PROGRAMME, LIST OF PARTICIPANTS and

# ABSTRACTS

**DCAMM**

19th Internal Symposium

Wednesday, March 6 -
Friday, March 8,
2024

**HOTEL CHRISTIANSMINDE**
**SVENDBORG**

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TECHNICAL UNIVERSITY OF DENMARK -
AALBORG UNIVERSITY - AARHUS UNIVERSITY -
UNIVERSITY OF SOUTHERN DENMARK

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Organizing Committee:
Niels Leergaard Pedersen, Erik Lund, Lars Pilgaard Mikkelsen and Gerda Helene Fogt

Organization:
DCAMM

**General Information:**

The language of presentation is English.

PhD students early in their projects present in the poster session. The session is divided in two parts; a presentation part (2 minutes, 2 slides maximum in pdf format), and a display of the posters. The posters should be in vertical A0 format. Please include a picture of yourself in the poster.

Second and third year PhD students are given 10 minutes for their presentation and 5 minutes for discussion.

All presenters are requested to send the electronic presentations to Erik Lund (el@mp.aau.dk) no later than 12.00 on Friday 1 March 2024, also the slides for poster session must be submitted (in pdf format). This is to avoid delays and technical problems between the presentations. All presentations will be available on a provided computer in the conference room. Acceptable formats are Microsoft PowerPoint files (.ppt), Adobe Portable Document files (.pdf) and multimedia files which can be viewed by Windows Media or QuickTime player.

## Programme for Wednesday afternoon, March 6$^{th}$, 2023

11:30 Arrival

12:00 - 13:00 Lunch

13:00 - 13:05 Welcome and practical information, NIELS L. PEDERSEN (DTU, Dept. of Civil and Mechanical Engineering, 5 minutes)

13:05 – 14:35 DYNAMICS
(Chairman: Mads Peter Sørensen, DTU, Dept. of Applied Mathematics and Computer Science)

KENNETH MAHAGARN JENSEN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Estimation of vehicle brake pad remaining useful life from usage data

MARTIN SUHR (AU, Dept. of Mechanical and Produktion Engineering, 15 minutes)
Edge-tracking as an operational modal analysis measurement method embrittlement

JACOB ØSTERBY HOLST RASMUSSEN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Dynamics of large-bore two-stroke marine engines

BRUNO RENDE (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Multi-physics modeling of magnetic bearings - combining rotordynamics, electromagnetism, and heat transfer

JENS RICHARDT (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Calibration of piezoelectric shunts for vibration damping

HOSSEIN SOLEIMAN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Revealing dynamics of systems with localized nonlinearity: harnessing nonlinear substructuring

14:35 - 15:15 Coffee break

15:15 – 16:45 OPTIMIZATION
(Chairman: Casper Schousboe Andreasen, DTU, Dept. of Civil and Mechanical Engineering )

HAO LI (SDU, Dept. of Mechanical and Electrical Engineering, 20 minutes)
Towards homogenisation-based topology optimisation of heat exchangers

RASMUS ELLEBÆK CHRISTIANSEN (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)
Topology optimization of nanophotonic devices for extreme light manipulation

PETER DØRFFLER L. JENSEN (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)
Efficient ultralarge-scale topology optimization for complex geometries using de-homogenization

ANDREAS H. FREDERIKSEN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Third medium contact, friction, non-linear topology optimization

GÖKTUG ISIKLAR (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Utilization of substitute harmonic approach for topology optimization of thermal initial value problems

17:00 – 17:40 POSTER PRESENTATIONS
(Chairman: Erik Lund, AAU, Dept. of Materials and Production)

17:40 – 19:00 POSTER SESSION

For PhD’s started after 1 April 2023 (17)

**SDU, Dept. of Mechanical and Electrical Engineering (1)**

(1) AMIRHOSSEIN BAYAT
Towards topology optimisation for high heat flux cooling

**AAU, Dept. of Materials and Production (5)**

(2) RICCARDO GROSELLE
Damage-tolerant designs for long term endurance of next-generation wind turbine blades

(3) NIKLAS STAGSTED
Bridging the gap: Uncovering the secrets of fibre bridging with a multiscale approach to fatigue damage in composite materials

(4) BEHNAM FIROOZI
Thin-walled parts: Linking manufacturing process with components’ dynamic properties for robust design

(5) KRISTIAN HANSEN
Development of methodologies for early-stage acoustic prediction from modularized centrifugal pumps

(6) NANNA BERGMANN WINTHER
Mapping the influence of non-proportional stress state on the fatigue life of welded steel components.

**DTU, Dept. of Wind and Energy Systems (2)**

(7) LUCIE LABORDERIE
A physics-based simujlation framework for modelling the manufacturing process of hybrid composite structures

(8) PINELOPI MAGEIRA
Finite element analysis and predictions in 2D and 3D of the mechanical properties of in-situ 3D x-ray determined compression failure of pultruded uni-directional composites

**AU, Dept. of Civil and Architectural Engineering (1)**

(9) ANDERS MALUND DAMMARK JENSEN
A framework for damage prognosis of offshore wind turbine foundations

**AU, Dept. of Mechanical and Production Engineering (2)**

(10) HJALTE DUROCHER
Modelling of the breeding blanket transporter for robotic remote maintenance of EU DEMO

(11) DARIO SIRANGELO
Towards reliable off-road autonomy: A simulation-driven approach

**DTU, Dept. of Civil and Mechanical Engineering (6)**

(12) NIKOLAS ANASTASIADIS
Slamming load calculation from large breaking waves on jacket structures based on simulated wave kinematics

(13) SEBASTIAN VIKÆR DAMSGAARD
Active gas foil thrust bearings - design and modelling challenges for increasing their load bearing capacity

(14) PHILIP ELBEK
Topology optimization with stochastic geometric perturbations for waveguide design

(15) MARKUS TANDRUP HOLM
Maximizing failure resistance of periodic and aperiodic architected materials

(16) JANUS JEDIG-WALENTIN JENSEN
Pushing the limits of air foil journal bearings through models and experiments

(17) PEDRO JOSÉ DE FREITAS
Structural optimization for modularization

19:00 – Dinner

## Programme for Thursday morning, March 7$^{th}$, 2024

07:00 - 09:00 Breakfast

09.00 – 10:45 MATERIALS, STRUCTURES AND DYNAMICS
(Chairman: Bent B. Sørensen, DTU, Dept. of Wind and Energy Systems)

RAMIN AGHABABEI (AU, Dept. of Mechanical and Production Engineering, 20 minutes)
Micromechanics of cutting and chip formation

SOUHAYL SADIK (AU, Dept. of Mechanical and Production Engineering, 20 minutes)
Nonlinear anisotropic viscoelasticity

AMMAR AL-HAGRI (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Estimation of fatigue lifetime in jacket structure joints using sparse and noisy measurements

LUIGI CAGLIO (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Estimation of nonlinear structural response during extreme events via Kalman filtering

KRISTIAN LADEFOGED EBBEHØJ (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Short-term damping estimation for structures in nonstationary operating conditions

AMIRALI SADEQI (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)
Active vibration control with collocated piezoelectric sensor-actuator feedback

10:45 – 11:15 Coffee break

11:15 – 12:00 INVITED PRESENTATION
(Chairman: Niels Leergaard Pedersen, DTU, Dept. of Civil and Mechanical Engineering)

PIA REDANZ (DNV Denmark, 45 minutes)
Accelerating the energy transition

12:00 - 13:00 Lunch

## Programme for Thursday afternoon, March 7th, 2024

13:00 – 13:50 STRUCTURES
(Chairman: Brian Lau Bak, AAU, Dept. of Materials and Production)

MARTIN LAUTENSCHLÄGER (SDU, Dept. of Mechanical and Electrical Engineering, 20 minutes)
Flow simulation in batteries: A multi-scale issue

CASPER AASKOV DRANGSFELDT (SDU, Dept. of Mechanical and Electrical Engineering, 15 minutes)
Condition monitoring of vessels to identify high-exposure operation

VIJAYASANKAR IRISSAPPANE (SDU, Dept. of Mechanical and Electrical Engineering, 15 minutes)
Digital twins of axial piston pumps (APPs) for machine learning-based condition monitoring

14:00 – 18:00 Social Event

19:00 – Banquet

# Programme for Friday morning, March 8th, 2024

07:00 - 09:00 Breakfast

09:00 - 10:20 FLUIDS
(Chairman: Konstantinos Poulios, DTU, Dept. of Civil and Mecanical Engineering)

CHRISTOFFER HANSEN (AU, Dept. of Mechanical and Production Engineering,
15 minutes)
Extension of the law of the wall exploiting weak similarity of velocity fluctuations in turbulent channels

SINA NOZARIAN (AU, Dept. of Mechanical and Production Engineering, 15 minutes)
Investigating drag reduction through spanwise forcing on rough walls

MARIO RINCÓN (AU, Dept. of Mechanical and Production Engineering, 15 minutes)
Progressive augmentation of RANS turbulence models by simulation-driven surrogate optimisation

DAVID STAMENOV (AU, Dept. of Civil and Architectural Engineering, 15 minutes)
Data-driven estimation of higher-order hydrodynamic loading

DEBABRATA ADHIKARI (DTU, Dept. of Civil and Mechanical Engineering,
20 minutes)
Perspective on the fluid-structure interaction-induced multi-scale permeability variations in liquid composite moulding

10:20 - 10:50 Coffee break

10:50 – 12:00 OPTIMIZATION AND COMPOSITES
(Chairman: Ole Balling, AU, Dept. of Mechanical and Production Engineering)

SUMIT MEHTA (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)
Topology optimization of pneumatic soft robotics

JONATHAN MIRPOURIAN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
A novel interpolation scheme for topology optimization of strongly coupled acoustic-solid systems

ASGER PETERSEN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
Shape optimization of axial groove heat pipes

MARIE BRØNS (DTU, Dept. of Civil and Mechanical Engineering 20 minutes)
Estimating linear bolted joint stiffness and damping using frequency-based substructuring.

12:00 – 13:00 Lunch

## Programme for Friday afternoon, March 8th, 2024

13:00 - 14:00 COMPOSITES
(Chairman: Christian Berggreen, DTU, Dept. of Civil and Mechanical Engineering)

JESPER KJÆR JØRGENSEN (DTU, Dept. of Wind and Energy Systems, 15 minutes)
Predicting manufacturing defects in wind Turbine blade production

OLE FERGUSON (DTU, Dept. of Wind and Energy Systems, 15 minutes)
Compressive strength predictions for carbon fiber-reinforced pultruded profiles: Imaging modalities for quantifying the detrimental effect of fiber misalignment defects

JAMIE SIMON (DTU, Dept. of Wind and Energy Systems, 15 minutes)
Failure observations in thin and soft leading edge erosion test samples after whirling arm rain erosion testing

ANTONIOS TEMPELIS (DTU, Dept. of Wind and Energy Systems, 15 minutes)
Rain erosion of wind turbine blades; water droplet impact simulations and effect of surface roughness on impact stresses

14:00 – 14:15 Closing of the DCAMM Symposium

14:30 Departure from the hotel

# List of Participants

**DTU Construct**
**Dept. of Civil and Mechanical Engineering:**
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Caglio, Luigi*
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Damsgaard, Sebastian Vikær*
De Freitas, Pedro José*
Ebbehøj, Kristian Ladefoged*
Elbek, Philip*
Felle Olsen, Tim
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Fogt, Gerda Helene
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Hansen, Hans Nørgaard
Holm, Markus Tandrup*
Høgsberg, Jan B.
Isiklar, Göktug*
Jensen, Janus Jedig-Walentin*
Jensen, Kenneth Mahargarn*
Jensen, Peter Dørffler L.
Katsanos, Evangelos
Legarth, Brian Nyvang
Mehta, Sumit
Mirpourian, Jonathan*
Niordson, Christian F.
Pedersen, Niels L.
Petersen, Asger*
Poulios, Konstantinos
Rende, Bruno*
Richardt, Jens D.*
Richelsen, Ann Bettina
Sadeqi, Amirali
Sigmund, Ole
Soleimani, Hossein*
Thomsen, Jon Juel
Wang, Fengwen
Woldseth, Rebekka V.
Østerby Holst Rasmussen, Jacob*
Aage, Niels

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Drangsfeldt, Casper Aaskov*
Irissappane, Vijayasankar*
Lautenschläger, Martin
Li, Hao
Wiggers, Sine L.

**§8-members:**
Bender, Jens Jakob, SGRE
Christiansen, Christian Kim, DTU Engineering Technology
Felter, Christian Lotz, DTU Engineering Technology
Filsoof, Oliver Tierdad, Grundfos
Fremmelev, Mads, SGRE
Heide-Jørgensen, Simon Drachmann, VELUX
Nielsen, Kim Lau, Coloplast
Redanz, Pia, DNV
Ringgaard, Kasper, Vestas Wind Systems A/S
Sørensen, René, SGRE

| | Ph.d. | andre |
|---|---|---|
| DTU Construct | 18 | 25 |
| DTU Compute | | 2 |
| DTU Wind | 6 | 4 |
| MP, AAU | 5 | 4 |
| CAE, AU | 2 | 1 |
| MPE, AU | 6 | 4 |
| MEE, SDU | 3 | 5 |
| §8-members | | 10 |
| | 40 | 55 |
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* Ph.D.-student

## Programme for Wednesday afternoon, March 6th, 2024

13:05 – 14:45 DYNAMICS
(Chairman: Mads Peter Sørensen, DTU, Dept. of Applied Mathematics and Computer Science)

KENNETH MAHAGARN JENSEN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
**Estimation of vehicle brake pad remaining useful life from usage data**
Cars can possess significant kinetic energy attributed to their high mass and ability to travel at high speeds. Disc brakes are typically employed to allow for the dissipation of this energy safely and controllably by conversion to heat through friction. The friction, however, results in wear of the brakes. Instead of relying on physical inspections, wear estimation can predict the brakes' remaining useful life (RUL). The useful life is sometimes specified in terms of distance travelled, but this does not consider driving behaviour, e.g., driving with infrequent versus frequent braking. A wear model is proposed based on an estimated brake work, calculated as the product of longitudinal braking force and distance travelled during braking. A longitudinal dynamics model is used to estimate the braking force and to provide estimates of the braking state, i.e., application of the friction brakes, allowing for estimation of the distance travelled during braking. Real-time mass estimation is also considered, allowing for accommodating varying vehicle loads. The proposed methods are based on data from a vehicle-mounted sensor unit consisting of an inertial measurement unit (IMU), global navigation satellite system (GNSS) module, and vehicle on-board diagnostics II (OBD-II) connectivity. Experimental validation is performed using data from 10,200 km of driving from a single car, including periods with up to almost 25% increased vehicle mass. The four front brake pads are removed periodically to allow for measuring of their thickness, for a total of 31 measurement samples. It is shown that the mass can be estimated accurately within 5% across all the data. Braking state estimates are validated against actual states, with accuracies of about 91% across the three cases: (a) constant, (b) estimated, and (c) actual mass. The estimated brake work is shown to correlate very well with the wear. A model based on estimated masses and braking states is shown to perform almost identically to a model with actual masses and braking states, indicating that both the mass and braking states are estimated accurately. Finally, RUL is estimated with a distance-based model, resulting in an error of 2,000 km. The work-based models provide lower errors, with the constant mass model having a final error of 600 km against 190 km for the estimated mass.
*Supervisor: Ilmar Santos*

MARTIN SUHR (AU, Dept. of Mechanical and Produktion Engineering, 15 minutes)
**Edge-tracking as an operational modal analysis measurement method embrittlement**
Recently a growing interest in utilizing photogrammetry measurement methods for operational modal analysis has been seen. Commonly, the digital image correlation (DIC) method is utilized as it offers full-field displacement measurements in any direction; estimation of modal parameters by the method has been shown to allow for greater flexibility and quicker setup

compared to traditional measurement methods. Additionally, photogrammetry methods that do not require a “target” are possible, where modal parameters are extracted by tracking consistent unique structural features that reveal the structures displacement. However, limited knowledge is available on the efficacy of these methods when estimating modal parameters on large-scale structures. The focus of this method described in this study is tackling the challenges posed by measurements on wind-turbines; as these structures are large in scale, requiring a wide field of view of the images; and often lack many of the traditional features used in “non-target-based” methods, such as corners or steep edges. This study describes an edge-tracking method on images with a large field-of-view. The edge-tracking method relies on detecting zero-crossing points of the image derivatives. The structure used for evaluating the performance is a scale model of a wind turbine blade, with well-known modal parameters, excited by random noise and with subpixel deflections. The modal parameters are extracted from the acquired deflection signal using the operational modal analysis method. Results show that modal parameters from the edge-tracking method aligns with those from the accelerometer and DIC. Our study shows that non-target-based photogrammetry methods such as edge-tracking is a viable alternative to accelerometer-based analysis and DIC. The flexibility of this method is unparalleled as; no prior contact with a structure is needed before a measurement is possible, measurements can be done at ranges exceeding 100 meters.
*Supervisor: Anders Brandt*

JACOB ØSTERBY HOLST RASMUSSEN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)

**Dynamics of large-bore two-stroke marine engines**

The field of two-stroke marine engines represents a vital segment of maritime engineering, distinguished by its unique design, immense scale, and the substantial forces these engines contend with. Two-stroke engines are predominantly used in large vessels such as cargo ships and tankers, where power, efficiency, and reliability are paramount. Unlike their four-stroke counterparts, two-stroke engines complete a power cycle in just one crankshaft revolution. This design offers a high power-to-weight ratio, making them ideal for large-scale marine propulsion. Some of the largest two-stroke engines stand several stories tall and span considerable lengths. The enormity of these engines brings with it immense forces. The crankshafts and engine blocks must withstand tremendous pressures and loads, requiring robust materials and design to ensure structural integrity and operational longevity. Understanding and managing these forces are crucial for the efficient and safe operation of large marine vessels. Different modelling approaches are issued to understand the engine dynamics, spanning from simple beam-like structures to more advanced non-linear finite element models, all with different drawbacks and advantages. Theory from multibody dynamics is used to model the crankshaft and engine housing, while theory from fluid-solid interaction is utilized to bridge the gap between the multi-physical domains, offering a comprehensive understanding of the engine’s behavior under various conditions. Finally, experimental data forms the cornerstone of the modeling endeavors. The data provides tangible benchmarks against which the accuracy and reliability of the simulations can be measured.

By comparing model predictions with actual experimental observations, discrepancies can be identified and rectified, enhancing the fidelity of the calculations.
*Supervisor: Ilmar Santos*

BRUNO RENDE (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
**Multi-physics modeling of magnetic bearings - combining rotordynamics, electromagnetism, and heat transfer**
Magnetic bearings are becoming more common in the industry due to their possible broad applications. Mainly that is because they can support the shaft without mechanical contact and there is no need to use fluids or lubricants. This makes magnetic bearings suitable for application in harsh environments, including high-temperature applications. When operating at high temperatures, the temperature may affect the behavior of the magnetic bearings. Although there are some works in literature in this context, they model the different physical effects separated during their investigation. The present work uses a different approach, where a multi-physical model is built with all the equations representing the thermal effects in magnetic bearings - including rotor dynamics, electromagnetism, and heat transfer - being solved together. This procedure allows us to understand the dynamics of the rotor and the thermal behavior of the bearings. A multi-physical model of the magnetic bearings used in a small-scale flywheel energy storage system test rig is then presented.
*Supervisor: Ilmar Santos*

JENS D. RICHARDT (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
**Calibration of Piezoelectric Shunts for Vibration Damping**
Piezoelectric transducers shunted to a passive electrical circuit can be used for vibration mitigation of flexible structures when the electrical circuit is designed correctly. A simple electrical circuit that offers significant vibration reduction of a single vibration mode is a resistor in series with an inductor, referred to as a resonant (RL) shunt. The inductor introduces an electrical resonance which can be tuned to the mechanical resonance of the structure, thereby maximizing the energy that can be dissipated by the resistor. Additional energy dissipation can be obtained by having more than one piezoelectric shunt targeting the same vibration mode. However, the effectiveness of each shunt is sensitive to possible mistuning and the calibration must therefore be done with sufficient accuracy. The calibration of each shunt is often based on modal parameters such as the natural frequency, modal capacitance, and electromechanical coupling factor. The present study investigates the influence of residual modes and other piezoelectric shunts on the accuracy of the obtained calibration. Correction terms that account for these effects are proposed for an arbitrary circuit targeting a single vibration mode. Present work also includes experimental estimation of the structural parameters required for calibration of the shunts, allowing for calibration without additional measurement sensors or sophisticated numerical models of the structure.
*Supervisor: Jan B. Høgsberg*

HOSSEIN SOLEIMAN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)

**Revealing dynamics of systems with localized nonlinearity: Harnessing nonlinear substructuring**

In many engineering structures, localized behaviors, such as contact, cracks, and joints, make the dynamics of the whole system nonlinear. Analyzing these systems is computationally expensive and requires model order reduction in order to obtain solutions in reasonable time. In this presentation, a new nonlinear dynamic substructuring technique is introduced in the frequency domain, and its application through different case studies is discussed. The method uses the fact that each substructure behaves linearly, and nonlinearity is localized in limited degrees of freedom in the system despite the whole system behaving nonlinearly. By using this technique along with the multi-harmonic balance method, the required number of nonlinear equations will be reduced to half of the number of nonlinear DOFs in the system. The resulting non-linear system of equation is solved using Newton's method with prediction-correction scheme and continuation. Nonlinear frequency response functions for different harmonics have been derived for systems with contact and nonlinear energy sink. The results reveal nonlinear behavior in such a system, such as hardening, highlighting the necessity of nonlinear modeling.

*Supervisor: Niels Aage*

14:50 - 15:15 Coffee break

15:15 – 16:45 OPTIMIZATION
(Chairman: Casper Schousboe Andreasen, DTU, Dept. of Civil and Mechanical Engineering )

HAO LI (SDU, Dept. of Mechanical and Electrical Engineering, 20 minutes)

**Towards homogenisation-based topology optimisation of heat exchangers**

Simulating and optimising flow distribution in multi-scale media, such as compact heat exchangers, poses notable challenges. The intricate nature of the flow, necessitating the capture of finest scales, requires the use of an extremely fine mesh. Typically, this necessitates access to cluster environments, which is not generally available to all users. When it comes to optimising such a multi-scale flow system, the challenges are amplified. The intricacies of this dual challenge, simulating and optimising in a multi-scale context, emphasises the importance of design approaches that strike a balance between modelling accuracy and computational efficiency.

Homogenisation-based topology optimisation (TO) techniques are regaining popularity in enhancing multi-scale designs in the context of mechanical systems [1–3], and has been recently extended to modulated microfluidic channel [4,5]. The essence of these techniques relies on computing a deformed periodic grid that allows the reconstruction of fine-scale designs characterised by modulated and oriented patterns, commonly referred to as "dehomogenisation”.

This study leverages recent advancements in dehomogenisation to showcase its potential in the design of heat sinks. The homogenisation-based topology optimisation is specifically performed using a relatively coarse mesh, wherein spatially varying permeability and thermal conductivity matrices are defined. These matrices deviate from the traditional SIMP interpolated material properties and are instead numerically approximated on a fine mesh, considering a periodic cell problem to capture the multi-scale nature of this approach.

Subsequently, we derive optimised geometric arrangements for local channel spacing parameters and orientations. Established methods are then employed to reconstruct fine-scale designs. The fidelity of these reconstructions is verified through fine-scale simulations using upsampling techniques. On the numerical perspective, we implement homogenisation and dehomogenisation in a two-dimensional space within a parallel framework in FreeFEM.

**References**

[1] Groen, J. P., Sigmund, O. (2018). Homogenization-based topology optimization for high-resolution manufacturable microstructures. International Journal for Numerical Methods in Engineering, 113(8), 1148-1163.
[2] Geoffroy-Donders, P., Allaire, G., Pantz, O. (2020). 3-d topology optimization of modulated and oriented periodic microstructures by the homog- enization method. Journal of Computational Physics, 401, 108994.
[3] Wang, J., Westermann, R., Wu, J. (2023). A streamline-guided dehomogenization approach for structural design. Journal of Mechanical Design, 145(2), 021702.
[4] Geng, D., Wei, C., Liu, Y., Zhou, M. (2022). Concurrent topology optimization of multi-scale cooling channels with inlets and outlets. Structural and Multidisciplinary Optimization, 65(8), 234.
[5] Feppon, F. (2024). Multiscale Topology Optimization of modulated fluid microchannels based on asymptotic homogenization. Computer Methods in Applied Mechanics and Engineering, 419, 116646.

RASMUS ELLEBÆK CHRISTIANSEN (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)

**Topology Optimization of Nanophotonic Devices for Extreme Light Manipulation**

The talk discusses a set of inversely designed nanophotonic devices, for a variety of applications supporting and/or exploiting extreme light manipulation and confinement at or below the operating wavelength. The applications include the extreme spatial confinement of light for enhanced light-matter interaction [1]; optical waveguiding for low-loss on-device data transmission [2]; and optical lensing though micron-thick metasurfaces [3]. This work is motived by the rapid growth in nanophotonics research and the associated development of sophisticated fabrication tools, prompting the development of a set of inverse-design tools based on topology optimization [4].

The talk provides a brief introduction to electromagnetism and topology optimization, followed by a discussion of how to ensure device fabricability in the inverse design process. Then, the considered design problems are motivated, and the inversely designed solution presented including numerical and experimental validation. Among others, the talk shows that the time is ripe for marrying the unparalleled design-capabilities of topology optimization with the blooming _eld of nanophotonics and nanoscale device design more generally, with many exciting research opportunities, such as the exploration of inverse design for optomechanics to name a single area.

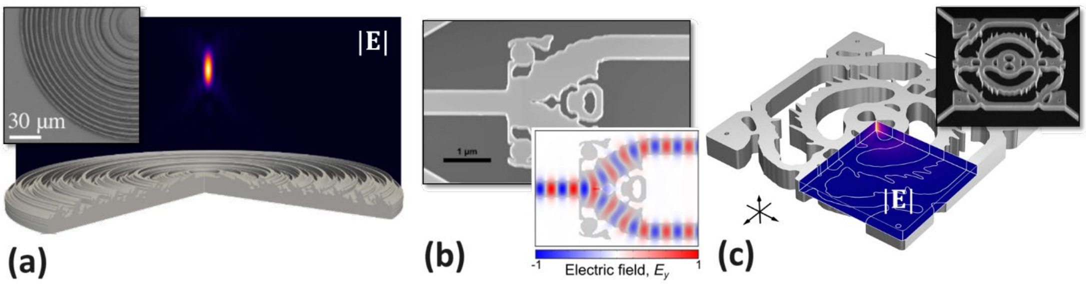


Figure 1: Inversely designed photonic devices. (a) metalens, (b) power splitter, (c) EDC cavity.

**References**

[1] M. Albrechtsen, B. V. Lahijani, R. E. Christiansen, V. T. H. Nguyen, L. N. Casses, S. E. Hansen,
N. Stenger, O. Sigmund, H. Jansen, J. Mørk, and S. Stobbe, Nanometer-scale photon confinement
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[2] S. E. Hansen, G. A. Bravo, A. N. Babar, R. E. Christiansen, and S. Stobbe., Inverse design and
characterization of compact, broadband, and low-loss chip-scale photonic power splitters, Materials
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[3] R. E. Christiansen, Z. Lin, C. Roques-Carmes, Y. Salamin, S. E. Kooi, J. D. Joannopoulos, M. Soljacic, and
S. G. Johnson, Fullwave Maxwell inverse design of axisymmetric, tunable, and multi-scale multi-wavelength metalenses, Optics Express, vol. 28(23), pp. 33854-33868, 2020.

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PETER DØRFFLER L. JENSEN (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)

**Efficient utralarge-scale topology optimization for complex geometries using de-homogenization**

The field of high-resolution topology optimization has provided new insights into structural design [1]. However, the high computational costs associated with these methods limit their practical use in industry. Meanwhile, additive manufacturing (AM) has seen significant improvements, highlighting the need for AM-specific high-resolution inverse design methods that integrate infill as a structural component.

To address these concerns, a de-homogenization topology optimization procedure has been developed for 3D unstructured grids [2]. The procedure involves obtaining a coarse-scale optimized unstructured complex geometry through multi-scale topology optimization. This geometry is then discretized with a 3D body-fitted hexahedral mesh. An anisotropic laminated rectangular-hole microstructure is used as a base material for the optimization problem. The number of laminates and microstructure densities is regulated to improve stability and control the upper and lower bound on infill material for the optimized AM design.

Based on the periodicity of the microstructure, the coarse-scale optimized design is up-sampled to a fine single-scale multi-laminar physical structure with a minor loss in structural performance. The upsampling is achieved through computing stream surfaces that align with the coarse-scale microstructure [3]. The periodicity and minimum length scale of the multi-lamellar physical geometry can be adjusted such that the material functions as a structural component and infill for AM designs.

This procedure has been demonstrated on several complex geometries suited for AM, and the use of an anisotropic microstructure design material has shown clear structural superiority over more commonly used isotropic infill material. Additionally, due to the relatively low cost of the optimization procedure, it consistently delivers structural performance values within a few percent of expensive large-scale density-based topology optimization solutions, while using an order of magnitude less computational resources.

**References**


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ANDREAS H. FREDERIKSEN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)

**Third medium contact, friction, non-linear topology optimization**

The Third Medium Contact (TMC) method, an implicit formulation for contact mechanics, has gained popularity due to its compatibility with topology optimization methods. Unlike explicit contact methods, TMC introduces a fictitious third medium surrounding the contacting bodies, eliminating the need for explicit contact detection. This method is continuous,

differentiable, and robust to mesh deformation, making it suitable for large deformation contact problems.
However, TMC has limitations, including potential computational inefficiency and inherent frictionless behavior. The frictionless behavior arises because tractions on contacting surfaces are determined solely by the third medium's material properties.
This study addresses TMC's frictionless behavior by introducing a plasticity-inspired framework that regulates the development of intercoupled shear and normal stresses in contact interfaces. The model incorporates a yield criterion, allowing controlled development of shear stresses while maintaining the ability to generate normal tractions. Incorporating this plasticity-inspired model into the TMC framework effectively addresses the limitations of frictionless behavior and enhances the method's ability to represent physically sound contact.
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*Supervisor: Konstantinos Poulios*

GÖKTUG ISIKLAR (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)
**Utilization of substitute harmonic approach for topology optimization of thermal initial value problems**
Heat transfer devices have extensive utility across various industries, including automotive, electronics, aerospace, food preservation, and biomedical. Ensuring efficient management and control of heat is essential to maximize performance and safety in these diverse applications. Topology optimization distinguishes itself as an inverse design technique, remarkably competent at engineering designs that effectively manipulate the thermal characteristics of heat transfer devices.
A significant portion of the existing literature regarding topology optimization for heat transfer problems has primarily concentrated on steady-state analysis [1]. Nevertheless, various applications necessitate the control of transient thermal system behavior to attain specific design objectives. Addressing the computational difficulties associated with solving time-domain gradient-based optimization problems present a challenge. These problems demand both forward and backward time stepping at each iteration to compute adjoint sensitivities [2].
In this study, we introduce an alternative optimization method based on harmonic analysis to mitigate these computational challenges. Leveraging an analytical solution for a one-dimensional heat conduction problem, we establish a conversion coefficient that relates the frequency of harmonic excitation to the desired transient time instance. By incorporating this harmonic formulation into the topology optimization of a two-dimensional transient heat conduction problem, we achieve a noteworthy acceleration, approximately 20 times faster per design iteration, while experiencing only a minimal (up to 5%) reduction in the figure of merit compared to the transient approach.
Furthermore, we extend the heat conduction problem by introducing boundary convection. Notably, we assess the benefits and limitations of the proposed

harmonic formulation approach by examining its performance in optimizing this heat conduction-convection problem.

**References**

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*Supervisors: Ole Sigmund*

17:00 – 17:40 POSTER PRESENTATIONS
(Chairman: Erik Lund, AAU Dept. of Materials and Production)

17:40 – 19:00 POSTER SESSION

AMIRHOSSEIN BAYAT (SDU, Dept. Of Mechanical and Electrical Engineering)

**Towards topology optimisation for high heat flux cooling**

Thermal management is critical for most applications, from large industrial equipment and micro electronic devices. Topology optimization is a promising way to maximize the heat transfer and will be explored for high heat flux cooling.

Topology optimisation is posed as a material distribution technique that answers the question "where should material be placed?" or for fluid dynamics "where should the fluid channel be placed?". Although a range of topology optimisation approaches exists, such as the level set and phase field methods, we are going to use the so-called "density-based" method, which remains the most popular in the field due to its relative ease of implementation. The governing equations are discretized and solved using the Finite Element Method (FEM).

The applications in mind are advanced cooling solutions for fusion reactors (~10 MW/m^2) and high energy-density electronics (~1 MW/m^2). We will use topology optimisation to design cooling channel layouts and tube inserts for enhanced heat transfer. The generated designs can directly address complex high heat flux challenges, but the generated designs will also offer insights to improve more practical and manufacturable solutions.

*Supervisor: Joe Alexandersen*

RICCARDO GROSELLE (AAU, Dept. of Materials and Production)

**Damage-tolerant designs for long term endurance of next-generation wind turbine blades**

Currently, manufacturing techniques for wind turbine (WT) blades involve manual labour to a high degree. This factor negatively affects the scalability potential and industrial throughput, especially as recent trends have shown a shift towards larger yet more cost-effective blades. The PhD research is part of the NextGenBlade (Sapere Aude) project, whose aim is to allow a paradigm shift in the structural design of WT blades by implementing the use of sequentially cast fibre-reinforced polymer (SC-FRP) structures, which can be produced in a highly automated manner. SC-FRPs can be placed directly in the mould and bonded by the liquid resin during the infusion process, thus reducing the overall lead time. The introduction of such parts poses a new set of structural challenges, mainly related to the inherent weakness of adhesive joints. The PhD will explore the capabilities of an innovative toughening concept, which aims to increase the damage tolerance and fatigue endurance of such bonded joints. The broader aim of the PhD project is to simulate and study the behaviour of toughened adhesive joints using a multiscale physics-based mechanical model, both under quasi-static and fatigue loading conditions. A novel modelling technique is being developed to simulate mixed-mode crack propagation, including the effects of large-scale bridging. The geometry is generated using a parametrized Python script, which builds a three-dimensional finite element model in Abaqus. Cohesive and bridging laws are decoupled, as crack propagation is simulated via connector elements, whereas the micromechanical effects are captured by modelling the fibre bundles directly. The approach will be validated against experimental data,

and the model will be used to provide insights into the micromechanical behaviour of the bridging fibres in mixed-mode loading, as well as generalized guidelines to maximize the damage tolerance of the interface.
*Supervisor: Brian L.V. Bak*

NIKLAS STAGSTED (AAU, Dept. of Materials and Production)
**Bridging the gap: Uncovering the secrets of fibre bridging with a multiscale approach to fatigue damage in composite materials**
A primary cause of failure in composite structures is delaminations in the form of cracks between fibre-reinforced polymer (FRP) layers of the structures. For delaminations, a significantly increased damage development is observed under varying loads compared to current model predictions. These models are typically based on experiments with constant amplitude cyclic loading, as the mechanisms governing damage under variable amplitude spectrum loading are poorly understood. On the microscale, delaminations in FRP experience fibre bridging, where fibres bridge the gap between crack faces and provide a shielding effect at the delamination front. This effect will be characterised experimentally by microscale measurements of the individual bridging fibres under fatigue loading and measurements of the mesoscale traction profile using inverse methods. Additionally, the fatigue damage development of individual fibres will be monitored under different load amplitudes to characterise the effects of load interactions on the damage state of the delaminations. Using the experimental knowledge generated, a physics-based micro-mesoscale model will be synthesised to simulate fatigue damage development of a mesoscale crack under variable amplitude spectrum loading. The model will utilise a discrete representation of bridging fibres to account for the microscale damage development of the bridging fibres. An elevation of the model to allow macro-scale simulations will be achieved by using the physics-based micro-mesoscale model to fit a computationally efficient surrogate model.
*Supervisor: Brian Lau V. Bak*

BEHNAM FIROOZI (AAU, Dept. of Materials and Production)
**Thin-walled parts: Linking manufacturing process with components' dynamic properties for robust design**
This project aims to investigate how the manufacturing induced residual stress, plastic strains and geometry imperfections influence vibration performance of thin walled spatially curved panels (possibly under heavy fluid loading). These panels serve as integral components in large centrifugal pumps. Within the assembled structure, they function both as resonators, generating tonal noise at elevated levels, and as waveguides, transmitting vibro-acoustic energy from the source (rotating fluid-loaded blades) to the outer regions of the piping system. It is anticipated that a high fidelity modelling of sheet metal forming by means of advanced numerical tools will provide the necessary information to identify the eigenfrequencies and eigenmodes of these components and predict the distribution of structural intensities at the dominant excitation frequencies. In the course of modelling, sensitivities of dynamic characteristics of panels to parameters of the manufacturing process will be assessed the intended work will also encompass the relative uncertainty assessment of the eigenfrequencies, eigenmodes and structural intensities in view of performance of assembled large centrifugal pumps under uncertain boundary conditions.
*Supervisor: Sergey Sorokin*

KRISTIAN HANSEN (AAU, Dept. of Materials and Production)

**Development of methodologies for early-stage acoustic prediction from modularized centrifugal pumps**

Grundfos A/S, addresses the critical challenge in early-stage product development for Grundfos, of predicting sound radiation and NVH characteristics of their pumps. A key focus of the project is the assessment of whether mode shapes of centrifugal pumps (or similar multicomponent mechanical systems), may be ranked based on their relative contribution to the sound radiation under either broad-band or frequency specific excitation, and if a sub-set of these may be used for the construction of reduced-order models for accurate prediction of sound radiation and NVH. The goal of these reduced-order modelling techniques is a significant reduction of computational complexity compared to traditional "full" numerical solution schemes. The abstract idea of extracting reduced-order models of individual components from reduced-order models of modularized centrifugal pumps is also addressed, with the goal of new reduced-order models to being constructable from these.

In addition to these tasks, the project investigates methods for calibrating developed reduced-order models based on empirical data from e.g. vibration-, sound or material tests. The calibration may be performed on model parameters like (modal) damping, stiffness, density, etc., but may also be at a higher level of abstraction by calibrating phenomena which are not modelled, but still based on the underlying physics e.g. the coefficients in a Fourier series.

Finally, the project aims to develop tools for uncertainty estimation of simulations and measurements, to determine confidence intervals on the early-assessment results, and to develop simple "rules of thumb" allowing engineers to roughly predict the effect on NVH, when changing parameters of a pump design, e.g. required speed, pump head, flow or changing the materials of pump components.

*Supervisor: Sergey Sorokin*

NANNA BERGMANN WINTHER (AAU, Dept. of Materials and Production)

**Mapping the influence of non-proportional stress state on the fatigue life of welded steel components.**

When a welded steel component is subjected to multiaxial loading, the mere introduction of a delay – a phase-shift – between forces has been found to significantly reduce fatigue life by a factor of two or more. This delay leads to non-proportional (NP) stress states, where principal stresses vary over time. Other than a delay NP stress states can emerge from frequency shifts between stress components, varying amplitude-to-mean ratios, and different load patterns. Extensive documentation supports that NP stress states cause a substantial reduction in component fatigue life. However, the lack of comprehensive experimental data poses a challenge in establishing reliable fatigue criteria. Current studies present conflicting findings, and existing codes offer only a limited number of methods, some with conservative safety factors or none at all, to evaluate the influence of NP stresses.

To address this gap, the objective is to conduct a series of experiments to better understanding this influence of NP stress states on the fatigue life. The goal is to collect these insights into a practical guideline by integrating them with state-of-the-art research and established design codes. The resulting guideline will provide engineers and designers with valuable recommend-

ations for assessing the fatigue life of welded steel components under non-proportional stress conditions.
*Supervisor: Jens H. Andreasen*

LUCIE LABORDERIE (DTU, Dept. of Wind and Energy Systems)
**A physics-based simulation framework for modelling the manufacturing process of hybrid composite structures**
Wind turbine composite rotor blades are classically manufactured via Vacuum Assisted Resin Infusion (VARI). Dry fibre fabrics, sandwich core materials and pre-manufactured inserts are typically placed in a mould sealed by a flexible vacuum bag. Driven by a pressure gradient, liquid resin flows through and impregnates the reinforcement lay-up.
The PhD project will focus on the vacuum infusion process of pre-manufactured components placed in a glass fibre/epoxy resin composite structure. The study's primary goal is to analyse how different manufacturing settings affect the infusion process (resin flow and distribution), cycle time, and quality of manufactured structures. Referring to Darcy's law, a physics-based simulation framework will predict the resin transfer with the PAM-ESI simulation software. Diverse infusion experiments will support the numerical and analytical work. The project will investigate the sensitivity of the infusion quality to a change in the different factors (i.e. process conditions, inlet and vent locations, consumable materials, lay-up alteration through the position and shape/features of the solid inserts). As a result of detailed material characterisation and in-depth analysis of material input parameters for simulations in PAM-RTM, a better understanding and an improved prediction of the infusion process will be achieved, offering ground for determining an optimised manufacturing strategy – resulting, among others, in a reduced risk of dry spots and void appearance, aiming to result in more consistent manufacturing quality.
*Supervisor: Rob Pierce*

PINELOPI MAGEIRA (DTU, Dept. of Wind and Energy Systems)
**Finite element analysis and predictions in 2D and 3D of the mechanical properties of in-situ 3D x-ray determined compression failure of pultruded uni-directional composites**
Manufacturing defects on pultruded composites for wind turbine blades can lead to the severe reduction of the component's strength, degrading the material and thus the structure's behavior. This work focuses on the process of predicting numerically the mechanical properties of pultruded carbon fiber composites from 3D x-ray CT scanned samples. It aims to potentially lead to improved strength and reliability of wind turbine composite blades, as well as the elimination of critical defects, while emphasis shall be given on the simulation and prediction of the kink band, a result of fiber misalignment during compressive loading that can lead to severe mechanical property degradation. In more detail data from unidirectional composite samples are used; a notch has been cut in the samples, so that the kink band formation to be triggered, while various datasets will be considered. 3D x-ray CT data are gathered, analyzed, and coupled with the structure tensor method, allowing for mapping the actual spatial fiber orientation on the finite element model. Two different modeling approaches are currently being explored based on the elastic-plastic non-linear incremental fiber matrix homogenized composite formulation. Each modelling approach is developed both in 2D and 3D. The compressive loading of this FEM model will lead in the prediction of the kink band compression, while the bending effect of the fibers will also be

investigated. The mechanical properties in compression and fatigue will be predicted, and then compared with actual experimentally measured values, while the in-situ observed compressive failure mechanism will be reproduced. This research represents a novel approach to enhancing wind turbine blade performance, with ongoing exploration of two modeling methods.

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*Supervisor: Lars P. Mikkelsen*

ANDERS MALUND DAMMARK JENSEN (AU, Dept. of Civil and Architectural Engineering)

**A framework for damage prognosis of offshore wind turbine foundations**

Structural health monitoring of offshore wind turbine foundation systems is challenging for a number of reasons. Little budget is typically available for monitoring systems and, therefore, few structural response signals such as accelerations and strains are measured. In addition, sensors, are typically installed above water level only and, therefore, the structural response of the submerged part of the foundation cannot be directly measured. Moreover, the sensitivity of the measured dynamic response to structural damage is very little. It follows that park owners are particularly keen on developing model-based damage prognosis tools, instead of data-driven damage diagnosis.

This standpoint motivates our work, which focuses on the development of a framework for damage prognosis of jacket foundations for offshore wind turbines. Damage prognosis is performed in two steps. First, a finite-element model of the system is calibrated based on response data. Then, based on the calibrated model, virtual sensing is utilized to estimate the strain response history of critical hot spots in the jacket foundation. Specifically, model calibration is performed using a sensitivity-based approach that minimizes the discrepancy between experimental vibration features and the corresponding model predictions. The model updating, and modal expansion are both formulated as inverse problems, which may be ill-posed or, at least, ill-conditioned. Therefore, singular value truncation is employed to regularize the formulations.

The study utilizes the finite-element model of a real wind turbine with jacket structure on pile foundation as a benchmark problem. Synthetic response data is generated using the finite-element model considering true (unknown) model parameters. Model and measurement uncertainty is numerically simulated using a Monte Carlo approach.

*Supervisor: Giuseppe Abbiati*

HJALTE DUROCHER (AU, Dept. of Mechanical and Production Engineering)

**Modelling of the breeding Blanket transporter for robotic remote maintenance of EU DEMO**

The future demonstration fusion power plant EU-DEMO must be maintained remotely in reasonable time to achieve safety as well as economic viability. The largest in-vessel components which will have to be replaced are the breeding blankets (BB's). Each vacuum vessel (VV) sector contains 5 BB segments: two inboard weighing 125 tons each and three outboard weighing 180 tons each. The BB transporter is a crane-like robotic arm which has been

previously designed at a conceptual level to remove and replace the BB segments through an upper port. It has an actuated gripper and 7 joints, which are required for grasping and manipulating the BB segments in 3D space. Detailed kinematic and dynamic modelling of the transporter are required to automate and control the BB maintenance tasks. The BB transporter has been analyzed as a robotic serial manipulator with 7 DOF by use of Newton-Euler and Lagrange methods, yielding closed-form kinematic and rigid-body dynamic models. Joints with underlying mechanisms having multiple DOF, including the rigid-chain elevator and the two "tilting" joints, have also been modelled. These models have been applied to verify the applicability of the BB transporter (with some design adjustments) to the BB segment removal tasks. First, this was done by solving the inverse kinematic problem to generate collision-free polynomial trajectories in joint-space based on task-space waypoints. Then, the inverse dynamic problem was solved to optimize these trajectories while staying within joint actuator and drivetrain limits. This also yielded estimates of the durations of the BB segment removal tasks, being in the range of 1-1.5 hours after some updates to the drivetrains from the conceptual design.
*Supervisor: Xuping Zhang*

DARIO SIRANGELO (AU, Dept. of Mechanical and Production Engineering)
**Towards reliable off-road autonomy: A simulation-driven approach**
Autonomous ground vehicles (AGV) are increasingly more common in the defence industry, with their primary applications being the automation of tedious or dangerous tasks and ground troops support roles. Despite their surge in popularity and the sustained interested of many NATO nations in fielding these systems, few methods are available in the literature to formally and quantifiably assess their performance and effectiveness when accomplishing navigation tasks in challenging off-road environments. Furthermore, autonomous navigation software stacks available in the public domain hardly benefit from the high mobility of these vehicle platforms, with most of their architecture and features conceived for navigation on flat terrains and structured urban environments.
The proposed framework aims to address gaps in off-road autonomy navigation and performance evaluation through a digital twin lens, using a validated digital model of an autonomous ground vehicle to jointly tackle simulation-driven autonomy development and assessment.
At the core of the approach is a comprehensive modelling and simulation (M&S) toolset established using open-source software for vehicle, sensors and environment modelling. The toolset includes digital twins of the relevant AGV subsystems and of an explorable area surrounding the vehicle, where a challenging off-road operational scenario used as reference for the study is enacted. Throughout the scenario, the cosimulation framework and its models are compared against their physical counterparts in a series of controlled experiments with the goal of assessing model validity and establishing a minimum required level of fidelity for the simulation.
Following the framework and model validation, popular combined planning and control algorithms for autonomous mobile robots, such as model predictive control (MPC) and model predictive path integral (MPPI) planning, are implemented through simulation-driven development and extended to explicitly handle realistic off-road mobility challenges. The planners are tested in both the physical and simulated environment and their performance

is compared through meaningful and quantifiable vehicle and autonomy metrics.
Finally, a suitable setup for uncertainty quantification (UQ) analysis is devised and employed with the goal of assessing system reliability and sensitivity to vehicle design variables and navigation system parameters, as well as leveraging the predictive capabilities of the M&S toolset to provide statistical insights on off-road autonomy behaviours that would be otherwise difficult to highlight through small samples from physical testing.
*Supervisor: Ole Balling*

NIKOLAS ANASTASIADIS (DTU, Dept. of Civil and Mechanical Engineering)

**Slamming load calculation from large breaking waves on jacket structures based on simulated wave kinematcs**

In recent years, climate-induced shifts in weather patterns have increased the expectancy of extreme wave events affecting offshore installations. Concerns arise for existing offshore structures designed under outdated specifications, necessitating vigilant monitoring during such occurrences to address potential vulnerabilities. The utilization of data-driven structural health monitoring (SHM) methods holds considerable promise for the robust and efficient oversight of such structures. Nevertheless, these techniques frequently necessitate a substantial volume of data for their development and evaluation, a requirement that may not always be met. As a result, It has become common practice to resort to data generated through simulation. Considering that many SHM methods rely on the dynamic response of the structure, it becomes evident that the quality of the generated data, including the intricacy of the simulation, can exert a significant influence on their performance during their evaluation. In the case of extreme wave events, slamming forces induced by breaking waves represent a significant source of non-linearity in the response of the structures. Up until now, the calculation of slamming loads has primarily been approached from an engineering perspective, that is applicable to simple structures or involve significant simplifications, eventually leading to conservative estimates. In consideration of this, a novel method is introduced, extending prior models of slamming load calculations to incorporate the complex morphology of large plunging waves and the diverse composition of jacket structures. The efficiency of the method in calculating slamming loads with minimal computational noise is demonstrated through its application to a finite element model of a jacket structure.
*Supervisor: Evangelos Katsanos*

SEBASTIAN VIKÆR DAMSGAARD (DTU, Dept. of Civil and Mechanical Engineering)

**Active gas foil thrust bearings - design and modelling challenges for increasing their load bearing capacity**

Active Gas Foil Thrust Bearings (AGFTB) are compliant self-acting hydrodynamic bearings using active hydrostatic lubrication. The thrust bearings are used in high-speed, oil-free, low and high temperature environments to support axial loads in turbomachinery. AGFTBs are often limited to lightly loaded applications when compared to other conventional bearings, primarily due to the inherently low viscosity of air and other gases. AGFTBs differ from their radial journal bearing counterparts by requiring a wedge profile to generate hydrodynamic lubrication. This introduces new geometric complexity during both the design and modeling phases. This presentation focuses on the primary challenges encountered in the design and

multi-physical modeling of AGFTBs with a focus on increasing their load bearing capacity and operational speed range. The challenges are many, including nonlinearities due to compressible flow and friction, thermal management, low speed rubbing and low damping. By highlighting these challenges, the presentation aims to open the door for more exploration and understanding in the field of active gas foil thrust bearings.
*Supervisor: Ilmar Sanos*

PHILIP ELBEK (DTU, Dept. of Civil and Mechanical Engineering)
**Topology optimization with stochastic geometric perturbations for waveguide design**
Manufacturing processes across industries inherit uncertainties, leading to the implementation of tolerances in devices. However, certain products exhibit high sensitivity, and even minor disturbances can profoundly impact their performance. Such delicate devices are frequently encountered in compliant mechanisms or situations involving the propagation of elastic, acoustic, or electromagnetic waves. In these cases even slight alterations to the device's geometry can result in a significant degradation of performance.
Robust topology optimization formulations taking into account uncertainties has been studied during the last decade, e.g. in [1] for acoustic waves and [2] for mechanics, using an over- / under etching technique. Current standard approaches does not ensure a good performance between the edge cases due to large material contrasts, does not allow for great variability in the uncertainty, and does not perform well computationally.
This presentation will showcase the possibilities of using stochastic perturbations for geometric uncertainty building on the knowledge in [3] but for an optical wave guide. The chance of showing good results are high due to the smaller contrast in optical problems. The geometric uncertainty are emulated by stochastic expansion modes which can resemble that of a manufacturing process, and the method only requires a single factorization per iteration making it computationally faster than standard approaches.
**References**
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*Supervisor: Ole Sigmund*

MARKUS TANDRUP HOLM (DTU, Dept. of Civil and Mechanical Engineering)
**Maximizing failure resistance of periodic and aperiodic architected materials**
This study aims to develop failure-resistant 2D architected materials. The failure resistance is measured by the fracture energy, defined as the total energy dissipation during crack propagation. The constituent material is assumed to behave linearly elastic and brittle, which enables the calculation of

energy dissipation based on linear elastic fracture mechanics (LEFM) and a simple quasi-static crack propagation model. Each strut in the lattice structure is modeled using rigidly connected Timoshenko beam elements. The use of beam theory allows for the use of a simple stress-based failure criterion and drastically reduces computational costs. The first part of the study presents a fair comparison of fracture energy between periodic and aperiodic lattice structures. The periodic layouts include the regular hexagonal honeycomb, the Kagome lattice and the regular triangular honeycomb. Further, the Penrose kite and dart lattice is included as an example of an aperiodic lattice. To optimize the toughness of the well-known layouts, the crack path is extended by altering the in-plane thickness of the struts in various predefined patterns. Multiple patterns are investigated and parameterized, and the best pattern is selected from a series of parameter studies and benchmarked against the uniform layouts. Establishing the benchmarks of well-known lattice layouts together with the results of the parameter study, will form the basis for future work on gradient-based optimization methods.
*Supervisor: Ole Sigmund*

JANUS JEDIG-WALENTIN JENSEN (DTU, Dept. of Civil and Mechanical Engineering)
**Pushing the limits of air foil journal bearings through models and experiments**
Air Foil Journal Bearings (AFJBs) offer a sustainable and oil-free solution for high-speed rotating lightweight machinery. However, expanding their use for heavier machinery is hampered by their limited capacity to carry loads and inherently low damping characteristics.
One possible way to mitigate these limitations is through hybridisation and active feedback control. This project intends to investigate the possibilities of using passive and active Hybrid Air Foil Journal Bearings (HAFJBs) with radial air injection to increase the load-bearing capacity and stability of a rotor-bearing system. The project aims to describe the dynamics of HAFJBs through efficient nonlinear models that can be used in designing HAFJBs for industrial equipment and extending the current use cases for AFJBs.
The presentation concludes with the presentation of preliminary theoretical results of a control scheme applied to the state-of-the-art model of a yet-to-be-built version of an existing industrial-scale second-generation AFJB test rig augmented with a piezo-electrically controlled radial injection system. The preliminary results show that HAFJBs can provide a substantial improvement in bearing dynamics, through higher load-carrying ability, and a reduction of sub-synchronous vibrations.
*Supervisor: Ilmar Santos*

(PEDRO JOSÉ DE FREITAS (DTU, Dept. of Civil and Mechanical Engineering)
**Structural optimization for modularization**
Complex products such as transport vehicles have a relatively long history and big production volumes. To reduce costs and speed up development processes, their associated workflows have converged to modular design paradigms. However, this is not true for bigger products with smaller production numbers, such as wind turbines. Wind turbines have relatively complex structural behavior, i.e.: adjacent bodies form coupled subsystems that can exhibit heavy nonlinear structural behavior, such as pretensioned bolted connections that can open and slide. This limits optimization

opportunities as state-of-the-art structural optimization primarily focus at the component level.
Assessing big and complex structures requires several stages at distinct focus levels. It is common to perform aeroelastic CFD analysis at the product level following more detailed analysis at scoping smaller regions. This work focus on these more detailed analysis. Without loss of generality, the rotor of a wind turbine will be used as an example. It will have the architecture of an existing Vestas turbine.
The main hypothesis is that is possible to design complex multibody products with strong nonlinear structural interaction between subsystems, such as wind turbines, for modularity and in an optimized way, by a divide and conquer approach. Topology or shape optimization is to be used for the hub wile parametric optimization, capturing all nonlinear efects, is to be used for the blade bearing and bolted connections.
*Supervisor: Niels Aage*

19:00 – Dinner

## Programme for Thursday morning, March 7th, 2024

MATERIALS, STRUCTURES AND DYNAMICS
(Chairman: Bent B. Sørensen, DTU, Dept. of Wind and Energy Systems)

09:00 – 10:45 RAMIN AGHABABEI (AU, Dept. of Mechanical and Production, 20 minutes)

**Micromechanics of cutting and chip formation**

The process of material cutting emerges from a series of nonlinear phenomena including frictional contact, plastic deformation, and fracture. While cutting dominated by shear deformation is of interest to achieve a smooth material removal and a high-quality surface finish, the fracture-induced chip breaking is of equal importance to prevent the formation of long chips. Here we show that discrepant observations and predictions of these two distinct cutting mechanisms can be reconciled into a unified framework. A simple analytical model is developed to predict the mechanism of chip formation in a homogeneous medium as a function of work piece intrinsic material properties, tool geometry, and the process parameters. The model reveals the existence of a critical depth of cut, below which the chip formation is gradually progressed by plastic deformation in the shear plane, and above which chips break off by abrupt crack propagation. The models' prediction is validated by systematic cutting experiments and simulation as well as literature data for a wide range of materials over multiple length scales. Additionally, we explore the evolution of surface roughness and demonstrate that the roughness is a direct outcome of the chip formation mechanism and is, in general, higher when chip breakage occurs

SOUHAYL SADIK (AU, Dept. of Mechanical and Production, 20 minutes)

**Nonlinear anisotropic viscoelasticity**

In this work, we revisit the mathematical foundations of nonlinear viscoelasticity. We study the underlying geometry of viscoelastic deformations, and in particular, the intermediate configuration. Starting from the direct multiplicative decomposition of the deformation gradient $\boldsymbol{F} = \boldsymbol{F_e}\boldsymbol{F_v}$, into elastic and viscous distortions $\boldsymbol{F_e}$ and $\boldsymbol{F_v}$, respectively, we point out that $\boldsymbol{F_v}$ can be either a material tensor ($\boldsymbol{F_e}$ is a two-point tensor) or a two-point tensor ($\boldsymbol{F_e}$ is a spatial tensor). We show, based on physical grounds, that the second choice is unacceptable. It is assumed that the free energy density is the sum of an equilibrium and a non-equilibrium part. The symmetry transformations and their action on the total, elastic, and viscous deformation gradients are carefully discussed. Following a two-potential approach, the governing equations of nonlinear viscoelasticity are derived using the Lagrange--d'Alembert principle, and the constitutive relations are found following the thermodynamics Coleman-Noll procedure. We discuss the constitutive and kinetic equations for compressible and incompressible isotropic, transversely isotropic, orthotropic, and monoclinic viscoelastic solids. We finally semi-analytically study creep and relaxation in three examples of universal deformations.

AMMAR AL-HAGRI (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)

**Estimation of fatigue lifetime in jacket structure joints using sparse and noisy measurements**

Offshore jacket structures operate in harsh marine environments. These environments are characterized, for example, by repetitive wind- and wave-induced loads and slamming forces due to extreme waves, while the capacity of structural elements may degrade due to corrosion phenomena. One of the most dominant and well-observed impacts of these adverse conditions is the fatigue-induced crack propagation that commonly takes place at the joints in the so-called "hot spots" of the steel jacket structures. Moreover, the remote location of the offshore installations, which are often situated miles away from the coastline, leads to obstacles in efficient inspection and maintenance. Moreover, the marine environment poses difficulties in adequately monitoring these structures due to the hindrance of reliable and continuous sensor operation, particularly in the submerged part of the structure. These constraints increase the likelihood of structural damage and the potential for it to escalate into severe and sudden failures, posing a collective threat to their functionality, integrity, and safety. In order to address such challenges, this project is dedicated to developing a data-driven framework oriented to predict fatigue-induced damages in structural joints, especially for those located in hard-to-access locations (e.g., submerged joints). The proposed methodology to be developed aims to identify the accumulated fatigue-induced damage at structural joints by integrating: i) a Kalman Filter (KF)-based state estimation scheme, ii) a mult-fidelity finite element (FE) analysis, iii) a supervised Machine Learning (ML) algorithm. The mult-fidelity FE analysis consists of a low-fidelity FE model simulating the response of the entire offshore jacket structure (at a global level) and a high-fidelity FE model to simulate the response of the joints (at a local level). The latter is represented by gradual fatigue-induced damage development, i.e., crack propagation data. Such a multi-fidelity simulation scheme is anticipated to allow for data generation to train the chosen ML algorithm, for which various joint configurations are to be considered under exposure to different load conditions. Following the training phase of the ML algorithm, the KF-based state estimation coupled with the low-fidelity FE model will be exploited to estimate via sparse and noisy measurements the global structural response in locations of the structure where sensors are not expected to be placed. Then, the estimated responses of the structure together with joint details, will be used as input to the trained ML algorithm, predicting, in turn, the damage development, specifically fatigue-induced crack growth at the joint. Such an integration of an advanced state estimation scheme, a mult-fidelity FE analysis, and the ML algorithm is expected to allow for accurate identification of damage resulting from fatigue loads.

*Supervisor: Evangelos Katsanos*

LUIGI CAGLIO (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)

**Estimation of nonlinear structural response during extreme events via Kalman filtering**

In the context of Structural Health Monitoring, the quick and reliable assessment of the condition of a structure following an extreme event can be essential, primarily to ensure people's safety against potential structural failures and to facilitate efficient repair activities. This is the case for offshore structures that are exposed to extreme storms or for buildings and bridges exposed to earthquakes. Such events can, in fact, induce a structure to exceed its design capacity and to respond in the nonlinear regime, which can render the identification of the structural damage particularly challenging.

Along these lines, the PhD project aims at developing methods that can allow an accurate estimation of the full nonlinear structural response during extreme events by making use of limited sensor measurements (e.g., acceleration or velocity responses) and a FE model of the structure, while the external load is unknown. The estimation of the response can, in turn, facilitate the assessment of the structural damage. In order to achieve this goal, a Kalman Filter estimation framework has been developed which is coupled with a nonlinear FE model of the structure.

The presentation will broadly explain the research that has been carried out during the PhD project. Additional challenges such as model uncertainties and complex load distributions (e.g., high-dimensional random wave loads) are discussed and methods for addressing these are mentioned, which can allow a reliable estimation of the structural damages and the uncertainty associated with the estimation.

*Supervisor: Evangelos Katsanos*

KRISTIAN LADEFOGED EBBEHØJ (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)

**Short-term damping estimation for structures in nonstationary operating conditions**

The dynamic response of a structure refers to the vibrations caused by some excitation. The dynamic response to a given excitation is governed by the structure's modal parameters, i.e., its natural frequencies, damping ratios, and mode shapes. Characterizing the dynamic response is critical for ensuring the structural integrity of various engineering structures, such as bridges and wind turbines.

The modal characteristics of some structures can vary considerably over short time periods, due to varying Environmental and Operational Conditions (EOCs). For example, a sudden change in wind speed can prompt a wind turbine controller to react (pitch blades, change rotor speed), which can result in considerable variations in modal damping over minutes or even seconds.

Modal parameters of structures in operation can be estimated from response measurements using conventional Operational Modal Analysis (OMA) methods. However, these methods assume time-invariant modal properties and require long time series to converge, which limit their capability of tracking short-term damping variations. To this end, a novel OMA method for short-term damping estimation for structures under EOC variability is introduced. The method combines physics- and data-driven system identification. Prior knowledge of the system is leveraged using environmental and operational variable measurements, i.e., measurements that can help identify the operational state of the structure. For wind turbines, useful environmental and operational variables include wind speed, rotor speed, and angular position of the rotor. The method is introduced and tested on both simulated and experimental application examples.

*Supervisor: Jon Juel Thomsen*

AMIRALI SADEQI (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)

**Active vibration control with collocated piezoelectric sensor-actuator feedback**

Collocated sensor-actuator elements are commonly used for active vibration control of engineering structures. The active damping provided by two classic control laws, integral force feedback and direct velocity feedback, is briefly presented. The numerical simulation and experimental testing are performed using a set of piezoelectric sensors and actuators mounted on a beam. This initial test setup simulates a simplified vibration control problem, which during the present InTreCon project is extended to a control mechanism for suppression of forearm tremors from e.g. Parkinson's disease. The presented findings aid in addressing some of the fundamental challenges encountered in the development of alternative solutions for mechanics-based medical treatments.

10:45 – 11:15 Coffee break

INVITED PRESENTATION
(Chairman: Niels Leergaard Pedersen, DTU, Dept. of Civil and Mechanical Engineering)

11:15 – 12:00 PIA REDANZ (DNV Denmark, 45 minutes)

**Accelerating the energy transition**

The global energy landscape is rapidly evolving, and the imperative to transition to sustainable and cleaner energy sources has never been more critical. Some insights are informed by DNV's Energy Transition Outlook 2023, an independent model of the world's energy system that extends through 2050.

In this presentation, focus will be on the engineering challenges associated with accelerating this transition. The following key areas play a pivotal role in reshaping the energy sector:

1. Offshore Wind: Harnessing the power of wind at sea presents unique engineering challenges. We explore the trend of bigger wind turbines and discuss challenges with offshore wind farms with both fixed and floating foundations.
2. Power-to-X (PtX): PtX technologies hold immense promise for decarbonization. We delve into the engineering intricacies of converting surplus renewable electricity into hydrogen, synthetic fuels, and other valuable products.
3. Carbon Capture, Utilization, and Storage (CCUS): CCUS is a critical tool for mitigating emissions from fossil fuel-based industries. We explore the challenges of capturing, transporting, and safely storing $CO_2$.

As engineers, our work in advancing these technologies is pivotal. Let us collectively accelerate the energy transition and shape a sustainable future.

12:00 – 13:00 Lunch

## Programme for Thursday afternoon, March 7th, 2024

STRUCTURES
(Chairman: Brian Lau Bak, AAU, Dept. of Materials and Production)

13:00 – 13:50 MARTIN LAUTENSCHLÄGER (SDU, Dept. of Mechanical and Electrical Engineering, 20 minutes)

**Flow simulation in batteries: A multi-scale issue**

Most of the physical phenomena in batteries occur at the pore scale and thus, are related to their microstructure. But also geometrical aspects and boundary conditions at the cell scale can have strong impacts when it comes to performance and economic indicators. Thus, for battery development a multi-scale perspective is often inevitable.

This situation is further aggravated by the fact that influencing factors at different length scales are mutually dependent. Thus, experiments are often challenging and require complementary numerical simulations. The latter are shown to be a useful tool in battery development and allow detailed insights on different length scales.

In this work, electrolyte filling as a show case is studied from a multi-scale perspective. The focus is on multi-phase flow and how flow dynamics in micro- and mesopores affect electrolyte filling at the cell scale. Interesting effects such as gas entrapment and pore clogging are observed and related to a potentially negative impact on battery performance. It is shown how different computational methods can be efficiently combined considering physical effects from different length scales. Amongst those, the lattice Boltzmann method (LBM) as an inherently mesoscopic method will be given greater importance.

The results indicate how simulations can support battery development – from microstructure, to cell, to process design.

CASPER AASKOV DRANGSFELDT (SDU, Dept. of Mechanical and Electrical Engineering, 15 minutes)

**Condition monitoring of vessels to identify high-exposure operations**

Recently, the offshore wind energy market has grown rapidly, and this trend is expected to accelerate further in the upcoming decades [4]. However, the increasing market poses challenges, especially in the context of Operation and Maintenance (O&M) for Offshore Wind Turbines (OWTs). Throughout the operational lifespan of an OWT, substantial costs are associated with O&M, exceeding the O&M costs for onshore turbines significantly [3]. A significant challenge and expense involve restricted accessibility. Transportation of personnel to the site requires the use of specially designed vessels, typically a Crew Transfer Vessel (CTV), where chartering can be costly [2]. In addition, the safe transfer of personnel to OWTs is weather-sensitive, further impeding accessibility. Facing these challenges, it becomes crucial to keep CTVs consistently operational. This ensures functionality in favourable weather conditions and establishes a competitive edge in the fast-growing market. This emphasizes the need for an optimum maintenance strategy, paving the way for an effective condition-based maintenance strategy.

A maintenance strategy based on Condition Monitoring (CM) is deemed as nondestructive where the internal condition is assessed externally continuously without interrupting the operation. External assessment is enabled through the extraction of internal information, such as particles in lubricant oil or vibration measurements. While CM has been a research topic for several decades, traditional methods are constrained to time-invariant systems [1]. The agile nature of a CTV, where swift manoeuvres and a demanding environment challenge the operation, leads to constant changes in statistical properties, resulting in a highly time-variant system. Addressing these challenges requires advanced techniques to model the time-dependent system.

The primary focus of this Ph.D. is developing an effective CM maintenance strategy for a CTV. Through data-driven partitioning of the operation into distinct modes initially based on a physical interpretation, CM is implemented for each mode. This not only enables continuous assessment of the structural integrity but also facilitates the identification of potential causes for accelerated deterioration. Identification of possible causes for accelerated deterioration enables the shipping company and the captain to alternate the operation if possible, thus increasing the lifetime potentially. The primary focus will, however, be solely on a specific CTV; nevertheless, adaptability for other CTVs will be considered.

**References**

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[3] S Tyler, Philipp C Beiter, and P Duffy. Cost of Wind Energy Review. 2019. url: https://www.nrel.gov/docs/ fy23osti/84774.pdf.

[4] Andrea Willige. The winds of change: 5 charts on the future of offshore wind energy. Aug. 12, 2020. url: https://www.weforum.org/agenda/2020/08/offshore-wind-energy-growth-energy-transition/.

*Supervisor: Marie Lützen*

VIJAYASANKAR IRISSAPPANE (SDU, Dept. of Mechanical and Electrical Engineering, 15 minutes) Digital twins of axial piston pumps (APPs) for machine learning-based condition monitoring

This project focuses on advancing the Condition Monitoring (CM) of Axial Piston Pumps (APPs) through the integration of high-fidelity Finite Element (FE) models and Machine Learning (ML) techniques. The primary focus is on accurately modeling APPs using sub-structuring methodologies, considering various components, and incorporating manufacturing tolerances. Numerical results from these models will be validated against real-life experimental data, refining the models as needed. Subsequently, a specialized ML-driven CM algorithm will be developed and trained using the validated FE models as synthetic data generators. The success of the project hinges on achieving precise FE modeling, ensuring numerical results align with experimental data, and deploying an effective ML-CM algorithm capable of detecting and classifying various damage scenarios in APPs. Successful outcomes promise significant benefits in operational and maintenance savings for critical industrial applications.

The procedure involves utilizing the authentic CAD model of the pump from Danfoss to generate a FE model through Ansys, a commercial FE software. These models undergo refinement using Model Updating techniques, incorporating experimental data. The validated model is then subjected to a deliberate failure or damage scenario, and the resulting responses from both the FE model and experimental data are compared for further validation,

essentially creating a digital twin of the pump. The data derived from this digital twin will serve as input for an ML model, enabling the identification of specific failure modes. Consequently, an algorithm can be developed to detect failures in the pump based on the ML model's analysis.
*Supervisor: Luis David Avendaño-Valencia*

14:00 - 18:00 Social Event

19:00 - Banquet

## Programme for Friday morning, March 8th, 2024

07:00 - 09:00 Breakfast

FLUIDS
(Chairman: Konstantinos Poulios, DTU, Dept of Civil and Mechanical Engineering)

09:00 – 10:20 CHRISTOFFER HANSEN (AU, Dept. of Mechanical and Production Engineering, 15 minutes)

**Extension of the law of the wall exploiting weak similarity of velocity fluctuations in turbulent channels**

This talk explores the similarity of the streamwise velocity fluctuations in turbulent channels. The analysis is based on the application of a one-dimensional proper orthogonal decomposition (POD) normal to the wall performed at several different Reynolds numbers. This approach naturally motivates the introduction of two different levels of similarity which we will refer to as strong and weak similarities. Strong similarity requires that the two-point correlation, and thus, all POD modes, show Reynolds number similarity, while weak similarity only requires that the first few POD modes show similarity. Focusing on weak similarity as it is more relevant for turbulence modeling, it is observed in both the viscous wall region and the outer part of the logarithmic layer. This presence of weak similarity suggests the existence of an extension to the law of the wall (LoW). An extension of the LoW is proposed which is inspired by the results of the POD analysis. The usefulness of the LoW extension is then assessed by comparing flow reconstructions according to the equilibrium LoW and the extended LoW. It is observed that the extended LoW provides highly accurate flow reconstructions in the wall layer, capturing fine-scale motions that are entirely missed by the equilibrium LoW.

*Supervisor: Mahdi Abkar*

SINA NOZARIAN (AU, Dept. of Mechanical and Production Engineering, 15 minutes)

**Investigating drag reduction through spanwise forcing on rough walls**

Friction between flowing fluids and solid surfaces constitutes one of the primary sources of energy loss in engineering applications. In most of these scenarios, the solid surfaces in contact with the flowing fluids possess substantial roughness. For instance, in the maritime industry, ship hulls frequently display rough surfaces, primarily attributed to factors such as biofouling. This circumstance serves as a compelling motivation to explore the feasibility and efficacy of various flow control methods when applied to rough surfaces. This study aims to assess the feasibility and effectiveness of employing flow control methods, specifically spanwise opposed wall-jet forcing (SOJF) as introduced by Yao et al. , to mitigate drag on rough surfaces. Key inquiries include the potential suppression of turbulent motion near rough walls, the achievement of drag reduction under similar actuation parameters as smooth walls, and the associated power requirements to induce the control.

The study utilizes Direct Numerical Simulations (DNS) with a pseudo-spectral incompressible Navier–Stokes solver (SIMSON) to compare drag reduction and power input in both smooth and rough channels, at the friction Reynolds number of $Re_\tau = 180$.

The maximum achieved drag reduction is approximately 2.4% and 2% for rough surfaces with lower and higher frontal solidity, respectively, achieved at higher forcing amplitudes compared to the optimal smooth case. The marginal drag reduction compared to the smooth case can be attributed to two factors. Firstly, the drag reduction mechanism in question does not reduce the pressure-dominated drag on roughness elements. Secondly, in the presence of roughness elements, wall-jets are less effective in suppressing the near wall streaks and the turbulent shear stress, which is deemed to be the drag reduction mechanism on the smooth parts of the wall. The study also observes a double-peak behaviour in dispersive-coherent stress profiles due to the interaction of roughness elements and the coherent motion induced by the control.
*Supervisor: Mahdi Abkar*

MARIO RINCÓN (AU, Dept. of Mechanical and Production Engineering, 15 minutes)

**Progressive augmentation of RANS turbulence models by simulation-driven surrogate optimisation**

The consistency of the a posteriori results and generalisability are the most critical aspects of new data-driven turbulence models. The generalisability challenge extends beyond addressing unseen cases outside the training dataset; it also involves the performance of new models on canonical cases such as channel flow. This study presents the progressive enhancement of the k-ω SST model for its known shortcomings in the prediction of the secondary flows of the second kind and the flow separation. The progressive approach is also combined with a simulation-driven optimisation technique to ensure the consistency of the a posteriori results.

In the first part of the study, the k-ω SST model is enhanced with the capability of predicting Pradtl's second kind of secondary flow without violating its original performance on canonical cases e.g. channel flow and periodic hills. The optimisation is based on a case square-duct flow to solely obtain an optimised correction for the secondary-flow effect. In the second part, a separation factor is introduced in the k-ω SST model to modify the turbulent viscosity while ensuring its activation only in the case of flow separation. The separation factor is optimised based on its performance in multiple training cases including periodic hills and curved backward-facing step flow.

Regarding their generalisability, the new models are tested on unseen cases with different geometries and Reynolds numbers, showing a successful improvement in the prediction of Pradtl's second kind of secondary flows [1] and flow separation [2]. These findings highlight the capability of the progressive approach to enhance the performance of linear eddy-viscosity turbulence models with data-driven methods while preserving the robustness and stability of the original models.

**References**:

[1] Rincón, M. J., Amarloo, A., Reclari, M., Yang, X. I., & Abkar, M. (2023). Progressive augmentation of Reynolds stress tensor models for secondary flow prediction by computational fluid dynamics driven surrogate optimisation. International Journal of Heat and Fluid Flow, 104, 109242.
[2] Amarloo, A., Rincón, M. J., Reclari, M., & Abkar, M. (2023). Progressive augmentation of turbulence models for flow separation by multi-case computational fluid dynamics driven surrogate optimization. Physics of Fluids, 35(12).

*Supervisor: Mahdi Abkar*

DAVID STAMENOV (AU, Dept. of Civil and Architectural Engineering, 15 minutes)

Data-driven estimation of higher-order hydrodynamic loading

Due to nonlinearities in the hydrodynamic loading process, an incoming bi-chromatic wave with frequencies $f_1$ and $f_2$ excites the individual frequencies separately but also any combination of sum $|f_1+f_2|$, difference $|f_1-f_2|$, and multiples $(2f_1,3f_1,..,2f_2,3f_2,\ldots)$ of the wave frequencies. Moored systems exhibit low stiffness in the horizontal degrees of freedom and as a consequence, their natural frequencies fall in the range where the difference frequency loads operate. In marine engineering, it is custom to model the low-frequency hydrodynamic loading via a difference quadratic transfer function that relates the wave elevation profile to the load exerted on the floating structure. Such transfer functions relate a bi-chromatic wave elevation profile characterized by two frequencies $\{f_1,f_2\}$ to a harmonic force excitation at frequency $|f_1-f_2|$. Potential flow-based solvers have been the main tool for estimating these transfer functions, although they are limited to an irrotational flow of an incompressible and inviscid fluid. While potential flow and perturbation theory provide an excellent basis for offshore engineering in mild sea-states, they show limitations in moderate-to-extreme sea states with steep waves. The theoretical limitations of the engineering tools result in an added uncertainty which can lead to structurally more inefficient designs, or in the worst case, failure. For that reason, an accurate estimation of the hydrodynamic loads, obtained by small scale experiments in hydrodynamic laboratories, is crucial for providing cost-competitive floater designs.

This work presents a data-driven approach providing a black-box model of the hydrodynamic loading, but also extracting its linear and quadratic transfer functions, which are current engineering practice. The procedure relies on constructing a nonlinear auto-regressive surrogate model for forecasting the hydrodynamic loads and a harmonic probing algorithm for extracting the transfer functions of the system. The implemented harmonic probing method is of numerical nature and avoids the use of computationally expensive symbolic coding tools. The method is validated against synthetic data generated from a potential-flow-based numerical model of the INO WINDMOOR 12 MW floater.

*Supervisor: Giuseppe Abbiati*

DEBABRATA ADHIKARI (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)

**Perspective on the fluid-structure interaction-induced multi-scale permeability variations in liquid composite moulding**

In recent times, various industrial sectors including aerospace, wind energy, automotive, marine, and others have shown significant interest in utilizing fiber reinforced polymer composites (FRP) as a substitute for traditional metals in structural applications. This is due to their superior specific strength, high stiffness to weight ratio, excellent durability, design flexibility, and lightweight nature. To address manufacturing cost reduction, time efficiency, and lower initial investment, liquid composite moulding (LCM) methods have emerged as efficient and sustainable alternatives to costly techniques like autoclave processing or automated tape placement. In LCM, dry fiber layups consisting of unidirectional, biaxial non-crimp fabric (NCF), or 3D preforms with a binder are applied onto moulds in specific layer arrangements, often including elements like balsa core, peel ply, release film, and distribution

media. The liquid thermoplastic/thermoset resin is then impregnated into the dry preform, saturating it prior to curing in an oven. However, during fabrication, the fiber preform undergoes complex multi-physics processes such as fiber compaction/displacement, infusion, and curing. Understanding this process modelling begins with material characterization, examining the structural configuration, and conducting flow simulations on the preform.
Characterization of the internal structure of the preform configuration is achieved through X-ray computed tomography (X-CT) scans of the composite laminate. Analysis of fiber deformation/displacement provides insight into the altered shape of the preform. A critical aspect affecting mould filling is the permeability of the deformed fiber arrangement within the layups. Notably, significant permeability variations exist among different layers, spanning orders of magnitude. These differences are evident in both intra and inter-fiber bundle porosity within fabric layers, with permeability levels differing by several orders of magnitude. High-fidelity numerical simulations based on real X-CT data offer superior accuracy compared to analytical models correlating permeability to factors like compaction pressure, fiber volume fraction, and orientation in fiber packing. The impact of X-CT analysis on virtual permeability predictions has been explored, along with the influence of X-CT data thresholding on constructing the computational domain of the preforms, starting from simple unidirectional configurations and progressing to more complex NCF fiber packing. At the conclusion, a viewpoint is offered on a methodological approach for conducting fluid-structure interaction analysis, aiming to propose practical process parameters for fabricating composite components through LCM.

10:20 – 10:50 Coffee break

10:50 - 12:00 OPTIMIZATION AND COMPOSITES
(Chairman: Ole Balling, AU, Dept. of Mechanical and Production Engineering)

SUMIT MEHTA (DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)

**Topology optimization of pneumatic soft robotics**

This work presents a new nonlinear topology optimization framework for designing three dimensional pneumatically triggered soft actuators. Unlike the majority of previous works on the identification of loading boundary, the design dependent pressure load is modeled using the Darcy flow equation. A coupled system is used, based on the two-field porohyperelasticity theory where displacement and pressure are treated as primary field variables in a mixed formulation. This study primarily focuses on density-based topology optimization where the objective is to maximize bending response due to an applied activation pressure, by tailoring the structural design for the soft pneumatic actuator. A level-set function is used to describe the presence (solid) and absence (void) of material and their respective regions in the design domain. The solid region is modeled with impermeable hyperelastic material whereas the void region is highly permeable allowing a pressurized flow without any resistance. To show the robustness of this model, a pneumatic segment of a straight tube is considered, and the optimal design is obtained by simultaneously solving the equations for objective function optimality, mechanical and pneumatic equilibrium, adjoint sensitivity analysis, strain energy constraints, and geometric constraints. The complex designs of actuators based on nonlinear topology optimization can potentially be useful for designing minimal invasive surgery devices which outperform currently available designs which are based on human intuition, biomimicry, and linear topology optimization.

JONATHAN MIRPOURIAN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)

**A novel interpolation scheme for topology optimization of strongly coupled acoustic-solid systems**

Acoustic-Solid Topology Optimization has emerged as a field of paramount importance, underscored by the increasing number of sophisticated devices ranging from compact smartphones to advanced hearing aids. Conventional approaches to Topology Optimization within this field have encountered significant hurdles, restricting their applicability to problems predominantly influenced by structural characteristics. These limitations are largely attributed to the persistent gradient issues stemming from the acoustic contributions, which severely hamper the optimization process and the achievable outcomes.

Addressing this limitation, we introduce the Multiphysics Interpolation with Gradient Control. The interpolation allows the optimization of tightly coupled Acoustic-Solid problems by explicitly managing the gradients throughout the optimization process. We verify the effectiveness of this approach through the application to several Acoustic-Solid optimization benchmark problems, including the acoustic partitioner benchmark problem. These applications demonstrate substantial improvements in both the objective value and the optimization process itself. Finally, we remark that the introduced interpolation technique is not limited to Acoustic-Solid problems alone, but extends to other multiphysics optimization problems, where precise gradient control is of the essence.

*Supervisor: Niels Aage*

ASGER PETERSEN (DTU, Dept. of Civil and Mechanical Engineering, 15 minutes)

**Shape optimization of axial groove heat pipes**

Heat pipes are passive thermal management devices capable of sustaining high heat flux due to heat transport occurring by latent heat of vaporization. They are commonly applied in among others laptop computers where they convey heat from the processor core to the heat sink.

Heat pipes are tube-like devices, which are made of an evaporator and condenser connected by a wick which consists of multiple grooves. The liquid sticks to these grooves in the condenser section and moves towards the evaporator section due to capillary action in the wick.

The structure of the wick geometry is important for the thermal performance of heat pipes. In this work the steady state heat flux of a heat pipe is improved by employing shape optimization on the wick geometry using a simplified mass-flux and thermal resistance model of the fluid flow and heat transfer within the wick. The numerical model is simplified to enhance runtime efficiency and numerical robustness. Its design ensures well-defined gradients, facilitating fast shape optimization of grooved wick geometries.

Maximizing steady-state heat flux in heat pipes leads to improved efficiency of laptop computers. This is achieved by employing shape optimization to minimize the pressure drop through the grooved wick thus allowing a larger fraction of the capillary pressure to drive the mass and heat circulation within the heat pipe.

*Supervisor: Casper S. Andreasen*

MARIE BRØNS
(DTU, Dept. of Civil and Mechanical Engineering, 20 minutes)
Estimating linear bolted joint stiffness and damping using frequency-based substructuring)

Accurate estimation of stiffness and damping of linear bolted joints is a challenge. Commonly employed approaches using frequency-based substructuring techniques can fail if the measurement quality is not good enough. Even a minimal noise level can impact the accuracy of the estimations significantly due to matrix inversions. This study proposes a novel approach that utilizing frequency-based substructuring with the emerging concept of Dynamic Disturbance (Dydis) to enhance the robustness of linear bolted joint parameter estimation.

Dydis can be any known disturbance of the dynamical system, such as an added mass or change in stiffness. Dydis causes a shift in the resonances and provides an independent set of information about the system. By incorporating Dydis data, with the original undisturbed data, into the recently proposed methodology, the estimated joint parameters can be validated across multiple working conditions. The estimated values are the compromise that satisfies both datasets the best.

The framework is based on a nonlinear maximum a posteriori method (MAP). The objective function consists of two terms. One minimizes the discrepancy between the measured responses of an assembled system and the responses obtained by coupling the measured responses of the individual substructures with a model joint, and another the discrepancy between an a posteriori guess of joint parameters and the estimated parameters. The a posteriori term helps regularizes the procedure, preventing the algorithm from diverging or converging to unphysical values. The dynamics of the system are assumed to be linear, but the FRFs of the coupled system (which are driving the objective function), change nonlinearly with the linear joint parameters. This makes it a nonlinear problem. The parameters are therefore estimated iteratively using the Gauss method of minimization, a well-established linearization scheme.

To validate the method, a study on simple theoretical MDOF systems is carried out. To demonstrate the potential of the approach on real structures, the procedure is tested on experimental vibrational data of the benchmark structure, known as the AM structure.

12:00 – 13:00 Lunch

## Programme for Friday afternoon, March 8th, 2024

COMPOSITES
(Chairman: Christian Berggreen, DTU, Dept. of Civil and Mechanical Engineering)

13:00 – 14:00 JESPER KJÆR JØRGENSEN (DTU, Dept. of Wind and Energy Systems, 15 minutes)

**Predicting manufacturing defects in wind turbine blade production**

In the production of wind turbine blades, several defects appear during manufacturing. As wind turbine blades become larger, the difficulty in managing the manufacturing defects increases. The blade consists largely of composite materials - A combination of fibres embedded in a matrix. This matrix is referred to as a resin. A resin is typically a thermoset polymer like epoxy or polyester. The liquid resin is transferred to the blade with a process known as Vacuum-Assisted Resin Infusion. After the infusion, the resin polymerises into a solid material, achieving the mechanical properties necessary for the composite material. This last step is known as curing. Curing is often performed at elevated temperatures to achieve a product within a reasonable production time and sufficiently cure it. A result of the curing process is residual stresses from the shrinkage of the resin during the curing. Residual stresses lead to reduced performance as they lead to additional defects.

Furthermore, the curing process releases exothermal heat because of the polymerisation. Depending on the uniformity of the heating, the additional heat can create steep thermal gradients across the composite that may lead to out-of-plane fibre waviness, commonly referred to as wrinkles.

This PhD project aims to better understand these manufacturing defects through manufacturing modelling based on characterisations and testing.

*Supervisor: Lars Pilgaard Mikkelsen*

OLE FERGUSON (DTU, Dept. of Wind and Energy Systems, 15 minutes)

Compressive strength predictions for carbon fiber-reinforced pultruded profiles: Imaging modalities for quantifying the detrimental effect of fiber misalignment defects

The introduction of carbon fiber-reinforced composites in wind turbine blade designs has posed new challenges with respect to manufacturing-induced defects. Compared with their glass counterpart, carbon fiber composites are extremely sensitive to fiber misalignment defects, where the reduction in compressive strength poses a structural risk to the blade. Pultruded profiles are used to mitigate the risk of severe fiber misalignment defects, but the manufacturing process has been observed to yield small inclusions in the form of accumulated carbon fiber balls, potentially leading to fiber misalignments in a larger region of the profile. Considering the shape and size of fiber misalignment defects, two imaging modalities are compared to assess the compressive strength of a carbon fiber-reinforced pultruded profile. Studying this, a 3-dimensional model based on X-ray computed micro-tomography is compared to a 2D equivalent model based on optical microscopy images. The 3D method quantifies the compressive strength based on realistic volumetric fiber orientation distributions but requires large volumetric scans to cover the entire region of interest at the cost of high computational times. On the contrary, the 2D method is less constrained with respect to image resolution, field of view, simulation time, and availability but neglects the out-of-

modeling-plane fiber orientation and is greatly affected by the choice of failure plane. Both methods quantify the fiber orientation distribution using a structure tensor-based imaging processing method. Orientation distributions are subsequently mapped onto a Finite Element model. A model used for compressive strength predictions. The presented study is based on a baseline pultruded profile with a typical fiber orientation distribution and will be used to uncover the capabilities of the methods and judge their prospects for studying the effect of large fiber misalignment defects.
*Supervisor: Lars Pilgaard Mikkelsen*

JAMIE SIMON (DTU, Dept. of Wind and Energy Systems, 15 minutes)
Failure observations in thin and soft leading edge erosion test samples after whirling arm rain erosion testing
Performance evaluation of leading-edge protection (LEP) systems against rain erosion is typically conducted utilizing a whirling arm rain erosion (RE) apparatus. It is an occurring problem that materials, in the initial design phase, are assumed to be perfect. This assumption is usually debunked when RE-testing measurements are performed due to high-impact stresses being the revealer of randomly positioned defects representing themselves as early blemishes in the topcoat prior to progressive surface erosion evolving from the tip. An effect typically omitted in most modelling-based research which relies upon homogenous and defect-free materials, resulting in generous lifetime estimates.
The present work focuses on unveiling some of these triggers from a macroscopic perspective to micro and nanoscale. By employing X-ray imaging and Scanning electron microscopy (SEM), current observations indicate that process and manufacturing variations significantly impact system behavior, thereby changing the progressive eroded surface pattern typically seen in some blade coatings to a defect-driven failure mode provoked by liquid droplet impact.

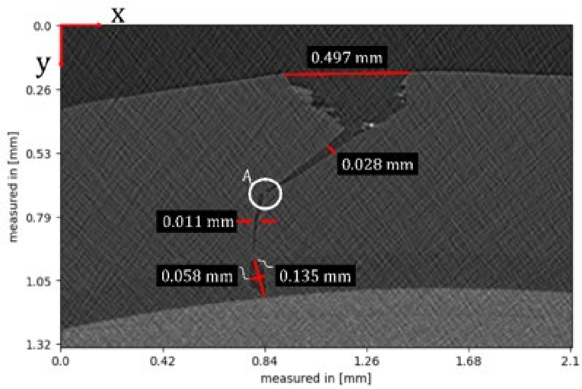


*Figure 1: Reconstructed -Xray image showing a Void in the substrate.*

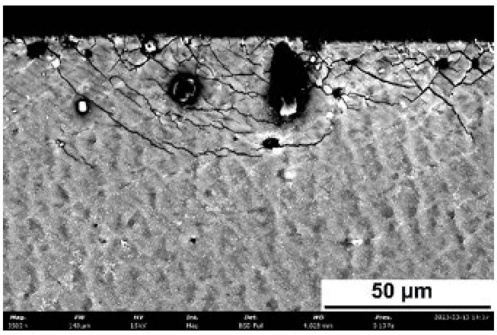


*Figure 2: Cross sectional SEM image of RET specimen after testing, courtesy of [1].*

*[1] T. H. Hoksbergen Faculty of Engineering Technology, Production Technology, University of Twente.*

*Supervisor: Lars Pilgaard Mikkelsen*

ANTONIOS TEMPELIS (DTU, Dept. of Wind and Energy Systems, 15 minutes)

Rain erosion of wind turbine blades; water droplet impact simulations and effect of surface roughness on impact stresses

Leading edge erosion of wind turbine blades is a big headache for the wind industry[1, 2]. This phenomenon causes roughness on the leading edge, which in turn reduces the aerodynamic efficiency of blades and the energy output of turbines[3, 4]. One of the main drivers of erosion is the repeated impacts of rain droplets on blades as they rotate with high tip speeds, which causes the protective coating material to fail over time. A lot of focus over the past years has been placed on predicting the lifetimes of coating materials through both analytic and computational models[5, 6], by calculating the stresses caused in the coating during the impact and using them in fatigue damage modelling frameworks.

This work focuses on modelling water drop impacts on the surface of the protective coating using the finite element software ABAQUS. Special focus is placed on simulating impacts on rough surfaces, in order to study erosion mechanisms and stress fields in coatings with initial defects or damage-induced roughness. The trends observed in the simulations are related to experimental observations obtained with rain erosion tests. The main findings are high stress areas inside erosion pits and valleys of roughness, which could explain faster erosion rates in damaged areas, as observed in experiments. High stress areas inside valleys of roughness could be explained by local flow acceleration of the water front, which is suddenly decelerated as it impacts the walls of the valley and causes large pressure build-up. The results of this work could be used in models that attempt to predict leading edge roughness after a period of operation, developed by the authors of this work.

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*Supervisor: Leon Mishnaevsky Jr.*

**14:00 – 14:15** Closing of the DCAMM Symposium

**14:30** Departure from the hotel