MODULE HANDBOOK

SEMESTER 3	
Tracks 2, 3 and 4	
Extended Methods for Finite Element Modelling	5 ECTS
Biomechanics	5 ECTS
Advanced Experimental and Numerical Dialogue	5 ECTS
Rubbing Contact: Coupling and Multi-scale Effects	5 ECTS
Limit Analysis and Shakedown	5 ECTS
Digital Twins and Deep Learning in Mechanics	5 ECTS

Module #1	EXTENDED METHODS FOR FINITE ELEMENT MODELLING		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Compulsory
Instructor(s)	J.-B. Colliat, J.-F. Shao		
Content	This course aims at presenting the most up-to-date methods dealing with kinematics enhancements within the classical FE method. - Recall of the standard Finite Element Method for linear and nonlinear structural problems (2h) - Enhancement of FEM through “weak” discontinuities and application to heterogeneous materials (2h) - Enhancement of FEM through “strong” discontinuities and application to fracture mechanics (2h) - The Hu–Washizu variational theorem (4h) - Local FE enhancements: the static condensation procedure and the E-FEM method (2h) - The partition of unity (2h) - Global FE enhancements: the X-FEM method (2h) A large part of the examples shall be devoted to the use and the analysis of some FE codes, and the implementation (in Fortran or Matlab) of the local and global methods of enhancements.		
Examination	Written exam of 2 hours		
Requirement for examination	No specific requirement		
Learning outcomes	Proficiency with theoretical background and computing techniques		

Module #2	BIOMECHANICS		
Information	Credit points: 5 ECTS	Workload: 46 hours	Mode: Compulsory
Instructor(s)	TT Dao, O. Mayeur		
Content	This course is an introduction to the biomechanics of biological tissues. It will address the notions of mechanical behaviour of biological tissues in relation to their composition. Students will experiment with methods for characterizing mechanical behaviour taking into account the difficulties associated with the manipulation of biological tissues. They will apply the notions of modelling mechanical behaviour in relation to experimental methods and in continuity with the notions introduced in continuum mechanics and the other courses of the Master STRAIN in order to choose the behaviour model, identify its parameters and validate it.		
Examination	Evaluations will be conducted during the sessions of the biomechanics course and a work of bibliography will be carried out.		
Requirement for examination	No specific requirement		
Learning outcomes	At the end of the module the student will be able to: • Choose, identify and validate a behaviour law of biological tissue • Analyse experimental data • From image build a numerical model of biological system • Perform numerical simulation of biological system • Adopt a global vision and grasp the problem in all its complexity • Take into account the uncertainty generated by complexity • Analyze the acceptability of a solution (assumptions, orders of magnitude, ...)		

Module #3	ADVANCED EXPERIMENTAL AND NUMERICAL DIALOGUE		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Compulsory
Instructor(s)	A. El Bartali (Centrale Lille), P. Lecomte (Centrale Lille), V. Magnier (U.Lille), J.F. Witz (CNRS)		
Content	The aim of this course is focused on the non-conventional experimental mechanical tests based on particular using Digital image (2D, DIC) and Volume (3D, DVC) correlation coupled to Finite Elements calculations to characterize mechanical properties under complex loadings. We will rely on the inverse methods to identify heterogeneous properties in heterogeneous materials. The steps of this course are the following: **Part I**: reminder of the DIC and introduction of the DVC **Part II**: Introduction to inverse methods **Part III**: Experimental practice **Part IV**: Characterization of heterogeneous material using experiment-numerical dialog		
Examination	Projects		
Requirement for examination	No specific requirement		
Learning outcomes	On successful completion of the course, students will be able to: • characterize the mechanical behaviour of various materials; • identify the constitutive laws; • build a physical model based on experiments.		

Module #4	RUBBING CONTACT: COUPLING AND MULTI-SCALE EFFECTS		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Compulsory
Instructor(s)	J.-F. Brunel, P. Dufrénoy, V. Magnier (U. Lille), A.-L. Cristol, E. Davin (Centrale Lille)		
Content	This course deals with multi-scale and multi-physic couplings involved in rubbing systems (dry friction). Tribological, thermal, thermomechanical and dynamical aspects are considered, from micro to macro scales, dealing with friction, wear and phenomena induced by friction (damage, vibrations, particle emissions…) **Part I – Phenomena induced by friction** Physical coupling at the friction interface, contact fatigue, thermal contact, thermomechanics and thermal localization, vibrations and noise. **Part II – Advance friction experiment** Tribosystem analysis and multi-physic couplings, similitude rules, scale shift from full-scale to laboratory test, rubbing-surface infrared thermography, multi-scale characterization of rubbed surfaces, identification of couplings and friction-wear mechanisms. **Part III – Experimental and numerical practice** • Numerical analysis of thermal – mechanical coupling involved in rubbing systems; • Numerical analysis of contact structure dynamical interaction; • Experimental case study of friction-induced vibrations; • Experimental case study of friction and wear mechanisms including particle emissions in the environment. • Results analysis of the key influencing parameters using machine learning methods		
Examination	Project		
Requirement for examination	No specific requirement		
Learning outcomes	At the end of this module, students will be able to design an experiment that is representative of a friction-related problem (for example, a braking system). They will carry out the tests and explain the friction behaviour and the resulting phenomena by describing the tribological mechanisms (changes in the contact interface). They will also have a broad vision of tribological problems.		

Module #5	LIMIT ANALYSIS AND SHAKEDOWN		
Information	Credit points: 5 ECTS	Workload: 45 hours	Mode: Compulsory
Instructor(s)	G. de Saxcé, J.-B. Tritsch, A. Oueslati		
Content	The course allows to acquire a thorough knowledge of the calculus of the collapse plastic load under proportional loadings (limit analysis) and repeated variable loadings (shakedown analysis), as opposed to the incremental methods. The application concerns the structures as well as the materials. • Limit analysis theory: proportional loadings, collapse by mechanism, statical and kinematical bound theorems, applications to plates and shells. Numerical methods. • Shakedown analysis: repeated variable loadings, collapse by ratchet and accommodation, criticism of the incremental methods, Melan's statical theorem, Koiter's kinematical theorem, extension of the classical forms, applications. Numerical methods. • Technics of limit and shakedown analysis in mechanics of materials: obtaining macroscopic criteria of plasticity and fatigue by homogenization.		
Examination	Written final exam		
Requirement for examination	No specific requirement		
Learning outcomes	On successful completion of the course students will be able to: • Demonstrate an understanding of bound theorems for proportional and repeated variable loadings; • Demonstrate an ability to apply these theorems to various kind of structures in order to assess their collapse load; • Demonstrate a knowledge of the corresponding numerical technics; • Demonstrate a knowledge of analytical tools used in mechanical of materials.		

Module #6	DIGITAL TWINS AND DEEP LEARNING IN MECHANICS		
Information	Credit points: 5 ECTS	Workload: 50 hours	Mode: Compulsory
Instructor(s)	TT Dao		
Content	This course provides foundational knowledge and hands-on experience in the development and evaluation of digital twins for complex mechanical systems using contemporary deep learning approaches. In particular, it introduces methods for combining physics-based and data-driven models to enable faster, adaptive, and accurate simulations and predictions of complex mechanical systems. Through a combination of lectures and laboratory activities, students will explore how different sources of knowledge and information can be integrated into digital twin frameworks. Mechanical knowledge and physical constraints provide the foundation for modeling system behavior; imaging and sensor data provide information about the real-world system; and deep learning offers powerful tools for learning complex behaviors, identifying useful patterns, and making reliable predictions. By integrating these complementary approaches, the course equips students with the concepts and practical skills needed to develop data-informed and physics-aware digital twins for advanced mechanical applications. Lectures and Lab Works Lecture 01: Introduction to Digital Twins (history, levels, applications) Lab work: Point Cloud Processing (I) Lecture 02: Digital Representation (Geometric modeling, 3D static CAD model) Lab work: Point Cloud Processing (II) Lecture 03: Digital Shadow (one-way sending info Physical → Digital): Imaging, sensing and data acquisition Lab work: Image and Signal Processing Lecture 04: Digital Twin: Mechanistic Modeling and Simulation Lab work: Abaqus Simulation Lecture 05: Predictive Twin: Machine Learning, Deep Learning, Deep Learning Architectures, Reduced-Order Models, -Informed Neural Networks, Hybrid AI-Mechanistic Modeling Lab work: Python Coding Lecture 06: Autonomous Twin (Autonomous decision and action): Reinforcement learning Lab work: Python Coding Project: Digital Twins for Predictive Maintenance Digital Twins for Design Optimization		

	Digital Twins for Damage and Fault Detection Digital Twins for Structural Health Monitoring
Examination	Project
Requirement for examination	No specific requirement
Learning outcomes	By the end of the course, a student should be able to understand how to build a reliable system that connects the following elements: Mechanics, Simulation, Imaging, Sensing, Deep Learning and Digital Twin. Moreover, students will be able to explain the key concepts and principles of digital twins for complex mechanical systems; integrate physics-based models with imaging and sensor data and deep learning methods; develop hybrid models for efficient simulation and prediction; implement and evaluate digital twin workflows; and assess their accuracy, efficiency, adaptability, and physical consistency in practical mechanical engineering applications.