TECHNISCHE UNIVERSITÄT DARMSTADT

Modulhandbuch MSc. Mechanics PO 2023

Course overview of the MSc. Mechanics program

1 Table of Contents

2 Compulsory Area

Module Description

Module name

2.1 Nonlinear Finite Element Methods (FEM II)

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-E1-M020	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Dominik Schillinger

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-E1-0005-vl	Finite Element Methods II	0	Lecture	2
13-E1-0006-ue	Finite Element Methods II - Exercise	0	Exercise	2

2 Study Content

Overview of nonlinear structural behavior; Theory of moderate deformations, geometrically nonlinear plane Euler-Bernoulli beam element, Newton-Raphson method, arc length methods, nonlinear spatial Timoshenko beam, nonlinear plates; Material and spatial formulations of volume elements; Inelastic material behavior, von Mises plasticity, elasto-viscoplasticity, damage; Linear elastodynamics, eigenfrequencies, nonlinear elastodynamics, explicit time integration, Newmark method, instationary heat conduction.

3 Learning Outcomes

Students have the ability to analytically analyze specific tasks and work out solutions.

Students have the ability to apply fundamental methods to engineering problems.

Students have the ability to work out problems related to the content of this course on their own according to scientific principles.

4 Requirements for Participation

Recommended: Finite-Element-Methoden I (13-E1-M001)

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Homework Assignment, Standard)
- Module Examination (Technical Examination, oral Examination, Duration 15 min, Standard)

Study Examination (homework assignment): Submission of 5 homework assignments (assessment: 10% Weight each) distributed over the lecture period.

6 Requirements on the Award of Credit Points

Passing the module examination(s)

7	**Grading** Final Module Examination: • Module Examination (Study Examination, Homework Assignment, Weight: 50%, Standard) • Module Examination (Technical Examination, oral Examination, Weight: 50%, Standard)
8	**Usability of the Module**
9	**Literature** Literature will be announced at the beginning of the course.
10	**Comment**

Module Description

Module name

2.2 Continuum Mechanics II (Material Theory)

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-E2-M003	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Ralf Müller

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-E2-0006-vl	Continuum Mechanics II (Material Theory)	0	Lecture	3
13-E2-0007-ue	Continuum Mechanics II (Material Theory) - Exercise	0	Exercise	1

2	**Study Content** Linear and nonlinear elasticity theory, thermoelasticity, stability, wave propagation, acceleration waves - acoustic tensor, introduction in viscoelasticity and plasticity (for small and large deformations), micropolar elasticity, numerical aspects
3	**Learning Outcomes** The students have the capability of analysing specific tasks, generating solutions and applying mathematical-scientific methods to engineering problems.
4	**Requirements for Participation** Knowledge of 'Tensorrechnung für Ingenieure' (13-E2-M004) and 'Kontinuumsmechanik I' (13-E2-

	M002) is necessary.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Literature will be announced at the beginning of the course.
10	**Comment**

Module Description

Module name

2.3 Seminar Continuum Mechanics

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-E2-M009	4 CP	120 h	90 h	1 Semester	Every semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Ralf Müller

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-E2-0003-se	Seminare Continuum Mechanics	0	Seminar	2

2	**Study Content** Current and alternating topics of solid, fluid, computational mechanics, thermodynamics, natural or engineering science with special relation continuum mechanics
3	**Learning Outcomes** The students

	•master the basics of a scientific approach to a new topic •learn to work autonomously and under guidance on a new topic •deepen their understanding and knowledge of continuum mechanics,thermodynamics and computational mechanics •are able to present their results in oral and written from •are participating in scientific discussions
4	**Requirements for Participation** Recommendation: Knowledge of mechanics, continuum mechanics, tensor calculus
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, Special Form, Duration 20 min, Standard) Modul examination (presentation slides, presentation including scientific discussion)
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Special Form, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Literature will be announced in the seminar.
10	**Comment**

Module Description

Module name

2.4 Seminar Computational Mechanics

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-E1-M021	4 CP	120 h	90 h	1 Semester	Every semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Dominik Schillinger

1	Courses of the Module				
	Course no.	**Course name**	**Workload (CP)**	**Form of**	**Contact**

				Teaching	Hours per Week
	13-E1-0021-se	Seminar Computational Mechanics	0	Seminar	2

2	**Study Content** Current and alternating topics of solid and fluid mechanics, multiphysics, and natural or engineering sciences with special focus on computational methods and scientific computing
3	**Learning Outcomes** The students •master the basics of a scientific approach to a new topic •learn to work autonomously and under guidance on a new topic •deepen their understanding and knowledge of computational methods applied toproblems in engineering mechanics •are able to present their results in oral and written from •are participating in scientific discussions
4	**Requirements for Participation** Recommendation: Knowledge of continuum mechanics, finite element methods
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, Special Form, Duration 20 min, Standard) Modul examination (presentation slides, presentation including scientific discussion)
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Special Form, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Literature will be announced in the seminar.
10	**Comment**

Module Description

Module name **2.5 Seminar Fluid Mechanics, Continuum Mechanics and Geophysical Mechanics**					
Module no. 16-64-617b	**Credit Points** 3 CP	**Workload** 90 h	**Self-study** 60 h	**Duration** 1 Semester	**Frequency** Every semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr.-Ing. Martin Oberlack		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-64-5170-se	Seminar in Fluid Mechanics, Continuum Mechanics and Geophysical Mechanics	0	Seminar	2

2 Study Content

Presentation of present scientific works and/or working on a scientific text in Fluid Mechanics and/or Continuum Mechanics.

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Screen and analyse the relevant scientific literature in databases, libraries and third-party sources.
2. Structure a given task and organise a realistic time schedule.
3. Formulate the results in written and oral form in an accepted scientific manner.
4. Conduct a critical scientific and interdisciplinary discourse and debate with other participants of the course.

4 Requirements for Participation

Basic knowledge in mathematics and mechanics

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Study Examination, Standard)

Written elaboration and oral exam 30 min.

6 Requirements on the Award of Credit Points

Passing the examination

7 Grading

Final Module Examination:

- Module Examination (Study Examination, Study Examination, Weight: 100%, Standard)

8	**Usability of the Module** Master Mechanik
9	**Literature** Reference suggestions will be provided.
10	**Comment**

Module Description

Module name

2.6 Research Seminar Applied Dynamics

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-25-611b	3 CP	90 h	60 h	1 Semester	Every semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr. Richard Markert

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-25-5110-fs	Research Seminar Applied Dynamics	0	Research Seminar	2

2 Study Content

3 Learning Outcomes

4 Requirements for Participation

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Study Examination, Standard)

6 Requirements on the Award of Credit Points

7 Grading

Final Module Examination:

	• Module Examination (Study Examination, Study Examination, Weight: 100%, Standard)
8	**Usability of the Module**
9	**Literature**
10	**Comment**

3 Elective Area A: Advanced Modules in Mechanics

Module Description

Module name

3.1 Micromechanics for Materials Science

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
11-01-4109	6 CP	180 h	135 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Ph. D. Bai-Xiang Xu

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
11-01-7050-ue	Exercises in Micromechanics for Materials Science	0	Exercise	1
11-01-7050-vl	Micromechanics for Materials Science	0	Lecture	2

2 Study Content

This lecture deals with fundamentals of micromechanics in the framework of elasticity and plasticity theory. Important topics include: Basics of elasticity, defect mechanics, plasticity, crystal plasticity, theory of configurational force, micro-macro transition and homogenization, phase-field theory, and phase-field fracture modeling.

3 Learning Outcomes

The successful students can interpret the elastic and plastic behavior of a material using the continuum theory, and describe the stress situation around certain a microstructure, e.g. at crack tips and near defects. They can also apply the basic concept of homogenization to calculate the effective properties of heterogeneous materials. They have the competence to follow advanced textbooks and scientific literature on nonlinear continuum mechanics and composite mechanics.

4 Requirements for Participation

recommended: basics of mathematics and elastomechanics

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral / written Examination, Standard)

Modulprüfung (Fachprüfung, mündliche / schriftliche Prüfung, Standard)

6 Requirements on the Award of Credit Points

passing of exam

7 Grading

Final Module Examination:

	• Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module**
9	**Literature** 1.Cai W., W.D. Nix; Imperfections in Crystalline Solids, Cambridge, 2016 2.Gross D., Seelig T.; Fracture Mechanics with an Introduction to Micromechanics, 2nd Edi. 2011 3.Le, Khan Chau; Introduction to Micromechanics, Nova Science Publ, 2010 4.Mura, T.; Micromechanics of Defects in Solids, Martinus Nijho_ Publishers 1982 5.Zohdi T.I., Wriggers P.; An Introduction to Computational Micromechanics, Springer, 2004 6.Weertman, J.; Dislocation based fracture mechanics, World Scienti_c 1996 7.Provatas, N., Elder, K.; Phase-Field Methods in Materials Science and Engineering, Wiley-VCH Verlag GmbH Co. KGaA, 2010
10	**Comment** Cycle: each winter semester

Module Description

Module name

3.2 Finite Elements III: Stabilized Methods for Computational Fluid Dynamics

Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
13-E1-M018	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	**Person responsible for the Module**
English	Prof. Dr.-Ing. Dominik Schillinger

1 Courses of the Module

Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
13-E1-0018-vu	Finite Elements III	0	Lecture and Exercise	4

2 Study Content

Part I: Fundamentals, mathematical background and problem statements
1. Prototypical fluid mechanics equations: the advection(-diffusion), Burgers, Stokes and Navier-Stokes equations
2. Relevant components of functional analysis theory
3. Analysis of the model equations with emphasis on the challenges of finite element formulations

Part II: Solution strategies
1. Stabilized methods; Galerkin least-squares (GLS), artificial diffusion, streamline-upwind Petrov-Galerkin (SUPG)

	2. Suitable interpolation pairs in mixed methods (e.g. Taylor-Hood) 3. Discontinuous Galerkin methods Part III: Multiscale modeling 1. A short introduction to the physics of turbulence 2. Classical turbulence models: Reynolds-averaged Navier-Stokes (RANS) and large eddy simulation (LES) 3. The variational multiscale method
3	**Learning Outcomes** Understanding of potential benefits of using the finite element method for flow problems, advanced aspects of finite element theory and challenges that arise when the finite element method is applied to flow problems. Knowledge of stabilized methods, discontinuous Galerkin formulations and suitable velocity/pressure interpolation pairs. Basic understanding of turbulence modeling and the variational multiscale method, including some open research questions in this area. Understanding of the advantages and disadvantages of the finite element method in this context with respect to finite volume methods.
4	**Requirements for Participation** Recommended: Finite-Element-Methoden I (13-E1-M001)
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 15 min, Standard) • Module Examination (Study Examination, Homework Assignment, Standard) Study Achievement (homework assignment): Submission of 7 homework assignments (assessment: 10% Weight each) distributed over the lecture period.
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 30%, Standard) • Module Examination (Study Examination, Homework Assignment, Weight: 70%, Standard)
8	**Usability of the Module**
9	**Literature** J. Donea, A. Huerta: Finite Element Methods for Flow Problems (2003), Wiley. T.J.R. Hughes et al.: Multiscale and Stabilized Methods. In: Encyclopedia of Computational Mechanics (2018), Part 1 Fluids, Chapter 2. B. Cockburn: Discontinuous Galerkin Methods for Computational Fluid Dynamics. In: Encyclopedia of Computational Mechanics (2018), Part 1 Fluids, Chapter 5.

10	**Comment**

Module Description

Module name **3.3 Computational Plasticity**					
Module no. 13-E1-M019	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Dominik Schillinger		

1	**Courses of the Module**

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-E1-0019-vu	Computational Plasticity	0	Lecture and Exercise	4

2 Study Content

Part I: One-dimensional plasticity: formulation and numerical implementation
1. Derivation of one-dimensional constitutive equations, building on the phenomenological interpretation of plasticity
2. Strong and weak forms of the initial boundary value problem (IBVP), its discretization and linearization
3. Integration algorithms (return map algorithms) for one-dimensional constitutive equations

Part II: Three-dimensional classical rate-independent plasticity
1. Review of classical governing equations within continuum mechanics and thermodynamics
2. Theory of yield surfaces and classical small-strain plasticity models
3. Maximum plastic dissipation principle and its interpretation as a constrained convex optimization problem
4. Derivation of constitutive equations from convex optimization principles

Part III: Integration algorithms for plasticity
1. Incremental form of constitutive equations and geometric interpretation as closest point projection
2. Radial return map algorithm for J2 plasticity
3. General return map algorithms (closest point projection algorithms, cutting plain algorithms)

3 Learning Outcomes

Students develop a rigorous understanding of integration algorithms for elastoplastic constitutive problems and their mathematical foundations from a convex optimization perspective. They are able to solve and implement multidimensional problems for inelastic solids focusing on return map algorithms for rate-independent plasticity models, linearization of nonlinear global governing equations, and

	discretization and solution in the context of the finite element method.
4	**Requirements for Participation** Recommended: "Finite Element Methods I" (13-E1-M001) should be taken in parallel.
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Homework Assignment, Standard) • Module Examination (Technical Examination, oral Examination, Duration 15 min, Standard) Technical Examination (oral examination): Presentation (25% Weight) and oral examination (15 min., 25% Weight) Study Examination (homework assignment): Submission of 5 homework assignments (assessment: 10% Weight each) distributed over the lecture period.
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Homework Assignment, Weight: 50%, Standard) • Module Examination (Technical Examination, oral Examination, Weight: 50%, Standard)
8	**Usability of the Module**
9	**Literature** Simo, J.C. and Hughes, T.J., 2006. Computational Inelasticity. Springer Science amp; Business Media. de Souza Neto, E.A., Peric, D. and Owen, D.R., 2011. Computational Methods for Plasticity: Theory and Applications. John Wiley amp; Sons.
10	**Comment**

Module Description

Module name					
3.4 Fracture Mechanics					
Module no. 13-I2-M002	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr.-Ing. Michael Vormwald		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-I2-0007-vl	Fracture Mechanics	0	Lecture	3
13-I2-0008-ue	Fracture Mechanic - Exercise	0	Exercise	1

2 Study Content

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
Laboratory techniques for determining critical values
Energy release rates, J-integral, strip-yield and cohesive-zone models, crack tip opening displacement
Proof of strenght based on Failure-Assessment and Crack-Driving-Force diagrams
Fatigue crack growth including load sequence and short crack effects

3 Learning Outcomes

After finishing this lecture students are able to:
Decide which numerical method provides stress intensity factors with an optimum with respect to accuracy and effort,
calculate stress intensity factors. J-integrals, and crack tip opening displacements,
evaluate the strength of structures with defects,
assess the results of experimental investigations,
calculate fatigue crack growth lives.

4 Requirements for Participation

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)

6 Requirements on the Award of Credit Points

Passing the module examination(s)

7 Grading

Final Module Examination:

	• Module Examination (Technical Examination, oral Examination, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Vorlesungsunterlagen, Skript. Gross, D.: Bruchmechanik mit einer Einführung in die Mikromechanik. Springer, ISBN 978-3-540-37113-7, 2006 Zerbst, U., Schödel, M., Webster, S., Ainsworth, R.: Fitness-for-Service Fracture Assessment of Structures Containing Cracks. Esevier, ISBN 978-0-08-044947-0, 2007
10	**Comment**

Module Description

Module name

3.5 Structural Durability

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-I2-M001	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr.-Ing. Michael Vormwald

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-I2-0001-vl	Structural Durability	0	Lecture	2
13-I2-0002-ue	Structural Durability - Exercise	0	Exercise	2

2	**Study Content** Materials mechanics basics: deformation and failure behaviour under constant and variable amplitude loading Overview on life assessment approaches Load date analysis and cycle counting methods Local strain approach - computer aided fatigue analysis, nominal, structural, and notch stress approach Standards and codes for the proof of structural durability Fatigue crack growth
3	**Learning Outcomes** After finishing this lecture students are able to: Determine fatigue loads and apply cycle counting methods, evaluate statistically the results of experimental investigations, perform a proof of structural durability according to actual technical standards,

	rank all approaches for proof of structural durability with respect to their required effort and their expected accuracy as well as apply such approaches, improve the the structural durability by appropriate methods.
4	**Requirements for Participation**
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Lecture notes, script. Radaj, D., Vormwald, M.: Ermüdungsfestigkeit - Grundlagen für Ingenieure, Springer, ISBN 978-3-540-71458-3, 2007 Radaj, D., Vormwald, M.: Advanced Methods of Fatigue Assessment, Springer, ISBN 978-3-642-30739-3, 2013 Haibach, E., Betriebsfestigkeit, Springer, 2002, ISBN 3-540-43142-x
10	**Comment**

Module Description

Module name **3.6 Composite Structures**					
Module no. 16-12-3174	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 37.5 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Christian Mittelstedt		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-12-3174-ue	Composite Structures	0	Exercise	3.5
16-12-3174-vl	Composite Structures	0	Lecture	2

2 Study Content

Historical developments, Nomenclature, Fibers and matrices, Semi-finished products, Behaviour of a laminate layer, Classical Laminate Plate Theory, Influence of moisture and temperature, Fracture and degradation, Joints (circumferential joints, bolted joints, bonded joints), Optimization of laminates, Design guidelines, Stress concentration problems, Stability problems, Examples from aircraft engineering, Example: Predesign of a thin-walled composite beam

3 Learning Outcomes

Upon successful completion of this module, students should be able to:

1. Select fibers, matrices and semi-finished products according to a specific task.
2. Perform basic static analyses of thin-walled composite structures.
3. Apply classical laminated plate theory for basic composite laminate problems and to perform strength assessments under consideration of static loads as well as moisture and temperature loads.
4. Understand the most relevant stability and stress concentration problems in the framework of composite structures and to perform according analyses.
5. Understand and apply construction principles in composites engineering.

4 Requirements for Participation

Attending and succesfully completing the modules „Lightweight Engineering I“ and “Lightweight Engineering II” is recommended.

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)

Course Examination:

- [16-12-3174-ue] (Technical Examination, Report, Passed / Not Passed)

Oral exam 30 min., divided into 10 minutes presentation of the results of the design project (1/3) and 20 minutes oral examination (2/3)and report (design project, pnp).

6	**Requirements on the Award of Credit Points** Passing the examinations.
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard) Course Examination: • [16-12-3174-ue] (Technical Examination, Report, Weight: 0%, Passed / Not Passed)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung Master MB II SP SUR WPB Master PST IV (Kernlehrveranstaltungen der Papiertechnik) Angewandte Mechanik Mechatronik
9	**Literature** ALTENBACH, H., ALTENBACH, J. und RIKARDS, R., 1996. Einführung in die Mechanik der Laminat- und Sandwichtragwerke. Stuttgart: Deutscher Verlag der Grundstoffindustrie. JONES, R.M., 1975. Mechanics of composite materials. Washington, USA: Scripta Book Co. MITTELSTEDT, C. und BECKER, W., 2016. Strukturmechanik ebener Laminate. Darmstadt: Studienbereich Mechanik, TU Darmstadt. SCHÜRMANN, H., 2005. Konstruieren mit Faser-Kunststoff-Verbunden. Berlin et al.: Springer.
10	**Comment**

Module Description

Module name

3.7 Introduction to Turbulence

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-64-5130	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Martin Oberlack

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-64-5130-ue	Introduction to Turbulence	0	Exercise	1
16-64-5130-vl	Introduction to Turbulence	0	Lecture	3

2 Study Content

Origin of turbulence and introduction of stability theory; introduction to turbulence and its statistical description; Reynolds decomposition, filtering and averaging the basic equations; correlation equations (one- and multi point); isotropic turbulence and the Karman-Howarth equation; turbulent decay; turbulent length-scales; Kolmogorov theory; energy spectrum; deeper investigations of isotropic turbulence (Intermittency); turbulent wall bounded flows; boundary and turbulent scaling laws; free shear flows; detached turbulent flows.

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Knowthe regularities for the statistic description of turbulence, based on the Navier-Stokes equations.
2. Express basic definitions for turbulent parameters such as length and time scales.
3. Explain the deduction of the Kolmogorov theory and turbulent energy spectra as well as extensions for higher correlations.
4. Explain the deduction of the two- and multi-point correlation equations.
5. Distinguish a multiplicity of classical flow forms e.g. near-wall or free turbulent flows and to outline these flows under specification of the respective scale laws.
6. Know the modelling concepts of the different RANS concepts, to distinguish them on the basis of their disadvantgages and advantages and to outline and clarify the main modelling concepts.
7. Describe the substantial ideas of the Large Eddy Simulation on the basis of equations, show advantages as well as carry out a delimitation of the RANS models.
8. Delimit the possibilities and limitations of all calculation methods.

4 Requirements for Participation

Recommended:
1) Technical Fluid Mechanics or basic knowledge of fluid mechanics
2) Ordinary and partial differential equations

5 Form of Examination

Final Module Examination:

	• Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral exam 30 min
6	**Requirements on the Award of Credit Points** Passing the examination.
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Pope: Turbulent Flows, Cambridge Universtity press 2000; Davidson: Turbulence: an introduction for scientist and engineers; Teenekes and Lumley: A first Course in turbulence; Tsinober: An informal introduction to turbulence; Rotta: Turbulente Strömungen, Teubner Verlag 1972; Lecture notes
10	**Comment**

Module Description

Module name

3.8 Advanced Fluid Mechanics II

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-64-5120	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Apl. Prof. Dr.-Ing. Yongqi Wang

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-64-5120-ue	Advanced Fluid Mechanics II	0	Exercise	1
16-64-5120-vl	Advanced Fluid Mechanics II	0	Lecture	3

2	**Study Content** Basic equations of incompressible and compressible fluid flows; Jump conditions on singular surfaces; Potential flows; Steady and unsteady compressible flows; Perpendicular and moving shocks; Compressible boundary layer flows; Introduction of acoustics; Viscoelastic flows

3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Describe incompressible and compressible flows in a differentiated way and explain the balance equations 2. Construct jump conditions on phase interfaces or shocks 3. Describe flows of ideal fluids by means of potential theory 4. Solve compressible flow problems involving shock waves 5. Derive simplified equations of compressible boundary layer flows 6. Develop a fundamental understanding of acoustic phenomena 7. Understand various modelings and behaviors of viscoelastic fluids
4	**Requirements for Participation** Recommended are: 1) Fundamentals of fluid mechanics, 2) Ordinary and partial differential equation. Knowledge of Part I of this lecture is not required.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Angewandte Mechanik
9	**Literature** Hutter, K., and Wang, Y.: Fluid and Thermodynamics. Springer Verlag. Volume 1: Basic Fluid Mechanics (2016), Volume II: Advanced Fluid Mechanics and Thermodynamic Fundamentals (2016), Volume III: Structured and Multiphase Fluids (2018). Lecture Notes in moodle
10	**Comment**

Module Description

Module name					
3.9 Mathematical Methods in Fluid Mechanics: Exact and Symmetry Methods					
Module no. 16-64-5230	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr.-Ing. Martin Oberlack		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-64-5230-ue	Mathematical methods in fluid mechanics: Exact and symmetry methods	0	Exercise	1
16-64-5230-vl	Mathematical methods in fluid mechanics: Exact and symmetry methods	0	Lecture	3

2 Study Content

Basic equations of incompressible fluid flow; examples of exact solutions of the Navier-Stokes equations; introduction into the mathematical concept of symmetry; the theory of Lie Groups; Lies 1. and 2. fundamental theorem; dimensional analysis; invariance of differential equations; the Lie algorithm for determining symmetries; invariant solutions of non-linear partial differential equations; direct construction method of conservation laws in divergence form.

3 Learning Outcomes

On successful completion of this module, students should be able to:
1. Simplify the complexity of the Navier-Stokes equations for various simple flow problems and reach their exact solutions.
2. Apply the analytic theory, based on Lie symmetries, for solving ordinary and partial differential equations, especially for flow problems.
3. Analyse the symmetries and invariances of given differential equations by means of the theory of Lie groups.
4. Develope potential local conservation laws of differential equations with the aid of the direct construction method.

4 Requirements for Participation

Basic knowledge of mathematics; basic knowledge of fluid mechanics.

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 15 min, Standard)

Oral exam 30 min.

6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Angewandte Mechanik
9	**Literature** lecture notes; Bluman, Kumei: Symmetries and Differential equations, Springer Verlag, 1996; Stephani: Differentialgleichungen, Symmetrien und Lösungsmethoden, Spektrum Akademischer Verlag, 1994; Cantwell: Introduction to Symmetrie Analysis, Cambridge University Press, 2002; Bluman, G.W., Cheviakov, A.F., and Anco, S.C.: Applications of Symmetry Methods to Partial Differential Equations. Applied Mathematical Sciences Vol. 168. Springer 2010.
10	**Comment**

Module Description

Module name

3.10 Mathematical Methods in Fluid Mechanics: Regular and Singular Perturbations

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-64-3254	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Apl. Prof. Dr.-Ing. Yongqi Wang

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-64-3254-ue	Mathematical Methods in Fluid Mechanics: Regular and Singular Perturbations	0	Exercise	1
16-64-3254-vl	Mathematical Methods in Fluid Mechanics: Regular and Singular Perturbations	0	Lecture	3

2	**Study Content** Asymptotic series and expansions; applications of the regular perturbation method in some flow problems; failure of the Poincare expansions; method of strained coordinates; renormalization technique; method of matched asymptotic expansions; flows around a sphere or a cylinder with small Reynolds numbers; method of multiple scales; turning point problems.
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Explain and apply the regular perturbation method for solving differential equations, especially flow problems, by means of parameter or coordinate perturbation. 2. Recognize the limitations of the regular perturbation method. 3. Choose and apply alternative suitable singular perturbation methods if the regular perturbation method fails for given differential equations. 4. Recognize relations and distinctions of different singular perturbation methods, e.g. methods of strained coordinates, renormalization, multiple scales.
4	**Requirements for Participation** Basic knowledge of ordinary and partial differential equations and the corresponding solution methods; basic knowledge of fluid mechanics. Knowledge of Part I of this lecture is not required.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral exam 30 min.
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Angewandte Mechanik
9	**Literature** lecture notes; Nayfeh, A.H.: Perturbation Methods, John Wiley amp; Sons, 1975; Van Dyke, M.: Pertubation Methods in Fluid Mechanics, Parabolic Press, 1975.
10	**Comment**

Module Description

Module name					
3.11 High-Accuracy Methods for Computational Fluid Dynamics					
Module no. 16-64-3264	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Dr.-Ing. Florian Peter Kummer		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-64-3264-ue	High-Accuracy methods for Computational Fluid Dynamics	0	Exercise	1
16-64-3264-vl	High-Accuracy methods for Computational Fluid Dynamics	0	Lecture	3

2 Study Content

Theory: Motivation for higher order methods; piecewise approximation by polynomials; conservative form of PDEs; flux formulation, weak form and bilinear forms; numerical fluxes; interior penalty for second order problems; time discretization; solution algorithms
Computer lab: Implementation of solvers for multidimensional scalar problems of first and second order in an existing framework; Experimental examination of stability, convergence, conditioning and performance

3 Learning Outcomes

On successful completion of this module, students should be able to:
1. Explain fundamental properties (stability, consistency and convergence) of the Discontinuous Galerkin (DG) discretization
2. Assess the applicability and the expectable efficiency of higher order methods for a given problem
3. Derive the discrete form of problem statements and to implement basic solution algorithms efficiently
4. Conduct, analyze and evaluate numerical simulations based on DG
5. Analyze current publications about DG methods

4 Requirements for Participation

1) Basic knowledge of ordinary and partial differential equations
2) Lecture Numerical Computation Methods recommended
3) Elementary programming knowledge (e.g. MATLAB, C/C++, Java, C#) for exercise recommended

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)

Oral exam 30 min

6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master AE III Nat_Ing-Bereich WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Master Computational Engineering Master Mechanik
9	**Literature** Di Pietro, Ern: Mathematical aspects of discontinuous Galerkin methods. Springer, 2012 Toro: Riemann solvers and numerical methods for fluid dynamics. Springer, 2009 Lecture notes and additional study material will be made available at https://moodle.tu-darmstadt.de
10	**Comment**

Module Description

Module name

3.12 Multiphase Flows

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-64-5220	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Apl. Prof. Dr.-Ing. Yongqi Wang

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-64-5220-ue	Multiphase Flows	0	Exercise	1
16-64-5220-vl	Multiphase Flows	0	Lecture	3

2 Study Content

Kinematics; continuum mechanical modeling of the balance laws for immiscible multiphase flows with phase interfaces; jump conditions at phase interfaces and interfacial transport equations; particle-laden flows with the Euler-Langrange description; balance equations for miscible multicomponent mixtures; diffusion processes; some simple examples.

3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Explain the fundamental balance equations for the continuum-mechanical description of immiscible multiphase flows with phase interfaces, particle-laden flows and miscible multicomponent mixtures and to comprehend and to describe the associated flow physics. 2. Apply the approach of mathematical description and modeling to simple flow problems from various fields of multiphase and multicomponent flows. 3. Explain the behaviour of immiscible multiphase flows and mixtures for simple applications by means of balance relations. 4. Distinguish restrictions of various modelling methods.
4	**Requirements for Participation** 1) Fluid Mechanics or Technical Mechanics IV recommended; 2) Ordinary and partial differential equations; 3) Continuum Mechanics, advantageous but not required
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral exam 30 min.
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Lecture Notes
10	**Comment**

Module Description

Module name					
3.13 Modeling of Turbulent Flows					
Module no. 16-71-3024	**Credit Points** 8 CP	**Workload** 240 h	**Self-study** 150 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Christian Hasse		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-71-3024-ue	Modeling of Turbulent Flows	0	Exercise	2
16-71-3024-vl	Modeling of Turbulent Flows	0	Lecture	4

2 Study Content

Continuum mechanics (transport equations), basics of turbulence (properties, mathematical basics, time and length scales, spectral perspective), statistical turbulence modeling(RANS), Direct Numerical Simulation, Large Eddy Simulation (filtering, modeling, dynamic models, choice of model).

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Describe transient flow phenomena and their forms of appearance.
2. Explain the mathematical background and flow parameters of turbulence.
3. Derive the describing governing equations as well as their modeled form and interpret them by means of fundamental types of flows.
4. Recognize and characterize the most important types of technical flows.
5. Depict the dynamics of turbulent flows and elucidate the mathematical methods for their description.
6. Describe the fundamental models within modern flow solvers, apply them correctly, and assess their results.
7. Explain the resolution requirements of the Direct Numerical Simulation and therewith estimate its resource demands for high performance computers.
8. Elucidate and apply the fundamentals and modeling approaches of the Large Eddy Simulation.

4 Requirements for Participation

Fundamental Fluid Mechanics recommended

5 Form of Examination

Final Module Examination:

	• Module Examination (Technical Examination, oral / written Examination, Standard) Written exam 90 min or oral exam 20 min
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung Master MB II SP CEPE WPB Master PST III (Wahlfächer aus Natur- und Ingenieurwissenschaft)
9	**Literature** Lecture slides and a german videotaping will be made available via Moodle. Further literature will be outlined in the lecture.
10	**Comment**

Module Description

Module name **3.14 Aerodynamics II**					
Module no. 16-11-5060	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 135 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Jeanette Hussong		

1	**Courses of the Module**				
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
	16-11-5060-vl	Aerodynamics II	0	Lecture	3
2	**Study Content** Compressible flows: stream filament theory, shock waves, Prandtl-Meyer expansions, gas dynamic equations, airfoil theory, lifting-line theory, compressible boundary layers.				

3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Describe the fundamental differences of the theoretical treatment of compressible flows as compared to incompressible flows. 2. Explain the processes responsible for the occurrence of shocks and expansion waves and their influence on the aerodynamic characteristic. 3. Apply the procedures for compensating the compressibility effects in incompressible computed flows. 4. Explain the effects of compressibility on the aerodynamic features of airfoils and aircraft and methods of utilizing or avoiding such effects. 5. Describe the impact of compressibility on boundary layer flows.
4	**Requirements for Participation** Aerodynamics I recommended
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Oral (30 min) or written exam (60 min)
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** Tropea/Grundmann Aerodynamik II (Shaker Verlag), erhältlich im Sekretariat des Fachgebiets Strömungslehre und Aerodynamik Tropea/Grundmann Aerodynamik II (Shaker Verlag), available at FG office
9	**Literature** Tropea/Grundmann Aerodynamik II (Shaker Verlag), available at FG office
10	**Comment**

Module Description

Module name **3.15 Dynamics of Interfacial Flows**					
Module no. 16-11-3224	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Dr.-Ing. Ilia Roisman		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-11-3224-vl	Dynamics of Interfacial Flows	0	Lecture	2

2 Study Content

Introduction; Surface Tension; Stress Boundary Conditions; Static liquid shapes; Capillary waves on a flat interface; Wetting; Dynamic contact angle; Wall flows; Dynamics of thin liquid films; Dip coating: Landau-Levich problem; Plateau - Rayleigh instability of an infinite cylinder; Oscillations of a liquid drop;Marangoni Flows.

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Identify basic interfacial phenomena which influence various engineering problems
2. Solve hydrodynamic problems with capillary flows in drops, films, and jets
3. Evaluate and present modern scientific publications in the field of hydrodynamics of capillary flows

4 Requirements for Participation

Fundamental Fluid Mechanics recommended

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)

Oral exam 30 min

6 Requirements on the Award of Credit Points

Passing the examination

7 Grading

Final Module Examination:

	• Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** D.A. EDWARDS, H. BRENNER, D. T. WASAN, Interfacial Transport Processes and Rheology, Butterworth, 1993. S. CHANDRASEKHAR, Hydrodynamic and Hydromagnetic Stability, Clarendon Press, 1961. B. G. LEVICH, Physicochemical Hydrodynamics, 1962. A. L. YARIN, Free liquid jets and films: Hydrodynamics and Rheology, Longman Scientificamp;Technical, 1993. De Gennes, P. G., Brochard-Wyart, F., amp; Quéré, D., Capillarity and wetting phenomena: drops, bubbles, pearls, waves. Springer Science amp; Business Media., 2013
10	**Comment**

Module Description

Module name

3.16 Basic Phenomena in Multiphase Flows

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-11-3214	4 CP	120 h	90 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Dr.-Ing. Ilia Roisman

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-11-3214-vl	Basic Phenomena in Multiphase Flows	0	Lecture	2

2	**Study Content** Introduction; Single particle motion; Bubble transport, bubble dynamics; Thin liquid films; Instabilities; Sprays and aerosols; Interaction phenomena in sprays; Suspensions and emulsions; Flows in porous media; Granular media, granular flows; Flows with phase change.
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Identify different types and basic phenomena of multiphase flows 2. Solve elementary problems related to multiphase flows 3. Evaluate and present modern scientific publications in the field of multiphase flows

4	**Requirements for Participation** Fundamental Fluid Mechanics recommended
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral exam 30 min
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Ashgriz (ed.) Handbook of atomization and sprays. Springer 2011 Crowe, Clayton T., (ed.) Multiphase flow handbook. Vol. 59. CRC press, 2005. Yarin, A.L., Roisman, I. V., Tropea, C, Collision Phenomena in Liquids and Solids. Cambridge University Press, 2017.
10	**Comment**

Module Description

Module name **3.17 Nano- and Microfluidics I**					
Module no. 16-15-5190	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 75 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr. rer. nat. Steffen Hardt		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-15-5190-ue	Nano- and Microfluidics I	0	Exercise	1
16-15-5190-vl	Nano- and Microfluidics I	0	Lecture	2

2	**Study Content** 1. Fundamental equations of continuum fluid dynamics 2. Pressure-driven flow 3. Electrokinetic flow 4. Molecular dynamics 5. Experimental characterization of micro flows 6. Applications
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Compute elementary flow fields of pressure-driven and electrokinetic flow. 2. Design simple microfluidic hydraulic networks. 3. Identify the limits of continuum models for liquids. 4. Explain the fundamentals and the limits of the molecular dynamics method. 5. Formulate simple models for the configuration and dynamics of polymers based on the principle of entropy maximization. 6. Explain the fundamentals and the limits of the Micro-Particle-Image-Velocimetry method. 7. Formulate elementary microfluidic design concepts based on micropumps, micromixers and microreactors.
4	**Requirements for Participation** Basic knowledge of fluid dynamics and heat and mass transport
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral exam 30 min
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Master Mechatronik
9	**Literature** Will be anounced in the lecture
10	**Comment**

Module Description

Module name					
3.18 Nano- and Microfluidics II					
Module no. 16-15-5220	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 75 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr. rer. nat. Steffen Hardt		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-15-5220-ue	Nano- and Microfluidics II	0	Exercise	1
16-15-5220-vl	Nano- and Microfluidics II	0	Lecture	2

2 Study Content

1. Gas kinetics
2. Interfacial flows
3. Particulate flows
4. Dispensing systems
5. Cooling systems
6. Droplet manipulation
7. Particle separation

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Explain how the dynamics of gases on the submicron scale is different from the corresponding macroscopic dynamics.
2. Explain how important physical phenomena play a role in interfacial flows on the micro- and nanoscale.
3. Identify the most important mechanisms that are important for the transport of micro and nanoparticles.
4. Develop design concepts of dispensing systems meeting specific requirements.
5. Design a cooling system meeting specific requirements in an elementary manner.
6. Develop design concepts for droplet-based microfluidic systems meeting specific requirements.
7. Identify suitable methods for particle separation meeting specific requirements.

4 Requirements for Participation

Basic knowledge of fluid dynamics and heat and mass transport.

5 Form of Examination

Final Module Examination:

	• Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral exam 30 min
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Will be announced in the course.
10	**Comment**

4 Elective Area B: Advanced Modules in Mathematics

Module Description

Module name

4.1 Introduction to Mathematical Modelling

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-10-0044/de	5 CP	150 h	90 h	1 Semester	Every 4. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr. rer. nat. Jens Lang

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0140-vu	Introduction to Mathematical Modelling	0	Lecture and Exercise	4

2 Study Content

basic concepts, statical linear, non-linear and discrete systems, dynamical systems in one and more dimensions, systems with opponent, random.

3 Learning Outcomes

Students understand and are able to apply the basic techniques of mathematical modeling. They are aware of particular solution concepts for exemplary applications and understand the underlying mathematical structures. The students are able to apply known modeling techniques to further applications and to interprete the results.

4 Requirements for Participation

recommended: Analysis, Linear Algebra

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, Special Form, Passed / Not Passed)
- Module Examination (Technical Examination, oral / written Examination, Duration 60 min, Standard)

Fachprüfung (technical examination): Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.

Studienleistung (study examination): Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.

6	**Requirements on the Award of Credit Points** Passing the Fachprüfung; Passing the Studienleistung is a prerequisite for taking the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Special Form, Weight: 0%, Passed / Not Passed) • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc. Mathematik, LaG Mathematik
9	**Literature** lecture notes
10	**Comment** recommended: Mathematics: Bachelor year 3, Teaching Degrees

Module Description

Module name

4.2 Introduction to Optimization

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-10-0040/de	9 CP	270 h	180 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr. rer. nat. Marc Pfetsch

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0023-vu	Introduction to Optimization	0	Lecture and Exercise	6

2	**Study Content** convex sets and functions; introduction to the theory of polyhedra; theory of optimality and duality in linear optimization; simplex method for the solution of linear optimization problems; polynomial complexity of linear optimization; procedure for problems of quadratic optimization
3	**Learning Outcomes** Students - are proficient in optimality and duality theory in linear optimization.

	- are familiar with the basics of the theory of polyedra and convex functions.. - know basic numerical methods for the solution of linear and quadratic optimization problems. - are able to solve and model applications with linear and quadratic optimization problems.
4	**Requirements for Participation** recommended: Analysis, Linear Algebra
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Special Form, Passed / Not Passed) • Module Examination (Technical Examination, oral / written Examination, Duration 90 min, Standard) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam. Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung ; Passing the Studienleistung is a prerequisite for taking the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Special Form, Weight: 0%, Passed / Not Passed) • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics, LaG Mathematik M.Sc. ETIT
9	**Literature** Chvatal: Linear Programming Geiger, Kanzow: Theorie und Numerik restringierter Optimierungsaufgaben; Jarre, Stoer: Optimierung Nocedal; Wright: Numerical Optimization; Schrijver: Theory of Linear and Integer Programming; Ziegler: Lectures on Polytopes

10	**Comment** recommended: Mathematics: Bachelor year 3 (opt), Teaching Degrees

Module Description

Module name

4.3 Differential Geometry

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-10-0035/de	5 CP	150 h	105 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr. rer. nat. Elena Mäder-Baumdicker

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0133-vu	Differential Geometry	0	Lecture and Exercise	3

2 Study Content

Curves: arc length and curvature; Surface theory: first fundamental form, shape operator; principal curvatures, Gaussian and mean curvature, surfaces of revolution; possibly intrinsic geometry.

3 Learning Outcomes

After having attended this module the students have developed an intuition for curvature of curves and surfaces. They know how to describe surfaces in terms of differential geometry and they are able to discuss examples of curves and surfaces.

4 Requirements for Participation

Recommeded: Analysis, gew. Differentialgleichungen, Lineare Algebra

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, Technical Examination, Standard)
- Module Examination (Study Examination, Study Examination, Passed / Not Passed)

Fachprüfung (technical examination): Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.

6	**Requirements on the Award of Credit Points**
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Technical Examination, Weight: 100%, Standard) • Module Examination (Study Examination, Study Examination, Weight: 0%, Passed / Not Passed)
8	**Usability of the Module** B.Sc.Math math. Wahlbereich; Master: Ergänzungsbereich
9	**Literature** Bär: Elementare Differentialgeometrie Montiel, Ros: Curves and surfaces Hoschek, Lasser: Grundlagen der Geometrischen Datenverarbeitung
10	**Comment** Verantwortlich: Herr Reif (geo)

Module Description

Module name

4.4 Differential Geometry

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-10-0035/en	5 CP	150 h	105 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr. rer. nat. Elena Mäder-Baumdicker

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0227-vu	Differential Geometry	0	Lecture and Exercise	3

2 Study Content

curves: arc length and curvature;
surfaces: first fundamental form, Gauß map, shape operator; principal curvatures, Gaussian and mean curvature, surfaces of revolution; perhaps intrinsic geometry;
modelling: Bernstein polynomials, Bézier curves and surfaces; de Casterjau algorithm

3	**Learning Outcomes** After having attended this module the students have developed an intuition for curvature of curves and surfaces. They know how to describe surfaces in terms of differential geometry and they are able to discuss examples of curves and surfaces.
4	**Requirements for Participation** Analysis, gew. Differentialgleichungen, Lineare Algebra
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Duration 60 min, Standard) • Module Examination (Study Examination, Study Examination, Passed / Not Passed)
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard) • Module Examination (Study Examination, Study Examination, Weight: 0%, Passed / Not Passed)
8	**Usability of the Module** B.Sc.Math math. Wahlbereich; Master: Ergänzungsbereich
9	**Literature** Bär: Elementare Differentialgeometrie Montiel, Ros: Curves and surfaces Hoschek, Lasser: Grundlagen der Geometrischen Datenverarbeitung
10	**Comment** Verantwortlich: Herr Reif (geo)

Module Description

Module name **4.5 Mathematical Modelling of Fluid Interfaces I**					
Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
04-10-0291	5 CP	150 h	105 h	1 Semester	Every 9. semester

Language of Instruction German and English	**Person responsible for the Module** Prof. Dr. rer. nat. Dieter Bothe

	Courses of the Module				
1	**Course no.**	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
	04-00-0286-vu	Mathematical Modelling of Fluid Interfaces	0	Lecture and Exercise	3

2	**Study Content** Basic calculus on surfaces; two-phase and surface transport theorems; remarks on quasilinear free boundary problems. Derivation of two-phase integral balance equations for mass, momentum and species mass; derivation of local balances and interfacial jump conditions; modeling of surface tension, mass transfer, evaporation, condensation. Continuum thermodynamics of fluid interface; entropy balance; entropy principle and second law; linear and non-linear closures.
3	**Learning Outcomes** Students learn to - describe the phenomena occuring at fluid interfaces - formulate the integral balances of two-phase fluid systems - formulate the differential form of the balance equations - formulate closure relations and transmission conditions - describe dissipative processes in single-component two-phase fluid systems
4	**Requirements for Participation** recommended: Analysis, Ordinary Differential Equations. Alternatively comparable prerequisites.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc Mathematik, M.Sc. Mathematik, M.Sc. Mathematics

9	**Literature** R. Aris: Vectors, Tensors and the Basic Equations of Fluid Dynamics, Dover 1962. J.C. Slattery, L. Sagis, E.-S. Oh: Interfacial Transport Phenomena (2nd ed.), Springer 2006. D.A. Edwards, H. Brenner, D.T. Wasan: Interfacial Transport Processes and Rheology, Butterworth-Heinemann 1991.
10	**Comment** recommended: Mathematics: Master (ana)

Module Description

Module name

4.6 Mathematical Modelling of Fluid Interfaces II

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-10-0309	5 CP	150 h	105 h	1 Semester	Every 9. semester

Language of Instruction	Person responsible for the Module
German and English	Prof. Dr. rer. nat. Dieter Bothe

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-10-0309-vu	Mathematical Modelling of Fluid Interfaces II	0	Lecture and Exercise	3

2	**Study Content** 1) Balance equations for multiphase fluid systems with interfacial mass; interface momentum and energy balance 2) Mass transfer across fluidic interfaces: chemical potential, interfacial jump conditions 3) Thermodynamically consistent modeling of dynamic three phase contact lines
3	**Learning Outcomes** Students learn to - describe advanced phenomena at fluid interfaces with interfacial mass - formulate the transmission and thermodynamical jump conditions for description of transport and transfer procces - describe the dissipative processes occuring at three phase contact lines
4	**Requirements for Participation** recommended: Analysis, Ordinary Differential Equations. Mathematical Modeling of fluid interfaces I
5	**Form of Examination** Final Module Examination:

	• Module Examination (Technical Examination, oral / written Examination, Duration 60 min, Standard) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc Mathematik, M.Sc. Mathematik, M.Sc. Mathematics
9	**Literature** I. Müller: Thermodynamics, Pitman 1985 J.C. Slattery, L. Sagis, E.-S. Oh: Interfacial Transport Phenomena (2nd ed.),Springer 2006. D.A. Edwards, H. Brenner, D.T. Wasan: Interfacial Transport Processes and Rheology, Butterworth-Heinemann 1991.
10	**Comment** recommended: Mathematics: Master (ana)

Module Description

Module name **4.7 Numerical Linear Algebra**					
Module no. 04-10-0043/de	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 105 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Dr. rer. nat. Alf Gerisch		

1	**Courses of the Module**				
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
	04-00-0139-vu	Numerical Linear Algebra	0	Lecture and Exercise	3

2	**Study Content** Systems of linear equations: iterative methods, singular value decomposition, eigenvalue problems.
3	**Learning Outcomes** Students know about the most important numerical methods of linear algebra and they are able to explain, classify, and apply them.
4	**Requirements for Participation** recommended: Linear Algebra, Introduction to Numerical Analysis or similar knowledge
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Special Form, Passed / Not Passed) • Module Examination (Technical Examination, Technical Examination, Standard) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam. Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung; Passing the Studienleistung is a prerequisite for taking the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Special Form, Weight: 0%, Passed / Not Passed) • Module Examination (Technical Examination, Technical Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics M.Sc. ETIT
9	**Literature** Trefethen/Bau: Numerical Linear Algebra, SIAM Demmel: Applied Numerical Linear Algebra, SIAM Stoer/Bulirsch: Numerische Mathematik 2, Springer
10	**Comment**

	recommended: Mathematics: Bachelor year 3 (num)

Module Description

Module name **4.8 Ordinary Differential Equations**					
Module no. 04-10-0011/de	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 105 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr. rer. nat. Matthias Hieber		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0054-vu	Ordinary Differential Equations	0	Lecture and Exercise	3

2 Study Content

Separation of variables, Theorems of Picard-Lindelöf and Peano, local and global theory, linear systems of first and higher order, variation of constants formula, linearised stability, Lyapunov stability.

3 Learning Outcomes

Students

- understand and are able to apply the notions, methods and results treated in the course
- develop a basic level of understanding of the theory of ordinary differential equations
- are able to recognise the treated concepts in various fields of mathematics.

4 Requirements for Participation

recommended: Analysis and Linear Algebra

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral / written Examination, Standard)
- Module Examination (Study Examination, Special Form, Passed / Not Passed)

Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated
during the first two weeks of the lecture, based on the prospective number of students taking the exam.

Studienleistung: Usually this means that the student successfully completes a certain proportion of the

	homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung; Passing the Studienleistung is a prerequisite for taking the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard) • Module Examination (Study Examination, Special Form, Weight: 0%, Passed / Not Passed)
8	**Usability of the Module** B.Sc. Mathematik, LaG Mathematik, B.Sc. Physik M.Sc. ETIT
9	**Literature** H. Amann: Gewöhnliche Differentialgleichungen, de Gruyter W. Walther: gew. DGL, Springer
10	**Comment** recommended: Mathematics: Bachelor year 2, Teaching Degrees

Module Description

Module name

4.9 Probability Theory

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-30-0045/de	9 CP	270 h	180 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr. rer. nat. Michael Kohler

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0141-vu	Probability Theory	0	Lecture and Exercise	6

2 Study Content

Measure theoretical foundations, theory of integration, random variables, concepts of convergence,

	characteristic functions, stochastic independence, 0-1-laws, conditional expectations, martingales in discrete time, limit theorems: law of large numbers, central limit theorem.
3	**Learning Outcomes** Students - understand and are able to apply the notions, methods and results treated in the course - develop a basic level of understanding of probability theory - are able to recognise the treated concepts in various fields of mathematics.
4	**Requirements for Participation** recommended: Analysis, Integration Theory, Introduction to Stochastics
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Duration 90 min, Standard) Fachprüfung (technical examination): Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung (technical examination)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics, LaG Mathematik
9	**Literature** Bauer: Probability Theory Billingsley: Probability and Measure Elstrodt: Maß-und Integrationstheorie Gänssler, Stute: Wahrscheinlichkeitstheorie Klenke: Wahrscheinlichkeitstheorie
10	**Comment** recommended: recommended: Mathematics: Bachelor year 3 (sto), Teaching Degrees

Module Description

Module name **4.10 Probability Theory**					
Module no. 04-30-0045/en	**Credit Points** 9 CP	**Workload** 270 h	**Self-study** 180 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr. rer. nat. Volker Martin Betz		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0071-vu	Probability Theory	0	Lecture and Exercise	6

2 Study Content

Measure theoretical foundations, theory of integration, random variables, concepts of convergence, characteristic functions, stochastic independence, 0-1-laws, conditional expectations, martingales in discrete time, limit theorems: law of large numbers, central limit theorem.

3 Learning Outcomes

Students
- understand and are able to apply the notions, methods and results treated in the course
- develop a basic level of understanding of probability theory
- are able to recognise the treated concepts in various fields of mathematics.

4 Requirements for Participation

recommended: Analysis, Integration Theory, Introduction to Stochastics

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral / written Examination, Duration 90 min, Standard)

Fachprüfung (technical examination): Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.

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6 Requirements on the Award of Credit Points

	Passing the Fachprüfung (technical examination)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics, LaG Mathematik
9	**Literature** Bauer: Probability Theory Billingsley: Probability and Measure Elstrodt: Maß-und Integrationstheorie Gänssler, Stute: Wahrscheinlichkeitstheorie Klenke: Wahrscheinlichkeitstheorie
10	**Comment** recommended: Mathematics: Bachelor year 3 (sto), Teaching Degrees

Module Description

Module name

4.11 Numerical Methods for ordinary differential equations

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-30-0393/de	9 CP	270 h	180 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr. rer. nat. Jan Giesselmann

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0138-vu	Numerics of Ordinary Differential Equations	0	Lecture and Exercise	6

2	**Study Content** initial value problems: one-step methods, multi-step methods; convergence analysis, notions of stability; boundary-value problems: Shooting methods, finite difference methods, stability and convergence; partial differential equations: Finite difference methods, convergence analysis;
3	**Learning Outcomes** Students know some basic numerical solution concepts for ordinary differential equations and for

	simple partial differential equations. They are able to analyze, compare, and apply them.
4	**Requirements for Participation** recommended: Analysis, Linear Algebra, Ordinary Differential Equations, Introduction to Numerical Analysis or similar knowledge as taught in an engineering programme.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Duration 90 min, Standard) Fachprüfung (technical examination): Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung (technical examination)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics (nicht zusammen mit 04-30-0042/de, 04-10-0042/de oder 04-10-0393/de belegbar)
9	**Literature** Deuflhard, Bornemann: Numerische Mathematik 2 Stoer, Bulirsch: Numerische Mathematik 2
10	**Comment** recommended: Mathematics: Bachelor year 3 (num)

Module Description

Module name **4.12 Complex Analysis**					
Module no. 04-10-0226/en	**Credit Points** 5 CP	**Workload** 150 h	**Self-study** 105 h	**Duration** 1 Semester	**Frequency** Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr. rer. nat. Matthias Hieber

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0225-vu	Complex Analysis	0	Lecture and Exercise	3

2 Study Content

Cauchy-Riemann differential equations, curve integrals, Cauchy's Integral Theorem and Formula; analyticity, Liouville's Theorem and Fundamental Theorem of Algebra; Winding Number; Laurent series and isolated singularities, Residue Theorem.

3 Learning Outcomes

Students
- understand and are able to apply the notions, methods and results treated in the course
- develop a basic level of understanding of Complex Analysis
- are able to recognise the treated concepts in various fields of mathematics.

4 Requirements for Participation

recommended: Analysis and Linear Algebra

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral / written Examination, Duration 60 min, Standard)
- Module Examination (Study Examination, Special Form, Passed / Not Passed)

Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated
during the first two weeks of the lecture, based on the prospective number of students taking the exam.

Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.

6 Requirements on the Award of Credit Points

Passing the Fachprüfung;
Passing the Studienleistung is a prerequisite for taking the Fachprüfung

7 Grading

Final Module Examination:

	• Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard) • Module Examination (Study Examination, Special Form, Weight: 0%, Passed / Not Passed)
8	**Usability of the Module** B.Sc. Mathematik, LaG Mathematik
9	**Literature** Freitag: Funktionentheorie I, Springer Remmert: Funktionentheorie I Conway: Functions of one complex variable, Springer
10	**Comment** recommended: Mathematics: Bachelor year 2, Teaching Degrees

Module Description

Module name

4.13 Functional Analysis

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-10-0036/de	9 CP	270 h	180 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr. rer. nat. Matthias Hieber

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-00-0069-vu	Functional Analysis	0	Lecture and Exercise	6

2	**Study Content** Normed vector spaces, completion; Theorem of Hahn-Banach, Theorem of Banach-Steinhaus, Open Mapping Theorem, Closed Graph Theorem; Hilbert spaces; reflexive spaces, weak convergence; Sobolev spaces, weak solution of the Dirichlet problem; spectral properties of linear operators; compact operators on Banach spaces, spectral theorem for compact operators.
3	**Learning Outcomes** Students learn to - combine ideas from linear algebra, analysis and topology - understand and explain basic principles of functional analysis - explain methods from functional analysis in the context of partial differential equations

4	**Requirements for Participation** recommended: Analysis, Integration Theory, Complex Analysis, Linear Algebra or comparable prerequisites acquired in mathematics courses in engineering programmes
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, Special Form, Passed / Not Passed) • Module Examination (Technical Examination, oral / written Examination, Duration 90 min, Standard) Fachprüfung: Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam. Studienleistung: Usually this means that the student successfully completes a certain proportion of the homework assignments. The precise proportion of necessary assignments and the marking scheme will be communicated by the instructor during the first lecture.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung ; Passing the Studienleistung is a prerequisite for taking the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Study Examination, Special Form, Weight: 0%, Passed / Not Passed) • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc. Mathematik, M.Sc Mathematik, M.Sc. Mathematics
9	**Literature** Alt: Lineare Funktionalanalysis; Conway: A Course in Functional Analysis; Reed, Simon: Functional Analysis: Methods of Modern Mathematical Physics I; Rudin: Functional Analysis; Werner: Funktionalanalysis; Ciarlet: Functional Analysis;
10	**Comment** recommended: Mathematics: Bachelor year 3 (ana)

Module Description

Module name **4.14 Applied Geometry**					
Module no. 04-11-0375	**Credit Points** 9 CP	**Workload** 270 h	**Self-study** 180 h	**Duration** 1 Semester	**Frequency** Every 9. semester
Language of Instruction German and English			**Person responsible for the Module** Prof. Dr. rer. nat. Ulrich Reif		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-10-0375-vu	Applied Geometry	0	Lecture and Exercise	6

2 Study Content

Bernstein polynomials, Bézier curves, B-splines, spline curves, tensor product splines, spline surfaces, subdivision algorithms, smoothing of curves and surfaces, curvature estimation on polylines and triangular meshes.

3 Learning Outcomes

Students

- understand basic mathematical principles of computer-aided geometric modeling of curves and surfaces
- are able to assess their significance for theoretical and applied purposes
- thoroughly understand the relationship between analytical properties of the involved function spaces and geometric properties of the manifolds they parametrise.

4 Requirements for Participation

recommended: Differential Geometry

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral / written Examination, Standard)

Fachprüfung (Technical Examination): Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.

6 Requirements on the Award of Credit Points

Passing the Fachprüfung

7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc Mathematik, M.Sc. Mathematik, M.Sc. Mathematics
9	**Literature** Hoschek und Lasser, Grundlagen der geometrischen Datenverarbertung, Teubner Prautzsch, Boehm und Paluszny, Bézier and B-Spline Techniques, Springer Peters und Reif, Subdivision surfaces, Springer Hoschek und Lasser, Grunglagen der geometrischen Datenverarbertung, Teubner Prautzsch, Boehm und Paluszny, Bézier and B-Spline Techniques, Springer Peters und Reif, Subdivision surfaces, Springer
10	**Comment** recommended: Mathematics: Master (geo)

Module Description

Module name

4.15 Computational Fluid Dynamics

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
04-10-0384	9 CP	270 h	180 h	1 Semester	Every 9. semester

Language of Instruction	Person responsible for the Module
German and English	Prof. Dr. rer. nat. Jan Giesselmann

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-10-0384-vu	Computational Fluid Dynamics	0	Lecture and Exercise	6

2	**Study Content** Modelling: Reynolds transport theorem; conservation of mass and momentum; Navier-Stokes and Euler equations; boundary conditions; siomplified models; Analysis: weak formulation; existence and uniqueness results for Stokes and Navier-Stokes; Numerics: The finite element method for coercive and non-coercive problems; convergence analysis; convection-diffusion problems; stable discretization for the Stokes problem; numerical tretament of the Navier-Stokes equations;
3	**Learning Outcomes** The students understand the basic equations of fluid dynamics, their origin, and elementary properties.

	They know about the basics results on solvability of these models and about their numerical solution by finite element methods. The students are able to explain, analyse, and implement the finite element methods.
4	**Requirements for Participation** recommended: required: basic knowledge of partial differential equations and numerical methods useful courses: Functional Analysis, Partial Differential Equations, Numerical Analysis of Elliptic/Parabolic Differential Equations
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Fachprüfung (Technical Examination): Usually the exam is taken in form of a written test, except when there are only a small number of potential participants. In this case, the exam can be taken in the form of an oral exam. The decision about the form of the exam is taken and communicated during the first two weeks of the lecture, based on the prospective number of students taking the exam.
6	**Requirements on the Award of Credit Points** Passing the Fachprüfung
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** B.Sc Mathematik, M.Sc. Mathematik, M.Sc. Mathematics
9	**Literature** D. Braess: Finite Elemente, Springer. D. C. Brenner, L. R. Scott: The mathematical theory of finite element methods, Springer. V. Girault, P.-A. Raviart: Finite Element Approximation of the Navier-Stokes Equations, Springer. C. Johnson: Numerical solution of partial differential equations by the finite element method, Dover. R. Temam, Navier-Stokes Equations, North-Holland Publishing.
10	**Comment** recommended: Mathematics: Master (num)

5 Engineering specialization Area

5.1 Aeronatics

Module Description

Module name

5.1.1 Flight Mechanics II: Dynamics

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-23-5040	6 CP	180 h	135 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Uwe Klingauf

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-23-5040-vl	Flight Mechanics II: Dynamics	0	Lecture	3

2 Study Content

Static stability of flight; static longitudinal and lateral motion; steady maneuvers; dynamic longitudinal and lateral stability; eigenvalues; 6-degrees-of-freedom model

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Model, analyse, and characterize the static and dynamic motion of aircrafts.
2. Explain the impact of the aircraft configuration on system behavior.
3. Evaluate the handling qualities.
4. Design control surfaces for the control of flight state.
5. Design models for flight simulation.

4 Requirements for Participation

Flight Mechanics I and Control Engineering recommended

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral / written Examination, Standard)

Written exam 90 min or oral exam 30 min

6 Requirements on the Award of Credit Points

Passing the examination

7 Grading

Final Module Examination:

	• Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Master Mechatronik
9	**Literature** Course notes and further material available online. Textbooks: Anderson: Introduction to Flight (McGraw Hill);Yechout: Introduction to Aircraft Flight Mechanics (AIAA); Stevens, Lewis: Aircraft Control and Simulation (Wiley); Cook: Flight Dynamics Principles (Elsevier); Etkin, Reid: Dynamics of Flight: Stability and Control (Wiley).
10	**Comment**

Module Description

Module name

5.1.2 Space Debris – Risks, Surveillance and Mitigation

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-23-3164	4 CP	120 h	90 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Dr. Ing. Holger Krag

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-23-3164-vl	Space Debris - Risks, Surveillance and Mitigation	0	Lecture	2

2 Study Content

This lecture will provide the scientific, technical and operational background in relation to the sources, surveillance and mitigation of space debris.
This covers risk assessment aspects: source and sink terms, particle flux models, aerodynamics and aerothermal aspects during atmospheric re-entry and related on-ground risk assessments;
all major aspects of space surveillance: ground-based radar and telescope systems, orbit determination methods (batch least square, Levenberg-Marquardt, Kalmanfilter), residuals, covariances, operational collision avoidance;
As well as space debris mitigation aspects: long-term environment projection models, international guidelines, passivation methods, shielding concepts, methods for post mission disposal and verification of measures;

3	**Learning Outcomes** On successful completion of this module, students should be able to: 1.name the sources of space debris and describe the human-made particle environment and the consequences of particle impacts; 2.analyse and determine the risks to a space mission due the natural and human-made particle environment and limit this this risk by suitable technical measures; 3.determine the on-ground risk caused by the atmospheric re-entry of a space object; 4.lay-out a space mission according to applicable space debris mitigation guidelines and verify the resulting setup along with international standards; 5.perform the main tasks of flight dynamics in operations (orbit determination and manoeuvre-planning) and explain the operational processes in the context of collision avoidance; 6.Present the main technical aspects of space surveillance, lay-out the required sensor systems and apply the related computational methods;
4	**Requirements for Participation** knowledge of the content of „Space Flight Mechanics" (module no. 16-25-5130) is an asset but not a pre-requisite.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 20 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master AE III Nat_Ing-Bereich WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Klinkrad: Space Debris – Models and Risk Analysis, Springer Springer Praxis Books Astronautical Engineering, 2006, ISBN 978-3-540-37674-3
10	**Comment**

Module Description

Module name **5.1.3 Machine Dynamics**					
Module no. 16-98-4094	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr.-Ing. Tobias Melz		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-98-4094-hü	Machine Dynamics	0	Auditorium Exercise	1
16-98-4094-vl	Machine Dynamics	0	Lecture	3

2 Study Content

Vibration Systems in Mechanical Engineering. Problems of Advanced Machine Dynamics.
Elements (parameter) of mechanical vibration systems in machines and structures.
Modelling and equations of motion of linear vibration systems for machines and structures.
Input-output relations, excitation and vibration response signals in the time and frequency domain.
Natural vibrations of linear SDOF- and MDOF systems, eigenvalues and eigenvectors, orthogonality.
Forced vibrations of linear SDOF- and MDOF systems due to different excitations.
Influence of (multiphysical) interactions (structure, fluid, electric and magnetic fields) on the vibration behavior.
Vibration monitoring and diagnosis. Measures for vibration control.
Vibration systems with distributed parameters (continua) and nonlinear vibrations.
Applications of Machine Dynamics in different areas of Mechanical Engineering.

3 Learning Outcomes

On successful completion of this module, students should be able to:
1. Work on basic problems in machine and structural dynamics and to find practical solutions.
2. Model real mechanical vibration systems (machines and structures) and to derive the equations of motion based on the principles of mechanics.
3. Determine and to analyse the dynamic characteristics (natural frequencies, damping behavior, vibration modes) of machines and structures.
4. Calculate forced vibrations (system responses) of machines and structures due to different types of excitations and to interpret the solutions.
5. Fundamentally recognize, to plan and to evaluate experimental investigations of vibration systems (frequency response, system identification, modal analysis).
6. Plan vibration monitoring and diagnosis for machines.
7. Suggest and to apply measures for vibration control.

4 Requirements for Participation

Technical Mechanics I to III (Statics, Elastomechanics, Dynamics) and Mathematics I to III

	recommended.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Duration 150 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the examination.
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Weight: 100%, Standard)
8	**Usability of the Module** Master MB Ia Grundlagen Master MB SP FAS WPB Ia Pflicht WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) WI/MB, Master Mechatronik
9	**Literature** Markert, R.: „Strukturdynamik", Shaker, 2013. Dresig, H.; Holzweißig, F.: „Maschinendynamik", 10. Auflage, Springer, 2011. Gasch, R.; Nordmann, R.: „Rotordynamik“, 2. Auflage, Springer,2005. Dresig, H.: „Schwingungen mechanischer Antriebssysteme“, Springer 2001. Fischer, U.; Stephan, W.: „Mechanische Schwingungen“, 3. Auflage, Fachbuchverlag Leipzig, 1993.
10	**Comment**

Module Description

Module name

5.1.4 Avionics System Safety

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-23-5110	4 CP	120 h	90 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Uwe Klingauf

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-23-5110-vl	Avionics System Safety	0	Lecture	2

2	**Study Content** Operational requirements for flight guidance systems, structure of flight guidance systems, architectures and design of safe systems, pilot assistance systems in the cockpit, human factors.
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Describe the basics of automated flight operations and human-machine interfaces in modern aircraft flight decks. 2. Explain the basic concepts and methods in the design of safety critical systems in flight control. 3. Differentiate between the different system architecture concepts. 4. Describe and discuss the complex interplay of technical systems, operational processes and humans using the example of avionics systems.
4	**Requirements for Participation** Recommended: Flight Mechanics I: Performance, Fundamentals of Navigation I, Systemic Evaluation of Air Transportation
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Written exam 60 min or oral exam 20 min
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Bahr, N.J.: System Safety Engineering and Risk Assessment: A Practical Approach, 2ndEdition, CRC Press 2015Dhillon, B.S.: Transportation Systems Reliability and Safety, CRC Press 2011C.C. Rodriges, S.K. Cusick: Commercial Aviation Safety, McGraw Hill 2011R. Isermann: Fault Diagnosis Systems, Springer 2006
10	**Comment**

Module Description

Module name

5.1.5 Composite Structures

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-12-3174	4 CP	120 h	37.5 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Christian Mittelstedt

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-12-3174-ue	Composite Structures	0	Exercise	3.5
16-12-3174-vl	Composite Structures	0	Lecture	2

2 Study Content

Historical developments, Nomenclature, Fibers and matrices, Semi-finished products, Behaviour of a laminate layer, Classical Laminate Plate Theory, Influence of moisture and temperature, Fracture and degradation, Joints (circumferential joints, bolted joints, bonded joints), Optimization of laminates, Design guidelines, Stress concentration problems, Stability problems, Examples from aircraft engineering, Example: Predesign of a thin-walled composite beam

3 Learning Outcomes

Upon successful completion of this module, students should be able to:

1. Select fibers, matrices and semi-finished products according to a specific task.
2. Perform basic static analyses of thin-walled composite structures.
3. Apply classical laminated plate theory for basic composite laminate problems and to perform strength assessments under consideration of static loads as well as moisture and temperature loads.
4. Understand the most relevant stability and stress concentration problems in the framework of composite structures and to perform according analyses.
5. Understand and apply construction principles in composites engineering.

4 Requirements for Participation

Attending and succesfully completing the modules „Lightweight Engineering I" and "Lightweight Engineering II" is recommended.

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)

Course Examination:

- [16-12-3174-ue] (Technical Examination, Report, Passed / Not Passed)

	Oral exam 30 min., divided into 10 minutes presentation of the results of the design project (1/3) and 20 minutes oral examination (2/3)and report (design project, pnp).
6	**Requirements on the Award of Credit Points** Passing the examinations.
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard) Course Examination: • [16-12-3174-ue] (Technical Examination, Report, Weight: 0%, Passed / Not Passed)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung Master MB II SP SUR WPB Master PST IV (Kernlehrveranstaltungen der Papiertechnik) Angewandte Mechanik Mechatronik
9	**Literature** ALTENBACH, H., ALTENBACH, J. und RIKARDS, R., 1996. Einführung in die Mechanik der Laminat- und Sandwichtragwerke. Stuttgart: Deutscher Verlag der Grundstoffindustrie. JONES, R.M., 1975. Mechanics of composite materials. Washington, USA: Scripta Book Co. MITTELSTEDT, C. und BECKER, W., 2016. Strukturmechanik ebener Laminate. Darmstadt: Studienbereich Mechanik, TU Darmstadt. SCHÜRMANN, H., 2005. Konstruieren mit Faser-Kunststoff-Verbunden. Berlin et al.: Springer.
10	**Comment**

Module Description

Module name **5.1.6 Space Flight Mechanics**					
Module no. 16-23-4234	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Dr.-Ing. Florian Renk		

1	**Courses of the Module**				
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per**

					Week
	16-23-4234-ue	Space Flight Mechanics	0	Exercise	1
	16-23-4234-vl	Space Flight Mechanics	0	Lecture	3
2	**Study Content** Kepler's laws, two-body problem; satellite orbits and orbital elements, perturbation of the orbital elements; orbital transfer manoeuvres, interplanetary trajectories, the three-body problem and current missions and trajectory design problems of the European space program.				
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Describe the orbit of spacecraft by means of geometric analysis, algebraic, and eventually numeric analysis. 2. Explain the basic laws of celestial mechanics such as the applicability and constraints of Keplerian elements and the methods to calculate perputation. 3. Use the principle of the patched conics approach for trajectory design. 4. Describe the challenges and capabilities of planetary and inter-planetary space flight. 5. Understand and apply the operational constraints that can affect the trajectory design. 6. Name and apply the special nomenclature and system of units that appear in celestial mechanics. 7. Name recent and older project and missions of space flight, especially with respect to the European space program.				
4	**Requirements for Participation** Recommended: Successful participation in the course/examination „Foundations of Space Stations“				
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Written final exam (90 min) or oral exam 20 min.				
6	**Requirements on the Award of Credit Points** Passing the examination				
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)				
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master AE III Nat_Ing-Bereich WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Mechatronik				
9	**Literature**				

	Course reader, available in the first lecture
10	**Comment**

Module Description

Module name **5.1.7 Fundamentals of Space Systems**					
Module no. 16-23-3134	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Reinhold Bertrand		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-23-3134-vl	Fundamentals of Space Systems	0	Lecture	2

2 Study Content

The lecture shall present the basics to understand, design and operate space systems, in particular: Historical development of spaceflight, utilisation of space, space environment, Ziolkowsky equation, foundations of orbit mechanics and maneuvers, overview on subsystems for space systems: energy provision, attitude and orbit control, thermal control, data handling and communication.

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Explain the historical development of space flight with the relevant technological and societal connections, together with the respective applications and utilisation scenarios.
2. Describe, characterise and estimate the relevant environmental factors for space systems (e.g. thermal environment, residual atmosphere, particle radiation etc.).
3. Describe basic orbit manoeuvres.
4. Describe and analyse typical subsystems in their functionality and design.

4 Requirements for Participation

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral / written Examination, Standard)

Facultative: oral (20 min) or written (45 - 60 min)

6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft)
9	**Literature** Messerschmid/Fasoulas: Raumfahrtsysteme, Springer Verlag - e-book Messerschmid/Bertrand: Raumstationen – Systeme und Nutzung, Springer Verlag
10	**Comment**

5.2 Bio Mechanics

Module Description

Module name

5.2.1 Biomechanik

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
03-05-0057	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr. phil. André Seyfarth

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
03-46-0007-vl	Einführung in die Biomechanik	0	Lecture	2
03-46-0008-ps	Biomechanik	0	Proseminar	2

2	**Study Content** Gegenstand und Selbstverständnis, Grundbegriffe, Modelle der Bewegung; Bewegungsanalyse; Motorische Test- und Diagnoseverfahren, Untersuchungsziele, Kenngrößen, Messverfahren und Prinzipien der Biomechanik, exemplarische Anwendung von sportmotorischen Tests und biomechanischen Untersuchungen.

3	**Learning Outcomes** • Kenntnisse des Selbstverständnisses, der Ansätze, der Methoden und Erkenntnisse der Biomechanik • Herstellen interdisziplinärer Verbindungen zwischen der Biomechanik und anderen Disziplinen bei der praktischen Anwendung wissenschaftlicher Erkenntnisse und Methoden • Herstellung und Einschätzung des praktischen Bezugs der Modelle, Theorien, Methoden und Erkenntnisse der Biomechanik • Reflexion konkreter sportpraktischer Fragen und Probleme vor dem Hintergrund biomechanischer Erkenntnisse
4	**Requirements for Participation** Keine
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Duration 60 min, Standard) Course Examination: • [03-46-0008-ps] (Study Examination, oral / written Examination, Standard) Die Prüfungsform wird zu Beginn der Lehrveranstaltung spezifiziert und den Studierenden mitgeteilt. Die Studienleistung im Proseminar kann in Form einer Portfolioprüfung, Hausarbeit, Referat, Klausur, Essay, Bericht, Hausübungen, Arbeitsblättern, Protokollen, mündlicher Prüfung, Kolloquium oder Präsentation abgenommen werden.
6	**Requirements on the Award of Credit Points** Bestandene Prüfungsleistungen
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Weight: 1, Standard) Course Examination: • [03-46-0008-ps] (Study Examination, oral / written Examination, Weight: 1, Standard)
8	**Usability of the Module** B.Sc. Sportwissenschaft
9	**Literature** Relevante Literatur wird zu Beginn der Lehrveranstaltung bekannt gegeben.

10	Comment

Module Description

Module name **5.2.2 Numerical modeling in Hydraulic Engineering**					
Module no. 13-L2-M006	**Credit Points** 3 CP	**Workload** 90 h	**Self-study** 60 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr.-Ing. Boris Lehmann		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-L2-0007-vl	Numerical Modelling in Hydraulic Engineering	0	Lecture	2

2 Study Content

- Definition of the model term, model types in hydraulic engineering
- Applications of numerical models for hydraulic engineering
- Mathematical principles: mass, momentum, energy
- Navier-Stokes equations and simplified forms
- Analytical solution possibilities
- Numerical solution possibilities
- Turbulence consideration in numerical solution methods
- Working steps in modelling and model application
- Examples of use

3 Learning Outcomes

The students can select a suitable numerical model approach for given hydraulic engineering problems and to carry out the necessary steps for model creation and application. The strengths, weaknesses and application limits of hydraulic engineering numerical models are known and an overview of software solutions currently used in practice is available.

4 Requirements for Participation

Recommended: „Grundlagen der Rohr- und Gerinnehydraulik" (13-L2-M021), „Wasserbau II: Flussbau, Hochwasserschutz und Wasserkraftnutzung (13-L2-M001/3) and Wasserbau II, III" (13-L2-M002/ 13-L2-M003/3)

5 Form of Examination

Final Module Examination:

	• Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Slide handouts and references to supplementary technical literature are distributed during the course.
10	**Comment**

Module Description

Module name

5.2.3 River Dynamics

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-L2-M009	3 CP	90 h	60 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr.-Ing. Boris Lehmann

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-L2-0003-vl	River Dynamics	0	Lecture	2

2	**Study Content** - definition of water course morphology - space-time models - bed-load transport - suspended load transport - interaction
3	**Learning Outcomes** By successfully passing the module examination, students can - outline phenomenon's of fluvial morphology, - estimate sediment transport rates,

	- define suspended load transport, - work out advanced demanding solutions.
4	**Requirements for Participation** „Grundlagen der Rohr- und Gerinnehydraulik" (13-L2-M009), Module „Wasserbau I, II, III" (13-L2-M001/3 / 13-L2-M002/ 13-L2-M003/3)
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Begleitmaterial, Folienhandouts, Skripte und Literaturhinweise werden im Rahmen der Kursstunden ausgegeben.
10	**Comment**

Module Description

Module name

5.2.4 Numerical Simulations in Geotechnical Engineering

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-C0-M041	3 CP	90 h	60 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Hauke Zachert

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-C0-0041-ue	Numerical Simulations in Geotechnical Engineering - Exercise	0	Exercise	1

	13-C0-0041-vl	Numerical Simulations in Geotechnical Engineering	0	Lecture	1
2	**Study Content** Fundamentals of continuum mechanics, initial conditions and boundary conditions of geotechnical systems, groundwater flow, multiphase elements, elasto-plastic and hypoplastic material models, parameter determination, modeling of geotechnical structural elements, dynamic simulations, finite element method in geotechnical design.				
3	**Learning Outcomes** The students acquire the necessary knowledge for the investigation of geotechnical constructions with the finite element method (FEM). They are able to independently solve technical problems according to scientific principles using the finite element method, choosing appropriate material models and element formulations. They are able to explain and justify the choice of calculation parameters and can critically review calculation results. The module forms a comprehensive basis for an in-depth examination of the FEM in geotechnical engineering in the context of a scientific career or a career in industry and provides incentives for students to acquire this in-depth knowledge.				
4	**Requirements for Participation** Recommended: Geotechnik I (13-C0-M005/3), Geotechnik II (13-C0-M023), Geotechnics III (13-C0-open), Geotechnics IV (13-C0-open), Finite-Element-Methoden I (13-E1-M001)				
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) • Module Examination (Study Examination, Homework, Worksheets, Passed / Not Passed) Study Examination: 2 homework assignments; handing in and out during the semester; group size up to 3 students				
6	**Requirements on the Award of Credit Points** Passing the module examination(s)				
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard) • Module Examination (Study Examination, Homework, Worksheets, Weight: 0%, Passed / Not Passed)				
8	**Usability of the Module**				
9	**Literature** - Deutsche Gesellschaft für Geotechnik, Empfehlungen des Arbeitskreises für Numerik in der Geotechnik – EANG, Berlin: Wilhelm Ernst Sohn, 2014 - Lees A., Geotechnical Finite Element Analysis - A practical guide, London: ICE Publishing, 2016				

	- Potts D.M. Zdravkovic L., Finite element analysis in geotechnical engineering. Vol. 2., London: Thomas Telford, 2001. - Belytschko T. et al., Nonlinear finite elements for continua and structures, John wiley sons, 2013 - Soilmodels.com
10	**Comment**

5.3 Artificial Intelligence and Digitalization

Module Description

Module name **5.3.1 Mathematics of Machine Learning**					
Module no. 04-10-0598	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr. rer. nat. Jan Giesselmann		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
04-10-0598-vu	Mathematics of Machine Learning	0	Lecture and Exercise	0

2 Study Content

Systems of linear equations and linear least squares problems, linear regression, eigenvalue and singular value decomposition, mean component analysis, Bayes stastistics, ridge regression, dimension reduction, low rank approximation, nonlinear least squares and minimization problems, Newton method, nonlinear regression, LASSO, regularization, interpolation and numerical integration, function approximation, radial basis functions, Monte-Carlo methods, networks for regression, convolutional neural networks, training of networks, deep learning

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Explain fundamental conceptions and concerns of data analysis and machine learning,
2. Describe and apply fundamental algorithms to analyze data and to explain their relations in content and logic,
3. Implement the most important computational methods by means of typical applications and assess their importance and reliability,
4. Obtain advanced mathematical knowledge in their future academic studies and jobs via self-study

4 Requirements for Participation

	Mathematics I-III recommended
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Duration 45 min, Standard)
6	**Requirements on the Award of Credit Points** Bestehen der Prüfungsleistung
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Weight: 100%, Standard)
8	**Usability of the Module** Bachelor MB compulsory
9	**Literature** Ethem Alpaydin: Maschinelles Lernen, de Gruyter Studium, 2019; Gilbert Srang: Linear Algebra and Learning from Data, Wellesley Cambridge Press, 2019; Trevor Hastie, Robert Tibshirani, Jerome Friedman, The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Springer , 2008
10	**Comment**

Module Description

Module name

5.3.2 Engineering Informatics I

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-F0-M003	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Uwe Rüppel

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-F0-0009-vl	Engineering Informatics I	0	Lecture	2
13-F0-0010-ue	Engineering Informatics I - Exercise	0	Exercise	2

2 Study Content

- Digital transformation of engineering processes (e.g. BIM, GIS);
- Software Engineering for engineering applications: Requirements engineering, design, data modelling,

	implementation, configuration and quality management, maintenance and development-process modelling; - Example applications of the models and methods and models from Civil- and Environmental Engineering.
3	**Learning Outcomes** The students have the ability to autonomously specify, implement and apply domain specific engineering tasks in teamwork with scientific computational methods and models.
4	**Requirements for Participation** Recommended: Basic knowledge in Engineering Informatics.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Duration 90 min, Standard) • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) Subject Examination: Oral Examination (45 min.) / Written Examination (90 min.) As a rule, the examination takes the form of an oral examination, or a written examination if there are more participants. Study Achievement: 2 Exercise blocks (throughout and at the end of the semester) as group work and Submission Colloquium
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 1, Standard) • Module Examination (Study Examination, oral / written Examination, Weight: 0, Passed / Not Passed)
8	**Usability of the Module**
9	**Literature** Literature will be announced at the beginning of the course.
10	**Comment**

Module Description

Module name					
5.3.3 Engineering Informatics II					
Module no. 13-F0-M004	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Uwe Rüppel		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-F0-0011-ue	Engineering Informatics II - Exercise	0	Exercise	2
13-F0-0012-vl	Engineering Informatics II	0	Lecture	2

2 Study Content

- Internet of Things (IoT) sensornetworks;
- BigData and distributed databases;
- Data Mining, Machine Learning and Artificial Intelligence;
- Cryptography and digital signature for securing engineering applications in networks;
- Exemplary application of the methods and models on examples from Civil- and Environmental Engineering.

3 Learning Outcomes

The students have the ability to autonomously model, implement and apply domain specific engineering tasks with scientific data centered principles in terms of Machine Learning/ Artificial Intelligence in secure computer networks.

4 Requirements for Participation

Recommended: Basic knowledge in Engineering Informatics.

5 Form of Examination

Final Module Examination:

- Module Examination (Study Examination, oral / written Examination, Passed / Not Passed)
- Module Examination (Technical Examination, oral / written Examination, Duration 90 min, Standard)

Subject Examination: Oral Examination (45 min.) / Written Examination (90 min.)
As a rule, the examination takes the form of an oral examination, or a written examination if there are more participants.

	Study Achievement: 2 Exercise blocks (throughout and at the end of the semester) as group work and Submission Colloquium
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 0, Passed / Not Passed) • Module Examination (Technical Examination, oral / written Examination, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Literature will be announced at the beginning of the course.
10	**Comment**

Module Description

Module name

5.3.4 Smart Products, Engineering Services

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-98-4084	6 CP	180 h	112.5 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Eckhard Kirchner

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-98-4084-pj	Smart Products, Engineering Services	0	Project	2.5
16-98-4084-ue	Smart Products, Engineering Services	0	Exercise	1
16-98-4084-vl	Smart Products, Engineering Services	0	Lecture	1

2	**Study Content** Introduction to artificial intelligence (AI), big data, cyber-physical systems, and smart mechatronic systems; smart machine elements: classification, integration of sensing functions, design, evaluation

	and calibration of sensing elements, applicability limitations; ideation and market analysis; rapid manufacturing and tolerance management for designing test components; agile project management and hardware development, Design Review Based on Failure Mode (DRBFM); business models and market introduction of products and Product-Service-Systems; Verification and Validation (VV)-methods: remote software updates and AI-based attribute changes during operation phase; predictive maintenance: damage prediction and monitoring; software-based lightweight development.
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Understand the basics of AI, Big Data and Cyber-Physical Systems, describe self-learning user-oriented system and Smart Mechatronic Systems and understand their implications for the development phase; and being able to apply the basics in a developmental software environment. 2. Analyze the requirements of smart sensing elements of a smart product followed by the design and evaluation of a product concept. Classify smart machine elements and explain the procedures of sensor integration and sensor calibration. 3. Explain the basics of innovation management, know methods for idea generation and idea sources, identify customer needs, select and analyze market segments. 4. Identify the limits of sensor concepts and assess the limits of their applicability. 5. Understand and apply rapid manufacturing technologies for the fast production of test components, know typical disturbances and perform tolerance management. 6. Perform agile management (Scrum), agile hardware engineering and understand DRBFM. 7. Explain the basics of adoption and diffusion of innovation, and master Business Model Frameworks, Business Model Innovation, and innovation of Product-Service-Systems. 8. Explain VV methods and understand the implications of remote software updates and machine learning based attribute changes during operation phase incl. user feedback and Safety issues. 9. Explain the concept of predictive maintenance, differentiate between damage prediction and damage monitoring during the operation phase and know the associated methods. 10.Perform software-based lightweight design (method ecoLIFE3).
4	**Requirements for Participation** Programming skills Matlab / Python benefitial.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Duration 60 min, Standard) Course Examination: • [16-98-4084-pj] (Technical Examination, Presentation, Standard) Written exam (60 min., 60 %) and Presentation of the prototype with proof of function and discussion (40 %).
6	**Requirements on the Award of Credit Points** Passing the examinations

7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Weight: 60%, Standard) Course Examination: • [16-98-4084-pj] (Technical Examination, Presentation, Weight: 40%, Standard)
8	**Usability of the Module** Master MB Ib Digitalisierung WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Lecture and recitation material via moodle.
10	**Comment** Lecturers: Prof. Dr.-Ing. S. Rinderknecht, Prof. Dr.-Ing. E. Kirchner and Prof. Dr. A. Kock (FB 1)

Module Description

Module name

5.3.5 Physics-Aware Machine Learning

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-73-4144	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr. rer. nat. Oliver Weeger

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-73-4144-ue	Physics-Aware Machine Learning	0	Exercise	1
16-73-4144-vl	Physics-Aware Machine Learning	0	Lecture	3

2 Study Content

* Physics-aware machine learning (ML) combines classical, physics-based modeling approaches with ML methods to improve the generalization capabilities, interpretability, robustness, reliability and efficiency of ML methods in engineering applications
* Introduction to ML methods and their essential theoretical properties, including in particular artificial neural networks (approximation capabilities, training, gradients, etc.)
* Foundations of physics-based modeling and simulation using differential equations and suitable temporal and spatial discretization methods (time integration and finite elements)
* Physics-based and data-driven model order reduction and surrogate modeling (e.g. modal analysis, orthogonal decompositions, kriging, kernel methods, etc.)
* Mathematical knowledge representations of conservation equations quantities, symmetries, invariances, etc. for physics-aware ML

	* Construction principles for informing or augmenting ML methods through appropriate design of training data, hypotheses for input and output variables of ML models, ML model architectures, or learning or training algorithms * Methods include e.g. Sobolev training, convex monotonic NNs, physics informed NNs (PINNs), Langrangian NNs, neural operators, stochastic NNs, recurrent NNs, convolutional NNs, graph NNs, autoencoders, generative NNs, Gaussian processes kernel methods, etc. * Applications and examples for solid mechanics, structural dynamics, material modeling, dynamic systems, multiscale and multiphysics problems, (additive) manufacturing processes, digital twins, etc.
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Know and identify possible applications for physics-aware machine learning in engineering modeling and simulation 2. Mathematically formalize physical and mathematical properties such as energy conservation, symmetries, invariances and solvability requirements 3. Describe, explain and discuss basic approaches and algorithms of physics-aware ML 4. Explain and evaluate suitable physics-informed and physics-augmented model architectures with neural networks for various fields of application 5. Describe and explain the improved generalization capabilities, interpretability, robustness, reliability and efficiency of physics-aware ML concepts
4	**Requirements for Participation** Basic knowledge on machine learning, physical modelling and numerical simulation (in particular differential equations, time integration, finite elements) is recommended
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Written exam (90 min) or oral exam (30 min)
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** Master MBSE WPB II (Kernlehrveranstaltungen aus dem Maschinenbau) Master AE BME WPB III Master Computational Engineering Master Mechanik
9	**Literature** S.J.D. Prince: “Understanding Deep Learning”, MIT Press, 2023

	S. Kollmannsberger, D. Davide, M. Jokeit, L. Herrmann: "Deep Learning in Computational Mechanics", Springer, 2021 S.L. Brunton, J.N. Kutz: "Data-Driven Science and Engineering", Cambridge University Press, 2022 S. Cuomo, V.S. di Cola, F. Giampaolo, G. Rozza, M. Raissi, F. Piccialli: "Scientific Machine Learning through Physics-Informed Neural Networks: Where we are and What's next", Journal of Scientific Computing 92:88, 2022
10	**Comment**

5.4 Mechanics of Earth Systems

Module Description

Module name

5.4.1 Mechanics of Glaciers and Ice Sheets

Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
13-E2-M008	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	**Person responsible for the Module**
German	Prof. Dr.-Ing. Ralf Müller

1 Courses of the Module

Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
13-E2-0014-vl	Mechanics of Glaciers and Ice Sheets	0	Lecture	3
13-E2-0015-ue	Mechanics of Glaciers and Ice Sheets - Exercises	0	Exercise	1

2	**Study Content** - Ice sheet, ice stream-glacier systems and their dynamics - Structure of ice and constitutive relations - Balance equations of ice sheets and glaciers, boundary conditions and approximations - Processes in ice sheets: firn densification, sliding, calving and ice sheet hydrology - recent research topics in ice sheet dynamics and stability
3	**Learning Outcomes** After successful completion of the module, students will have acquired an understanding of ice sheet and glacier dynamics and its processes, as well as having experience in applying the methods of continuum mechanics in glaciology.
4	**Requirements for Participation** Basic knowledge in mathematics, physics and mechanics.
5	**Form of Examination**

	Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 20 min, Standard)
6	**Requirements on the Award of Credit Points** Bestehen der Modulabschlussprüfung(en)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module**
9	**Literature** CuffeyPatterson, Physics of Glaciers, 2010 Greve Blatter 'Dynamics of Glaciers and Ice Sheets' Monograph, Series Advances in Geophysical and Environmental Mechanics" (AGEM), Springer, 2007
10	**Comment**

Module Description

Module name

5.4.2 Pollutants in the Water Cycle

Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
13-K8-M001	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	**Person responsible for the Module**
English	Prof. Dr. rer. nat. Holger Lutze

1 Courses of the Module

Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
13-K8-0001-vu	Pollutants in the Water Cycle: Sources and Fate in the Aquatic Environment	0	Lecture and Exercise	4

2	**Study Content** Sources of pollutants such as wastewater, agriculture, architecture, natural sources (water born) Transformation of pollutants in aquatic systems (e.g., photo-oxidation, reactive species such as free radicals) Mobility of pollutants: Sorption and desorption processes Control strategies: E.g., water treatment, soil and engineered surfaces Critical use of literature, options and limitations of scientific literature

3	**Learning Outcomes** Students learn fundamentals of the fate and reactions of pollutants in the aquatic environment regarding transformation and mobility. Students will learn how molecules behave on basis of their molecular structure. Principles of technical purification processes for elimination of pollutants and prevention of their spread into the environment. Fundamental aspects in water chemistry and water/surface interface reactions (e.g., buildings, soil) will be learned.Students will practice to evaluate current papers, find major flaws and thus, sharpen their critical few on published data.
4	**Requirements for Participation** Recommended: Knowledge in basic chemistry, reaction kinetics, acid/base speciation, intermolecular interactions, red/ox processes
5	**Form of Examination** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Passed / Not Passed) • Module Examination (Technical Examination, Written Exam, Duration 90 min, Standard) Subject Examination: Open book written examination (90 min.) Study Achievement: Report and Presentation Approx. 6 weeks after start of the course, groupwork
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Study Examination, oral / written Examination, Weight: 0, Passed / Not Passed) • Module Examination (Technical Examination, Written Exam, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Schwarzenbach, R.P., Gschwend, P.M. and Imboden, D.M. (eds) (2016) Environmental organic chemistry von Sonntag, C. and von Gunten, U. (eds) (2012) Chemistry of ozone in water and wastewater treatment, IWA Publishing. Weingärtner, H., Teermann, I., Borchers, U., Balsaa, P., Lutze, H.V., Schmidt, T.C., Franck, E.U., Wiegand, G., Dahmen, N., Schwedt, G., Frimmel, F.H. and Gordalla, B.C. (2016), Water, 1. Properties, Analysis, and Hydrological Cycle, Ullmann's Encyclopedia of Industrial Chemistry, Wiley-VCH Verlag GmbH amp; Co. KGaA.

	Lutze, H.V. (2016) Treatment by oxidation processes, Ullmann's Encyclopedia of Industrial Chemistry, Wiley-VCH Verlag GmbH amp; Co. KGaA.
10	**Comment**

Module Description

Module name **5.4.3 Sustainable Systems Design**					
Module no. 16-98-4074	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Peter Pelz		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-98-4074-ue	Sustainable Systems Design	0	Exercise	1
16-98-4074-vl	Sustainable Systems Design	0	Lecture	3

2 Study Content

Concept of sustainability; handling of limited resources; evaluation metrics for technical, economic, ecological and social effort of a system; lifecycle cost analysis; acceptance and availability of technical systems; system boundaries and interfaces; system analogies; formulation of functional dependencies; formulation of targets; specification of a playing field; modeling of components and complex systems; system description by means of 0D-methods; conservation laws; material laws; temporal and spatial granularity; model reduction; model validation; design of numerical and practical experiments; determination of manufacturing costs (investment and operational costs); technical-ecologicaleconomical-social dependencies; discrete and continuous optimization methods

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Identify and formulate system functions and purposes, derive necessary subfunctions from the system functions, span a playing field of possible solutions, and be able to take decisions on the most suitable solutions.
2. Abstract and model technical systems, estimate the necessary level of detail of a model and validate and if appropriate, simplify a model.
3. Evaluate the sustainability of technical systems with appropriate metrics and to apply methods for designing sustainable products and systems.
4. Identify and evaluate the technical-ecological-economical-social connections between effort, availability and acceptance of technical systems and design the system within the possible

	framework. 5. Formulate decision- and synthesis problems in the framework of mathematical optimization models, choose appropriate optimization methods, and critically scrutinize optimization strategies concerning their maximum attainable optimization results. 6. Apply basic mathematical methods in order to determine the solution of optimization models and judge the applicability of certain optimization models.
4	**Requirements for Participation**
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Duration 90 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Weight: 100%, Standard)
8	**Usability of the Module** Master MB Ia Grundlagen Master MB SP SUR WPB Ia Pflicht WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Master Mechatronik Master Wirtschaftsingenieurwesen – technische Fachrichtung Maschinenbau
9	**Literature** Study material available at www.moodle.tu-darmstadt.de Recommended books: Pahl, Beitz: Konstruktionslehre - Grundlagen erfolgreicher Produktentwicklung, Springer Verlag Suhl, Mellouli: Optimierungssysteme – Modelle, Verfahren, Software, Anwendungen, Springer Verlag
10	**Comment**

5.5 Experimental Mechanics

Module Description

Module name **5.5.1 Methods of experimental mechanics**					
Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**

13-I2-M006	6 CP	180 h	120 h	1 Semester	Every 2. semester
Language of Instruction German			**Person responsible for the Module**		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-I2-0014-tt	Experimentelle Methoden der Mechanik	0	Convention	2
13-I2-0015-ue	Experimentelle Methoden der Mechanik - Übung	0	Exercise	2

2 Study Content

Tensile tests, incremental step tests, digital image correlation, resonance test machines, strain gauges

3 Learning Outcomes

After the lecture students should be able to:

- Design and perform experimental, mechanical testing
- Explain and describe experimental setups
- Identify possible sources of errors for experimental testing
- Interpret, understand and evaluate experimental results and write test reports
- Compare experimental with calculation results and interpret the discrepancies
- Work together in teams, be a part of ethically correct discussions with opposite positions
- Present the results in a suitable manner

4 Requirements for Participation

-keine -

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, optional, Standard)

6 Requirements on the Award of Credit Points

Bestandene, schriftliche Ausarbeitung oder mündliche Prüfung

7 Grading

Final Module Examination:

- Module Examination (Technical Examination, optional, Weight: 1, Standard)

8 Usability of the Module

9 Literature

Mechanical behavior of Materials, Pearson Education, Inc. 3th edition, 2007

10	**Comment**

Module Description

Module name					
5.5.2 Analytical and Experimental Methods of Structural Dynamics					
Module no. 16-25-3194	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 120 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Dr. Ing. Benjamin Siegl		

1	**Courses of the Module**				
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
	16-25-3194-ue	Analytical and experimental methods of structural dynamics	0	Exercise	1
	16-25-3194-vl	Analytical and experimental methods of structural dynamics	0	Lecture	3

2	**Study Content** Building up a feasible measuring chain to detect vibrations; Functionality of devices e.g. (measuring) amplifiers, analog filters (and their digital usage in computers), integrators, differentiators; Signal analysis in time, frequency and amplitude domain; System Identification: different estimator functions for transfer functions, indicator functions for mode detection, experimental modal analysis; Structural Modification of already identified structures; Substructure Techniques e.g. modal reduction.
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Choose suitable sensors for dynamic measuring of mechanical quantities to construct a reasonable measuring chain with the chosen sensors 2. Analyze and interpret the measured signals accordingly to the measuring goal and quantify the occurring measurement errors 3. Manipulate the measured signals (where appropriate using MATLAB) in a manner that the quality regarding the measuring goal is increased (postprocessing) 4. Identify the modal parameters of the dynamic system unambiguously by performing an experimental modal analysis 5. Quantify subsequent changes on the–already identified–vibration system relating to the unmodified dynamic system
4	**Requirements for Participation** Advanced Machine Dynamics/Structural Dynamics recommended.

5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Written (60 min) or oral exam (30 min). Will be announced at the beginning of the term depending on the circumstances (number of students etc.).
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) (WI/MB, Mechatronik, ETIT)
9	**Literature** Markert, R.: Schwingungsmesstechnik. Skript zur Vorlesung.
10	**Comment**

Module Description

Module name

5.5.3 Measuring Techniques in Fluid Mechanics

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-11-5160	4 CP	120 h	90 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr.-Ing. Jeanette Hussong

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-11-5160-vl	Measuring Techniques in Fluid Mechanics	0	Lecture	2

2 Study Content

The role of experiments in fluid mechanics, interplay among experiment, theory, and simulations,

	model scaling and design of experiments, statistical description of turbulence flows and their measurement, signal and data processing, analysis of measurement data, including uncertainty analysis. Various measurement techniques: pressure measurements, visualization, thermal anemometry, laser Doppler technique, phase Doppler, particle image velocimetry
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Describe the measurement principles of the most common measurement techniques in fluid mechanics. 2. Select the most appropriate measurement technique for a given measurement task. 3. Describe challenges of performing measurements in turbulent flows and in wall proximity. 4. Analyse test data and select and apply various techniques of data analysis.
4	**Requirements for Participation**
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral exam 30 min.
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MPE III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Slides and further material are available via the Moodle system
10	**Comment**

5.6 Mechanics of Materials

Module Description

Module name

5.6.1 Welding and Welding Simulation

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-I2-M003	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
German	Prof. Dr.-Ing. Michael Vormwald

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-I2-0010-se	Welding and Welding Simulation	0	Seminar	4

2 Study Content

Introduction to Multiphysics of Welding
Transient Temperatur Fields
Heat Effect on Melting Zone
Idealised Heat Source
Heat Effect on Microstructure
Thermomechanical Coupling and Nonlinear Structural Behaviour
Specific Problems in Welding Simulation

3 Learning Outcomes

After completing this modul students are able to:
calculate transient temperature fields,
understand transformation of microstructure due to welding process,
simulate the thermomechanical problem of welding,
assess results of welding simulations.

4 Requirements for Participation

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, Paper, Duration 30 min, Standard)

Passing the examination and a written version of the presentation (Referat) has to be delivered.

6 Requirements on the Award of Credit Points

Passing the module examination(s)

7 Grading

Final Module Examination:

	• Module Examination (Technical Examination, Paper, Weight: 1, Standard)
8	**Usability of the Module**
9	**Literature** Radaj, D.: Eigenspannungen und Verzug beim Schweißen - Rechen- und Meßverfahren. DVS-Verlag, ISBN 3-87155-194-5, 2002. Lindgren, L.-E.: Computational welding mechanics. Woodhead Publishing, ISBN -78-1-84569-221-6, 2007. Pasquale, P.: Numerische Simulation schweißtechnischer Fertigungsschritte. Fraunhofer IWS, 2001.
10	**Comment**

Module Description

Module name

5.6.2 Glass and Polymers I: Glass Structures

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-M3-M003	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Jens Schneider

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
13-M3-0002-vu	Glass and Polymers I: Glass Structures	0	Lecture and Exercise	4

2	**Study Content** Glasprodukte mit allen Veredelungsformen, Floatglas, Einscheiben-Sicherheitsglas, Gussglas Sicherheitstheorie, Versagenswahrscheinlichkeiten Besonderheiten der Glasbemessung (Koppeleffekt, Schubverbund, Membraneffekt) Bemessung von Verglasungen (Isolierverglasung, Einfachverglasung, Überkopfverglasungen) Konstruktive Durchbildung, Lagerungsdetails Verglasungen mit besonderen Anforderungen (z.B. absturzsichernd, ...), erforderliche versuchstechnische Überwachungsmaßnahmen sowie Genehmigungsverfahren
3	**Learning Outcomes** Die Studierenden können sich in einer Gruppe zielführend für die gemeinsame Lösung einer ingenieurmäßigen Aufgabenstellung einbringen. Die Studierenden sind in der Lage linienförmig gelagerte Glaskonstruktionen zu konzipieren, konstruktiv zu beurteilen und zu bemessen. Die Studierenden kennen Ansätze für die Bemessung punktgehaltener Glaskonstruktionen.

4	**Requirements for Participation** Recommended: Statik I and II (13-M2-M001/13-M2-M002), Structural Analysis III and IV (13-M2-M003/13-M2-M004), TM I-III (13-E0-M001/13-E0-M002/13-E0-M003)
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 15 min, Standard) • Module Examination (Technical Examination, Written Exam, Duration 90 min, Standard)
6	**Requirements on the Award of Credit Points** Passing the module examination(s)
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 50%, Standard) • Module Examination (Technical Examination, Written Exam, Weight: 50%, Standard)
8	**Usability of the Module**
9	**Literature** Schneider, J., Kuntsche, J.K., Schula, S., Schneider, F., Wörner, J.-D.: Glasbau Grundlagen, Berechnung, Konstruktion Wörner, Schneider, Fink: Glasbau, Springer Verlag
10	**Comment** It is recommended to also complete the course Glass and Polymers II: Mechanics of Polymers. However, it is possible to attend both courses independently.

Module Description

Module name

5.6.3 Glass and Polymers II: Mechanics of Polymers

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
13-M2-M011	6 CP	180 h	120 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Jens Schneider

1	Courses of the Module				
	Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per

					Week
	13-M2-0019-vl	Glass and Polymers II: Polymer Mechanics	0	Lecture	2
	13-M2-0021-ue	Glass and Polymers II: Polymer Mechanics - Exercise	0	Exercise	2
2	**Study Content** Classification of polymer materials, fundamentals of continuum mechanics (non-linear stress and strain behavior, deformation rates), material modeling (elasticity, hyperelasticity, viscosity, plasticity) with application examples and methods of measurement, damage and failure models, modeling of composite materials				
3	**Learning Outcomes** After the attendence the lecture, the students are able to classify polymer materials with respect to their mechanical behavior and select appropriate material models for the calculation of components. The students have the ability to transfer mathematical and scientific methods to technical problems. The students have the ability to develop appropriate models for new materials and composites of polymers and know the limitations of modeling.				
4	**Requirements for Participation** Recommended: Technische Mechanik II (13-E0-M002), Technische Mechanik III (13-E0-M003), Werkstoffe im Bauwesen (13-02-M001/8)				
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 20 min, Standard)				
6	**Requirements on the Award of Credit Points** Passing the module examination(s)				
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 1, Standard)				
8	**Usability of the Module**				
9	**Literature** Gross et al.: Technische Mechanik 4, Springer Verlag G. A. Holzapfel: Nonlinear Solid Mechanics, Wiley				
10	**Comment** It is recommended to also complete the course Glass and Polymers I: Glass Structures. However, it is possible to attend both courses individually.				

Module Description

Module name **5.6.4 High Temperature Materials Behaviour**					
Module no. 16-08-5120	**Credit Points** 6 CP	**Workload** 180 h	**Self-study** 135 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Matthias Oechsner		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-08-5120-vl	High Temperature Materials Behaviour	0	Lecture	3

2 Study Content

Time dependent mechanism under high temperature exposure: Creep, oxidation, and fatigue.
Microstructural stability of metallic alloys: recrystallisation, recovery, grain growth and formation of precipitation
High temperature strength and deformation: Governing mechanisms and modelling concepts
Fatigue under high temperature exposure: Thermal fatigue; creep – fatigue interaction
High temperature corrosion: Thermodynamics and kinetics of oxidation; hot gas corrosion
High temperature alloys: Fe-, Co-, Ni-based alloys and intermetallics
Coatings for high temperature application: Types, deposition and characterization processes
Ceramics: Monolithics and Ceramic Matrix Composites

3 Learning Outcomes

After following this lecture the student will be able to:

1. Identify and describe relevant time-dependent mechanisms under high temperature exposure.
2. Explain microstructural evolution processes, discuss their driving force and their effect on the behaviour of materials and components
3. Explain the mechanisms of time-dependent deformation and strength; discuss constitutive as well as phenomenological description concepts and their model assumptions and their limitations;.
4. Estimates of a materials creep behaviour on the basis of experimental data and/or phenomenological description models.
5. Explain fatigue processes under high temperature loading; describe the influence of creep and relaxation on the fatigue behaviour
6. Explain thermodynamic principles and kinetic aspects of high-temperature corrosion; explain the phenomenon of hot gas corrosion
7. Know metallic and intermetallic material systems for high-temperature applications and discuss their application limits; select materials for given fields of application in a justified manner.
8. Explain the functions and working principles of high-temperature coatings, describe essential manufacturing processes and relevant characterisation methods.
9. Name ceramic materials for high-temperature applications; discuss the advantages and

	disadvantages of monolithic ceramics compared to Ceramic Matrix Composites.
4	**Requirements for Participation** Knowledge of fundamentals in Materials Engineering (e.g. Werkstoffkunde I) recommended
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Oral (45 min) or written exam 60 min
6	**Requirements on the Award of Credit Points** Passing the examination.
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** Oechsner, M: Umdruck zur Vorlesung (Foliensätze) Maier H.J., Niendorf T., Bürgel R. (2019) Handbuch Hochtemperatur-Werkstofftechnik. Springer Vieweg, Wiesbaden Rösler J., Harders H., Bäker, M. (2019) Mechanisches Verhalten der Werkstoffe, Springer-Verlag Birks, N., Gerald H. Meier G.H., Pettit F.S. (2006) Introduction to the high temperature oxidation of metals. Cambridge University Press
10	**Comment**

Module Description

Module name **5.6.5 Biomaterials and Tissue Engineering**					
Module no. 16-17-3294	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Andreas Blaeser		

1	Courses of the Module				
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
	16-17-3294-vl	Biomaterials and Tissue Engineering	0	Lecture	2
2	**Study Content** Biological fundamentals: anatomy of eukaryotic cells; cell culture fundamentals; interaction of cells and biomaterials in 2 and 3D; biomaterials and hydrogels for tissue culture; classification; composition and selection of biomaterials for culture of soft and hard tissue; characterization methods of biomaterials and hydrogels (rheological, mechanical and biological characterization); tissue culture in bioreactors; static and dynamic cell culture in culture dishes and various bioreactors; mechanobiological aspects of tissue culture.				
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Explain and classify biological fundamentals and applications of biomaterials. 2. Select biomaterials for the cultivation of soft and hard tissue and apply them in a use case. 3. Compare and contrast biomaterials in terms of their biomedical applicability. 4. Assess the interaction of cells and biomaterials in 2 and 3D. 5. Choose and apply suitable characterization methods for biomaterials and hydrogels according to appropriate criteria. 6. Evaluate different types of tissue culture in bioreactors. 7. Summarize key mechanobiological aspects of tissue culture.				
4	**Requirements for Participation**				
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Standard) Facultative: oral (30 min) or written (60 min) Will be announced at the beginning of the term depending on the circumstances (number of students, pandemic etc.).				
6	**Requirements on the Award of Credit Points** Passing the examination.				
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral / written Examination, Weight: 100%, Standard)				
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau)				

	WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik)
9	**Literature** The current lecture notes can be downloaded from moodle. Reference is made to other relevant literature (online available)
10	**Comment**

5.7 Structural Mechanics

Module Description

Module name **5.7.1 Energy Methods in Structural Mechanics**					
Module no. 16-12-3134	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 75 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Christian Mittelstedt		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-12-3134-ue	Energy Methods in Structural Mechanics	0	Exercise	1
16-12-3134-vl	Energy Methods in Structural Mechanics	0	Lecture	2

2	**Study Content** Work and energy; Virtual work; Principle of virtual displacements; Principle of virtual forces; Unity theorems; Castigliano's theorems; Reciprocity theorems; Approximate methods: Galerkin, Ritz, finite elements.
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Explain the basic energy methods of structural mechanics and to apply them to simple applications. 2. Choose an adequate method for a given specific lightweight engineering application case and to use it independently. 3. Develop practically relevant approximate methods for static problems, based on the basic principles and methods (e.g. principles of virtual displacements, virtual forces, Ritz method). 4. Develop fast and simple approximate solutions for practical lightweight engineering problems, based on the basic underlying principles.

4	**Requirements for Participation**
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral examination (30 min)
6	**Requirements on the Award of Credit Points** Passing the examination.
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MPE III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Angewandte Mechanik Mechatronik
9	**Literature** Mittelstedt, C., 2021. Rechenmethoden des Leichtbaus. Berlin: Springer Vieweg. Mittelstedt, C., 2021. Structural Mechanics in Lightweight Engineering. Cham (Switzerland): Springer Nature.
10	**Comment**

Module Description

Module name

5.7.2 Theory of Elastic Stability

Module no.	Credit Points	Workload	Self-study	Duration	Frequency
16-12-3144	4 CP	120 h	75 h	1 Semester	Every 2. semester

Language of Instruction	Person responsible for the Module
English	Prof. Dr.-Ing. Christian Mittelstedt

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-12-3144-ue	Theory of Elastic Stability	0	Exercise	1

	16-12-3144-vl	Theory of Elastic Stability	0	Lecture	2

2	**Study Content** Typical stability problems in elastostatics; Buckling of beams; Flexural torsional buckling and lateral buckling; Buckling of plates and shells.
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Differentiate and explain typical stability problems and use the according solution methods for application cases as they are relevant in lightweight engineering. 2. Solve stability problems of beam structures in an exact and approximate way. 3. Solve stability problems of plates in an exact and approximate way. 4. Choose and apply solution methods for given specific practical problems independently. 5. Develop approximate solutions for practically relevant stability problems. 6. Design lightweight structures concerning their stability behavior in a secure way.
4	**Requirements for Participation**
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard) Oral exam 30 min
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MPE III (Wahlfächer aus Natur- und Ingenieurwissenschaft) [Im WiSe 2016/17: WPB Master MPE II (Kernlehrveranstaltungen aus dem Maschinenbau)] WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Angewandte Mechanik Mechatronik
9	**Literature** ALFUTOV, N.A., 1999. Stability of elastic structures. Berlin et al.: Springer Verlag. CHEN, W.F. und LUI, E.M., 1987. Structural stability. New York et al.: Elsevier. PETERSEN, C., 1982. Statik und Stabilität der Baukonstruktionen. 2. Auflage. Braunschweig / Wiesbaden: Vieweg Verlag. PFLÜGER, A., 1975. Stabilitätsprobleme der Elastostatik. Berlin et al.: Springer Verlag. WIEDEMANN, J., 1996. Leichtbau 1: Elemente. 2. Auflage. Berlin et al.: Springer Verlag.

10	**Comment**

Module Description

Module name **5.7.3 Composite Structures**					
Module no. 16-12-3174	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 37.5 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction English			**Person responsible for the Module** Prof. Dr.-Ing. Christian Mittelstedt		

1 Courses of the Module

Course no.	Course name	Workload (CP)	Form of Teaching	Contact Hours per Week
16-12-3174-ue	Composite Structures	0	Exercise	3.5
16-12-3174-vl	Composite Structures	0	Lecture	2

2 Study Content

Historical developments, Nomenclature, Fibers and matrices, Semi-finished products, Behaviour of a laminate layer, Classical Laminate Plate Theory, Influence of moisture and temperature, Fracture and degradation, Joints (circumferential joints, bolted joints, bonded joints), Optimization of laminates, Design guidelines, Stress concentration problems, Stability problems, Examples from aircraft engineering, Example: Predesign of a thin-walled composite beam

3 Learning Outcomes

Upon successful completion of this module, students should be able to:

1. Select fibers, matrices and semi-finished products according to a specific task.
2. Perform basic static analyses of thin-walled composite structures.
3. Apply classical laminated plate theory for basic composite laminate problems and to perform strength assessments under consideration of static loads as well as moisture and temperature loads.
4. Understand the most relevant stability and stress concentration problems in the framework of composite structures and to perform according analyses.
5. Understand and apply construction principles in composites engineering.

4 Requirements for Participation

Attending and succesfully completing the modules „Lightweight Engineering I“ and “Lightweight Engineering II” is recommended.

5 Form of Examination

Final Module Examination:

- Module Examination (Technical Examination, oral Examination, Duration 30 min, Standard)

	Course Examination: • [16-12-3174-ue] (Technical Examination, Report, Passed / Not Passed) Oral exam 30 min., divided into 10 minutes presentation of the results of the design project (1/3) and 20 minutes oral examination (2/3)and report (design project, pnp).
6	**Requirements on the Award of Credit Points** Passing the examinations.
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard) Course Examination: • [16-12-3174-ue] (Technical Examination, Report, Weight: 0%, Passed / Not Passed)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master AE II Kernlehrveranstaltung Master MB II SP SUR WPB Master PST IV (Kernlehrveranstaltungen der Papiertechnik) Angewandte Mechanik Mechatronik
9	**Literature** ALTENBACH, H., ALTENBACH, J. und RIKARDS, R., 1996. Einführung in die Mechanik der Laminat- und Sandwichtragwerke. Stuttgart: Deutscher Verlag der Grundstoffindustrie. JONES, R.M., 1975. Mechanics of composite materials. Washington, USA: Scripta Book Co. MITTELSTEDT, C. und BECKER, W., 2016. Strukturmechanik ebener Laminate. Darmstadt: Studienbereich Mechanik, TU Darmstadt. SCHÜRMANN, H., 2005. Konstruieren mit Faser-Kunststoff-Verbunden. Berlin et al.: Springer.
10	**Comment**

Module Description

Module name **5.7.4 Theory of Shells**					
Module no. 16-12-3194	**Credit Points** 4 CP	**Workload** 120 h	**Self-study** 90 h	**Duration** 1 Semester	**Frequency** Every 2. semester
Language of Instruction German			**Person responsible for the Module** Prof. Dr.-Ing. Christian Mittelstedt		

1	Courses of the Module				
	Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
	16-12-3194-vl	Theory of shells	0	Lecture	2

2	**Study Content** Curved beams as introductory motivation (determination of stress resultants; pressure line determination; deformations); types of shells; shell loads; assumptions of technical shell theory; state variables; membrane theory: assumptions, basic equations, shells of revolutions, selected solutions, kinematics and deformations; bending theory of shells of revolution: basic equations, special cases, vessel theory; the force method: boundary layer phenomena, statically indeterminate shells; energy methods; finite elements for shells: shells of revolution, arbitrary shells; layered shells; higher-order shell theories; introduction to shell buckling; stiffened shells
3	**Learning Outcomes** On successful completion of this module, students should be able to: 1. Perform analyses for elementary shell structures autonomously. 2. Explain the special load bearing characteristics of shells and to use those for the dimensioning of shell structures. 3. Explain the stability behaviour of shells and to perform according buckling analyses.
4	**Requirements for Participation**
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Duration 20 min, Standard) Oral exam (20 min.)
6	**Requirements on the Award of Credit Points** Passing the examination.
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, oral Examination, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB III (Wahlfächer aus Natur- und Ingenieurwissenschaft) WPB Master PST III (Fächer aus Natur- und Ingenieurwissenschaft für Papiertechnik) Angewandte Mechanik Mechatronik
9	**Literature** FLÜGGE, W., 1962. Statik und Dynamik der Schalen. 3. Auflage. Berlin et al.: Springer. WIEDEMANN, J., 1996. Leichtbau 1: Elemente. 2. Auflage. Berlin et al.: Springer Verlag.

	BRUSH, D.O. / ALMROTH, B.O., 1975. Buckling of bars, plates and shells. New York et al.: McGraw-Hill.
10	**Comment**

Module Description

Module name

5.7.5 Fundamentals of Machine Acoustics

Module no.	**Credit Points**	**Workload**	**Self-study**	**Duration**	**Frequency**
16-26-5070	6 CP	180 h	135 h	1 Semester	Every 2. semester

Language of Instruction	**Person responsible for the Module**
German	Prof. Dr.-Ing. Tobias Melz

1 Courses of the Module

Course no.	**Course name**	**Workload (CP)**	**Form of Teaching**	**Contact Hours per Week**
16-26-5070-vl	Fundamentals of Machine Acoustics	0	Lecture	3

2 Study Content

The module includes the explanation and application of fundamental terms in technical acoustics (e.g., frequency, sound pressure, sound power, sound intensity, particle velocity, specific acoustic impe-dance, levels), level arithmetic, frequency analysis, acoustic filter and weighting functions, fundamental equation of machine acoustics, mirror sound sources and interference, various types of acoustic radiators, various sound power measurement methods

3 Learning Outcomes

On successful completion of this module, students should be able to:

1. Know the various physical quantities relevant for (technical) acoustics, explain the differences between them, and derive or combine such quantities from/with each other.
2. Calculate levels of various physical/acoustic quantities and perform various level calculations such as the total or average level of several sound sources.
3. Explain the fundamentals of Fourier/frequency analysis and recognize the advantages and drawbacks of various ways to present results of frequency analyses.
4. Distinguish various acoustic filter functions and calculate octave band and one-third octave band spectra from given narrowband spectra.
5. Apply acoustic weighting functions (such as A-, C- or Z-weighting) in a meaningful manner and explain the reasons for implementing such weighting curves.
6. Explain the physical sound generation mechanisms of dynamically excited machine structures.
7. Recognize the chain of sound generation from the dynamic excitation up to the sound radiation based on the fundamental equation of machine acoustics.
8. Recognize the influence and the effects of mirror sound sources and consider these when analyzing acoustic measurements.

	9. Explain the various types of acoustic radiators and their characteristics. 10. Know various methods of sound power measurements and their advantages and drawbacks.
4	**Requirements for Participation** no specific knowledge is required except a recommendation of basic understanding in machine dynamics, mechanics, physics, and machine elements.
5	**Form of Examination** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Duration 120 min, Standard) Written exam 2 h
6	**Requirements on the Award of Credit Points** Passing the examination
7	**Grading** Final Module Examination: • Module Examination (Technical Examination, Written Exam, Weight: 100%, Standard)
8	**Usability of the Module** WPB Master MB II (Kernlehrveranstaltung aus dem Maschinenbau) Master MB II SP FAS WPB Master PST III (Wahlfächer aus Natur- und Ingenieurwissenschaft)
9	**Literature** comprehensive class notes (two volumes, approx. 1100 pages for “Machine Acoustics – Fundamentals 1+2”) available for purchase additional recommended text books: Kollmann, F.G.: „Maschinenakustik“, 2. Auflage, Springer-Verlag, 2000 Kollmann, F.G., Schösser, T.F., Angert, R.: „Praktische Maschinenakustik“, Springer-Verlag, 2006 Henn, H., Sinambari, G.R., Fallen, M.: „Ingenieurakustik“, 4. Auflage, Vieweg+Teubner Verlag, 2008 Schirmer, W. (Hrsg.): „Technischer Lärmschutz“, 2. Auflage, Springer-Verlag, 2006 Möser, M.: „Technische Akustik“, 9. Auflage, Springer-Verlag, 2012 Müller, G., Möser, M. (Hrsg.): „Taschenbuch der Technischen Akustik“, 3. Auflage, Springer-Verlag, 2004 Möser, M. (Hrsg.): „Messtechnik der Akustik“, Springer-Verlag, 2010 Bies, D.A., Hansen, C.H.: „Engineering Noise Control: Theory and Practice“, 4. Auflage, 2009 Vér, I.L., Beranek, L. L.: „Noise and Vibration Control Engineering“, 2. Auflage, John Wiley amp; Sons, 2005 Rossing, T.D. (Hrsg.): „Springer Handbook of Acoustics“, Springer-Verlag, 2007.
10	**Comment**