Time: Definition and structure, Synthesis and determination - Design for assembly: Importance and rules - Manufacturing strategies: definition, lean concept methodologies

Learning results	Following participation in the module events, the participants are capable of, - describing processes in modern development and manufacturing. - executing CAE methods within development and manufacturing processes effectively and target-oriented. - planning the use of modern methods like product data management, knowledge management and industrial engineering. - executing and enhancing essential management skills like managerial responsibility, networked thinking, organization and leadership of teams. - steering and leading development processes.
Materials, methodology	Handout, case studies, presentation slides, whiteboard, internet

Prerequisite for participation	None Expected prior knowledge: Experience with development tasks or experience with manufacturing
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 23
	Hours examination preparation: 62
Semester hours per week	4
Examination prerequisites	None
Type of examination	Student research paper (assignment without oral presentation)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - K. Ulrich, St. Eppinger: Product Design and Development, MacGrawHill Education, 2016
	Further literature: - will be announced during the course

4.17 Compulsory Elective Module: Experimental Validation

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr. Marcus Jautze**
Lecturer (s)	Prof. Dr. Marcus Jautze, Prof. Dr.-Ing. Tim Rödiger.
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Introduction to experimental techniques and their limitations - Introduction to accuracy of simulation models and their limitations - Measurement techniques of mechanical quantities (e.g. forces, accelerations, distances, rotational speed) - Measurement techniques of electrical quantities Thermofluidic measurement techniques: - thermofluidic test / wind tunnel facilities - flow visualization - pressure measurements - heat-transfer measurements - flow-velocity / mass-flux measurement - Examples and practical exercises on numerical and experimental techniques
Learning results	Following participation in the module events, the participants are capable of - understanding the principles of experimental techniques and their limitations (accuracy, resolution etc.). - selecting appropriate experimental techniques for technical problems. - formulating demands on the quality of experimental data and understand the limitations of both numerical and experimental simulations. - interpreting discrepancies between experimental and numerical simulations. - understanding the limitations of simulation models.
Materials, methodology	All: Lecture notes, Moodle Lecturer: Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None

	Expected prior knowledge: Basic knowledge (undergraduate level) of mathematics (calculus and algebra), structural mechanics, fluid mechanics, technical thermodynamics and heat transfer is assumed.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Practical examination (practice-related application)
Weighting in the overall grade (%)	7%
Literature	Basic literature: • W. Nitsche, A. Brunn: Strömungsmesstechnik, Springer-Verlag Berlin Heidelberg, 2006 • P.R.N. Childs, J.R. Greenwood, and C.A. Long. Heat flux measurement techniques. Proc. Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, Vol. 213, No. 7, pp. 655-677, 1999 • H. Eckelmann: Einführung in die Strömungsmesstechnik, Vieweg+Teubner Verlag, 1997
	Further literature: - Will be announced during the course.

4.18 Compulsory Elective Module: Mechatronics

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr. Fritz Pörnbacher**
Lecturer (s)	Prof. Dr. Fritz Pörnbacher; Dr. Martin Hanke
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Fundamentals of field theory - Field description: potentials, field strength, flux density - Boundary conditions: Dirichlet, d'Alembert, Neumann - Field examples: Temperature, electrostatic, current conduction, electro-magnetic - Field coupling - Coupling mechanisms, numerical coupling methods - Field coupling: explicit vs. implicit, strong – weak, matrix – load, sequential – Parallel - Examples: piezoelectricity, Joule heating - System coupling - Reduced order model extraction - System simulation - Main components of mechatronic systems - Control components - Mechanical components - Electronic components - Actuators - Description and simulation of actuators - Magnetic valves - Electrical drives - Linear and rotating electrical drives - Control aspects - Convertors - Motion and speed control
Learning results	Following participation in the module events, the participants are capable of - recognizing the general field concept as a basis to handle different physical domains. - learning physical and numerical coupling procedures between fields.

	- understanding the description and simulation of mechatronic systems and their components. - using their skills to model related systems as well as understand the dynamic operation of mechatronic systems.
Materials, methodology	All: Lecture notes, Moodle Lecturer: Blackboard or whiteboard, Video-projector, PC

Prerequisite for participation	None Expected prior knowledge: Basic knowledge of numerical methods, mathematics and physics, typically taught in undergraduate classes.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Written examination (90 minutes)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - Shadowitz: The electromagnetic Field, Dover Publications, 1988 - G. Pelz: Modelling and Simulation of Mechatronic Systems, Wiley, 2003 - R. Isermann: Mechatronic Systems, Springer Verlag, 2005 - J. Schwab: Begriffswelt der Feldtheorie, Springer Verlag, 2002 - B. Heinrich (Hrsg): Mechatronic, Vieweg Verlag, 2004
	Further literature: - will be announced during the course

4.19 Compulsory Elective Module: Fluid Dynamics and Heat Transfer

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr. Jiří Horák, Prof. Dr. Bernhard Gubanka**
Lecturer (s)	N/A
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Basic concepts of fluid dynamics: continuum hypothesis, Newtonian and non-Newtonian fluids, surface tension, streamlines/path lines, vorticity/circulation, special flow types - Conservation laws: conservation of mass, momentum and energy; continuity equation; Navier-Stokes and Euler equations, Bernoulli equation - Boundary layer, flow separation - Vortex flow - Characteristics of turbulent flows, instabilities; scales, energy cascade, Kolmogorov hypothesis, statistical description of turbulent flows (RANS equations) - Classification of turbulence models, in particular: turbulent-viscosity, Reynold-stress, scale-dependent models (LES, DES); Direct Numerical Simulation (DNS); current trends - Free turbulent shear flows, turbulent wall flows - Concepts of heat transfer: temperature, temperature gradient, heat, heat flow rate, heat flux, heat capacity; Nusselt, Prandtl, Péclet, and Grashof numbers - Thermal conduction: heat equation (boundary conditions, analytic and numerical solution), application in CFD simulations - Forced and free convection: heat transfer coefficient, empirical models and their limitations; application in CFD simulations - Thermal radiation: Black-body radiation, radiation of real objects; Stefan-Boltzmann law; application in CFD simulations
Learning results	Following participation in the module events, the participants are capable of, - characterizing a flow problem and selecting the corresponding flow model in a CFD analysis - deriving specific requirements for the CFD model (e.g., mesh refinement, time stepping, etc.) from the expected flow characteristics

	- choosing an appropriate turbulence model for CFD simulations - assessing a heat transfer problem, identifying the dominant heat transfer mechanisms, and recognizing the simplifications required to analyze the problem by means of CFD - evaluating the use of analytical methods to support computational approaches in the assessment of a heat study
Materials, methodology	Lectures, exercises, examples/demonstrations in commercial CFD software and on experimental facilities, if possible.

Prerequisite for participation	None <u>Expected prior knowledge:</u> The knowledge of calculus and algebra is assumed. This includes in particular from undergraduate courses - Functions of one and several real variables, derivative, integral and their application - Spherical coordinates, trigonometric and exponential functions - Number vectors and matrices - Differential equations and from module 2 (Mathematics and Computational Methods) - Linear Algebra (dot product, cross product, tensors) - Vector calculus (gradient, divergence, curl) - Integral theorems Furthermore, the knowledge in fluid dynamics on undergraduate level is assumed. This includes in particular - Definitions: system, flow variables, ideal gas, real gas - Conservation laws, continuity equation, Bernoulli equation, 1st law of thermodynamics - Flow phenomena, laminar and turbulent flow, Reynolds number Turbomachinery: efficiency, pump characteristic, system characteristic, cavitation
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Written examination (90 minutes)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - H. Oertel, Prandtl-Essentials of Fluid Mechanics, Springer-Verlag, 3rd edition, 2012 - P. A. Davidson, Turbulence: An Introduction for Scientists and Engineers, Oxford University Press, 2nd edition, 2015

	Further literature: - will be announced during the course.

4.20 Compulsory Elective Module: Simulation: State-of-the-Art in Industry and Sciences

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr. Tim Rödiger**
Lecturer (s)	Prof. Dr. Tim Rödiger, N.N.
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Overview on state-of-the Art and future simulation techniques a. for different branches b. over the whole product lifecycle - Simulation Driven Product Development: - Scientific writing and essays - Scientific/technical presentations
Learning results	Following participation in the module events, the participants are capable of - knowing up-to-date simulation methods for different physical applications. - perceiving numerical analysis as possibility to visualize and examining a product over its lifecycle. - appraising the use of a range of different simulation techniques for specific engineering tasks. - describing the concept of Simulation Driven Product Development. - evaluating the degree of conversion of SDPD in their company and identifying further potential. - researching independently a selected scientific/technical subject. - carrying out a systematic and thorough literature, internet and scientific/technical database research in order to quickly familiarize themselves with a new subject and its context. - structuring and formulating a scientific essay or paper on a selected subject. - evaluating, reviewing and discussing critically the content of scientific essays with their peers. - presenting their results in a structured presentation using modern media and visualization techniques.

	- competently preparing and holding a presentation and moderating a subsequent discussion. - grasping the important ideas of scientific essays and presentations and coherently summarizing and explaining complex technical issues stated in scientific essays and presentations.
Materials, methodology	All: Lecture notes, Database/ Internet search, Moodle Lecturer: Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None <u>Expected prior knowledge: None</u>
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 23
	Hours examination preparation: 62
Semester hours per week	4
Examination prerequisites	None
Type of examination	Student research paper (assignment without oral presentation)
Weighting in the overall grade (%)	7%
Literature	Basic literature: • Deutsche Forschungsgemeinschaft DFG: Proposals for Safeguarding Good Scientific Practice, Recommendations of the Commission on Professional Self-Regulation in Science, WILEY-VCH Verlag, 1998/2013, ISBN 978-3-527-33703-3 • R.A. Day: Howto write and publish a scientific paper, 5th edition, ORYX Press, 1998
	Further literature: - will be announced during the course

4.21 Compulsory Elective Module: Computational Fluid Dynamics in Practice

(Serial no. Acc. Appendix to SPO: **10/11**)

Module Director	**Prof. Dr. Jiří Horák, Prof. Dr. Bernhard Gubanka**
Lecturer (s)	N/A
Semester according to study schedule	4
Type of module	Compulsory elective module
Frequency of module	When selected
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Seminar / practise
Content	- Simulation process: physics modeling, code implementation, verification, validation, interpretation and presentation of results; CFD simulations as a part of the product development process - Mesh generation: mesh types; quality criteria, relevance for CFD simulations; boundary layer resolution, dimensionless wall distance y+; available software for mesh generation - Sources of errors (hierarchy of errors): round-off errors; iteration errors (convergence, equation residuals, simulation abort criterion); discretization errors (need for grid independence study); model errors (need for model validation); user errors (need for experimental or analytical validation); software errors (need for experimental or analytical validation) - Experimental validation: overview of available flow measurement techniques - CFD software: overview of available commercial and open-source CFD software, typical field of application, advantages and disadvantages - Success stories and typical pitfalls - CFD simulation project: application of the theoretical knowledge of the simulation process to an industrial problem; project plan and schedule, presentation of the results
Learning results	Following participation in the module events, the participants are capable of - perceiving CFD analysis as one of several techniques to solve fluidic problems and deciding if the application of CFD simulations is appropriate to the problem - formulating hypotheses or research questions for their fluidic problem - selecting appropriate numerical grids, physical and numerical models and boundary conditions in order to solve their fluidic problem with required accuracy and best possible efficiency

	- evaluating the mesh quality of a CFD simulation based on commonly used criteria - appraising the use of a range of different CFD codes for flow simulation problems - defining a project plan and a project schedule in order to work on and solve their fluidic problem - documenting, presenting, and defending the findings of their CFD analysis in an oral presentation for an expert audience
Materials, methodology	All: Lecture notes, ANSYS Fluent, Moodle Lecturer: Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None <u>Expected prior knowledge:</u> The knowledge of undergraduate calculus and algebra is assumed. This includes in particular - Functions of one and several real variables, derivative, integral and their application - Number vectors and matrices Experience in individual project work and presentation techniques at undergraduate level is assumed. Furthermore, basic knowledge in the handling of simulation software (CFD or FEM) is recommended. The handling of the CFD software chosen by the students will not be taught.
Usability for other study courses	none
ECTS-credit points	5
Workload and distribution in hours	Hours total: 125
	Hours in attendance: 24
	Hours self-study: 11
	Hours examination preparation: 90
Semester hours per week	4
Examination prerequisites	None
Type of examination	Seminarpaper (assignment with oral presentation)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - Laurien and H. Oertel: Numerische Strömungsmechanik: Grundgleichungen und Modelle - Lösungsmethoden – Qualität und Genauigkeit. SpringerLink: Bücher. Springer Fachmedien Wiesbaden, 2013. - S. Lecheler: Numerische Strömungsberechnung: Schneller Einstieg in ANSYS CFX 18 durch einfache Beispiele. Springer Fachmedien Wiesbaden, 2017.
	Further literature: - will be announced during the course

4.22 Geometrically Nonlinear and Contact Analysis

(Serial no. Acc. Appendix to SPO: **12**)

Module Director	**Prof. Dr.-Ing. Alexander Popp**
Lecturer (s)	Prof. Dr.-Ing. Alexander Popp
Semester according to study schedule	4
Type of module	Mandatory module
Frequency of module	Each student group
Duration of module	1 semester
Teaching language	English

Form of teaching and learning	Seminar / practise
Content	- Introduction to nonlinear modeling - Important phenomena in geometrically nonlinear analysis - Introduction to nonlinear continuum mechanics - Tools for geometrically nonlinear analysis - Stability / Determining critical points - Finite elements for geometrically nonlinear analysis - Introduction to nonlinear dynamics - Introduction to contact modeling - Contact constraint enforcement techniques - Contact discretization techniques - Contact search and solution algorithms - Practical examples with commercial / research software
Learning results	Following participation in the module events, the participants are capable of - naming the most important sources of nonlinearities in mechanical modeling and with the most common strategies for their treatment. - stating the fundamental concepts of nonlinear continuum mechanics and applying these to practically relevant engineering problems. - describing numerical tools for geometrically nonlinear analysis and using them adequately for nonlinear finite element procedures. - naming tools to identify and overcome critical points and stability problems in geometrically nonlinear analysis. - developing basic nonlinear finite element procedures themselves. - giving an overview of time integration schemes for nonlinear dynamics. - assessing the specific challenges of nonlinear contact modeling.

	- describing contact-related physical effects such as frictional sliding and their mathematical formulation in the nonlinear realm. - understanding the most common constraint enforcement techniques for computational contact analysis. - stating the advantages and disadvantages of traditional as well as cutting-edge contact discretization schemes for large deformation and large sliding contact. - implementing basic finite element contact procedures themselves. - assessing practical engineering problems regarding their degree of nonlinearity and complexity and know how to make adequate simplifications. - showing a basic understanding of contact search and solution algorithms. - demonstrating their gained experience in identifying nonlinearities as well as the associated computational challenges in commercial / research software.
Materials, methodology	All: Lecture notes, Matlab scripts, Audience response system (PINGO), Moodle Lecturer: Blackboard or whiteboard, LCD-projector, PC

Prerequisite for participation	None Expected prior knowledge: The knowledge of fundamental mathematics, continuum mechanics, and numerical methods (including at least a short introduction to finite element methods for linear elasticity) is assumed. This includes in particular from module “Mathematics and Computational Methods”: - Vectors and matrices, inverse matrix, determinant, Gaussian elimination, eigenvalues and eigenvectors, basis and dimension of a linear vector space, linear dependence and independence, dot and cross products - Scalar and vector-valued functions of several real variables, partial and total derivatives, gradient, divergence, planar and volume integrals - Interpolation and approximation, numerical differentiation and integration, numerical solution of ODEs, numerical solution of linear systems of equations, numerical solution of nonlinear systems of equations from module “Solid Mechanics”: - Displacements, stress and strain tensors, linearized strains, stresses, equilibrium, linear elasticity, initial boundary value problem, constitutive equations, stress differential equations, stress functions, principle of virtual work from module “Finite Element Method”: - Finite element methods for elliptic PDEs, weak formulation, shape functions, element vectors and matrices, assembly, isoparametric concept, convergence, locking and remedies, linear dynamics, implicit and explicit time integration Basic programming knowledge is also expected.
Usability for other study courses	none

ECTS-credit points	5

Workload and distribution in hours	Hours total: 125
	Hours in attendance: 40
	Hours self-study: 62
	Hours examination preparation: 23
Semester hours per week	4
Examination prerequisites	None
Type of examination	Written examination (90 minutes)
Weighting in the overall grade (%)	7%
Literature	Basic literature: - Y. Basar, D. Weichert: Nonlinear Continuum Mechanics of Solids, Springer, 2000. - T. Belytschko, W.K. Liu, B. Moran, K.I. Elkhodary: Nonlinear Finite Elements for Continua and Structures, Wiley, 2014. - P. Wriggers: Nonlinear Finite Element Methods, Springer, 2010. - P. Wriggers: Computational Contact Mechanics, Springer, 2006. - T.A. Laursen: Computational Contact and Impact Mechanics, Springer, 2002.
	Further literature: - will be announced during the course

4.23 Masterarbeit und Kolloquium

(Serial no. Acc. Appendix to SPO: **13**)

Module Director	**Prof. Dr. Jiří Horák, Prof. Dr.-Ing. Detlev Maurer**
Lecturer (s)	N/A
Semester according to study schedule	5
Type of module	Mandatory module
Frequency of module	Every semester
Duration of module	1 semester
Language of Instruction	English

Form of teaching and learning	Final thesis and thesis defense
Content	The student has to solve an actual complex problem within the area of applied sciences or engineering practice. A student's company may be involved in the master thesis by providing a project to be developed within the thesis. Additionally, several project topics are offered by the universities. - Application of theoretical, numerical or experimental methods within the field of simulation-based engineering - Information management including literature survey - Project definition and planning - Project and time management - Information management including literature survey - Compilation of a technical or scientific report including a summary and the visualization of the results. - Presentation of the attained results of the thesis - Scientific discussion during a colloquium
Learning results	Following participation in the module events, the participants are capable of - analyzing and solving a complex problem out of the applied sciences or engineering practice on a scientific basis. - developing of technical products, methods or processes. - collecting and evaluating of information. - knowing relevant scientific literature in the field of their topic and taking advantage out of it - carrying out responsible applications of theoretical, numerical and / or experimental methods within the field of simulation-based engineering. - validating and critical analyzing the obtained results. - compiling profound technical and scientific reports effectively. - visualizing and documenting of technical and scientific topics.
Materials, methodology	As necessary

Prerequisite for participation	At least 30 ECTS credits, cumulated from other modules of the program Expected prior knowledge: Contents of the other modules of the master's program
Usability for other study courses	none
ECTS-credit points	30
Workload and distribution in hours	Hours total: 750
	Hours in attendance: 0
	Hours self-study: 0
	Hours examination preparation: 750
Semester hours per week	4
Examination prerequisites	None
Type of examination	Master thesis with thesis defense
Weighting in the overall grade (%)	25%
Literature	Basic literature: - As necessary
	Further literature: - As necessary

5 Legal references

Legal framework conditions are regulated in:

- the Rahmenprüfungsordnung für Bayerische Fachhochschulen (General Examination Regulations for Bavarian Universities) (RaPO) in the version from 06.08.2010
- the Allgemeine Prüfungsordnung der Technischen Hochschule Ingolstadt (General Examination Regulations or the Technical University of Ingolstadt) (APO THI) in the version from 24.11.2014

You can find specific regulations for the study course in the Study and Examination Regulations (SPO) in the version from 01.10.2019.