Department of Mechanical Engineering   DTU

Annual Report 2003

MEK

Preface

This is the third annual report from the Department of Mechanical Engineering (Institut for Mekanik, Energi og Konstruktion, MEK) at the Technical University of Denmark (DTU). MEK was established on 1 January 2001 as a merger of five Departments: Naval Architecture and Offshore Engineering, Energy Engineering, Solid Mechanics, Control and Engineering Design, and Applied Engineering Design and Production. On 1 June two other groups joined MEK: the Coastal and River Engineering group of the former Department of Hydrodynamics and Water Resources, and a mechanics group from the former Department of Structural Engineering and Materials joined MEK.

Since then we have established an organization framework, reorganized most of our courses and at the same time tried not to loose momentum within those research areas of excellence already established by the old departments. A number of new initiatives have been taken. For instance, MEK has become a central partner in a new engineering programme in Design and Innovation and two new M. Sc. programmes in Wind Energy and Coastal and Maritime Engineering have been launched.

The main objective of MEK is to conduct teaching and research in basic mechanics, advanced design tools, product development, energy systems and marine technology. The Department is responsible for essential parts of the Mechanical Engineering line of the B.Sc. programme at DTU and contributes to the M.Sc. programmes in Mechanical, Energy and Civil Engineering.

The Department of Mechanical Engineering covers the fundamental engineering disciplines within the fields of mechanics, including mechanical properties of materials, strength and vibration analyses, thermodynamics, fluid mechanics, hydrodynamics, safety theory, and control engineering.

Our energy research is centred on efficient exploitation of renewable energy resources such as biomass, wind and waves, efficient energy transformation in combustion engines, energy transport, and energy consumption including refrigeration and indoor environment optimization.

Within the areas of design and product development, MEK develops industrial products that take safety, economy, environmental impact, aesthe-

tics and durability into account. MEK attaches great importance to integrated product development and the development of design principles for land-based and marine structures.

This publication highlights some of the achievements during our third year of existence.

Preben Terndrup Pedersen
Head of Department

FEATURE ARTICLES

Large-Scale Coastal Morphology

Coastal and River Engineering

A sandy coast is a highly variable environment due to the transport, erosion and deposition of sediment. The shifting sand changes the morphology over a large range of scales in time and space. On the smallest scale we often observe wave ripples with a wave length of the order of 10 cm, which can form or change on a time scale of a few minutes. On an intermediate scale the profile of the beach changes continuously. Longshore bars are formed during storms and change their position and dimensions under more gentle wave conditions. The profile variation takes place on a time scale from a single storm event up to seasons or a few years. On larger scales, coastal features such as barrier islands, tidal inlets or spits develop over decades or centuries.

On the larger scales the dominant sediment transport mechanism is related to wave-driven currents. Water waves are associated with a "thrust" or momentum flux, the radiation stress. When the waves break in the surf zone the thrust is exerted on the water, thereby driving a current. The wave-driven current can be in the form of horizontal or vertical circulations (the latter known as undertow), and obliquely incident waves will drive a current along the coast. The longshore current causes a sediment transport, the littoral drift, which in many cases plays a very important part in the sediment budget for a stretch of coastline.

Research on large- and medium-scale coastal morphology has been carried out in the section for Coastal and River Engineering, focusing on the formation of spits and on longshore bars and rip channels (in Danish: krumodder, revler og hestehuller). The morphology of spits has been studied by a combination of mathematical models and laboratory experiments aiming at finding the mechanisms governing the dimensions and growth rate of a spit, and at determining the shape of a spit growing with constant form.

A growing spit is built up by deposition of sediment supplied by the littoral drift from the up-drift coastline. Sediment accumulates along the coast and the littoral drift decreases gradually to become zero at the tip of the spit. The variation in the littoral drift is due to the variation in the orientation of the coastline relative to the incoming waves. Practically no wave energy comes to the tip of the spit, because the waves are deflected by refraction at the up-drift part of the spit. The detailed distribution of wave energy along the spit determines the shape and the growth rate. The growth rate varies with the width of the spit and attains a maximum for a width of approximately 8-10 times the width of the breaker zone where the littoral transport takes place.

The plane shape of longshore bars has been studied by application and development of numerical models. Different descriptions of the processes forming the profile have been introduced, giving a very detailed representation of the dynamics of a bar on a shorter time scale and a more integrated long-term prediction of the bar geometry.

The work has been carried out in combination with several externally financed research programmes: "Intermediate Scale Coastal Behaviour: Measurement, Modelling and Prediction"
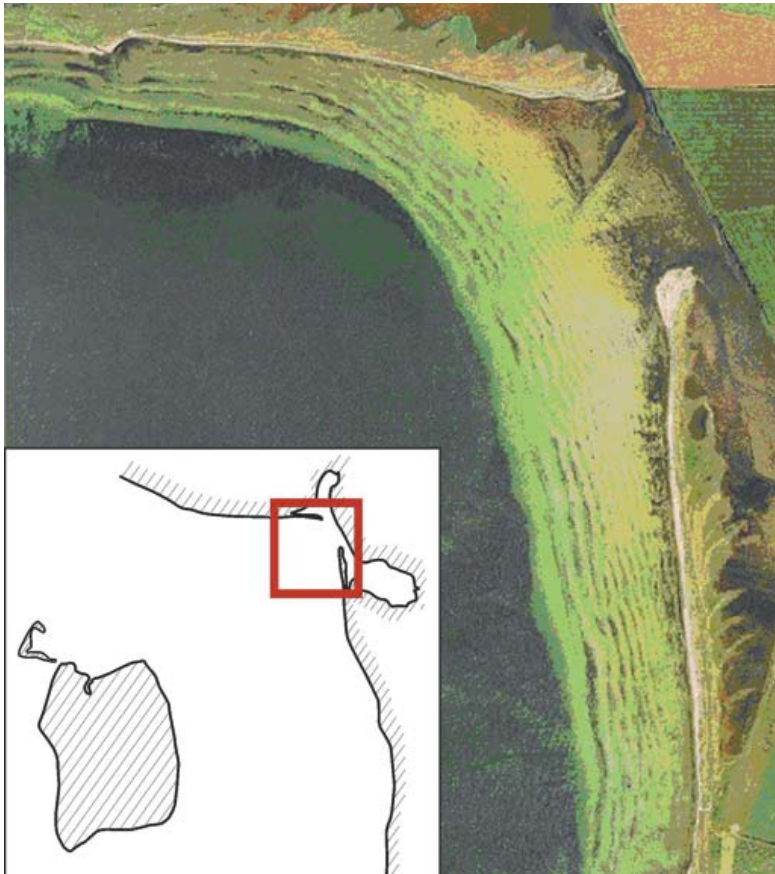
Two spits formed at Sdr. Aaby, Denmark. An island southwest of the site shelters for waves from this direction (insert), so the two spits are formed by waves coming predominantly from west and south respectively. Aerial photo from DDOland, with permission from COWI A/S.
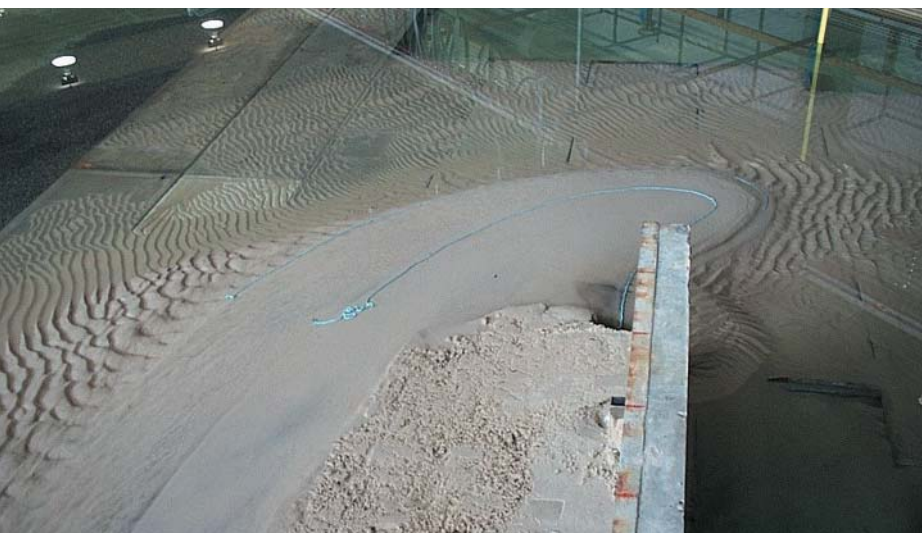
Spit formed in MEK's laboratory. The blue string indicates the water line. Note the oblique wave incidence, and the small wave ripples that are parallel with the fronts of the waves that have formed them.
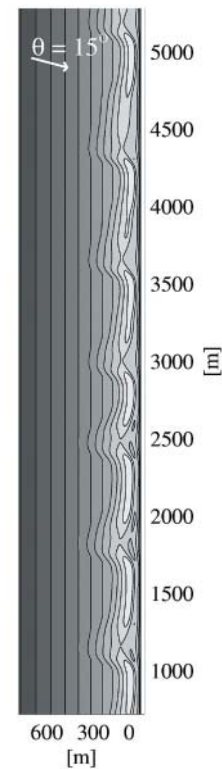
Contour map of modelled equilibrium bar configuration, wave approach angle: 150 from coast normal.

Mathematical/Numerical Modelling of Water Waves

Maritime Engineering

The motion of water waves plays an important role in coastal-, ocean- and maritime engineering, and for most geographical areas, waves are the major source of environmental actions on beaches or on man-made fixed or floating structures. Natural wave trains are irregular in shape and they interact due to non-linear processes. Classical wave theories fail to describe the combined effect of these processes and they can be divided in two categories: 1) A non-linear description of monochromatic waves of a specific frequency or wave length; B) A linear description of irregular waves based on superposition of individual frequency components with random phases. For the determination of natural wave trains both approaches have their obvious limitations.

At MEK we have derived a new formulation for water waves that includes the description of the dynamics and kinematics of irregular and non-linear waves propagating over an uneven bottom. The theory belongs to the so-called Boussinesq family but in contrast to conventional Boussinesq formulations, which are restricted to weakly non-linear shallow water phenomena, the new formulation

is applicable for fully non-linear waves in deep as well as in shallow water. Numerical models solving these equations in two-horizontal dimensions have been developed. In the following we highlight some of the phenomena that have been studied with the new model.

Wave loads on structures

As a first step towards the deterministic identification of wave loads, we have modelled the velocity and pressure variation in the highest possible wave in shallow water and in deep water. Results compare favourably to solitary wave and stream-function wave theories, respectively. Furthermore, velocity and pressure distributions have been determined in irregular wave trains shoaling up to the point of wave breaking, and results have been shown to be significantly better than conventional methods such as Wheeler-stretching. The new results have been used to establish design criteria for offshore windmill

foundations in shallow water. Recently, the model has also been extended to allow bottom-mounted structures in two horizontal dimensions. In this connection a highly non-linear run-up on a vertical plate has been computed and found to be in excellent agreement with experimental data (Figure 1).

Waves over a rapidly varying bathymetry

When surface waves propagate over a rapidly varying sea bed as e.g. sand dunes, ripples or trenches, they are exposed to resonant interaction which may lead to significant reflection (Figure 2). An example is the so-called Bragg-scatter from a sinusoidal sea bed involving an interaction between the surface (water) wave and the bottom (sand) wave, which is analogous to the mechanism of non-linear wave-wave interaction for surface waves. We have investigated and simulated the three established classes involving the interaction between: a) two surface waves and one
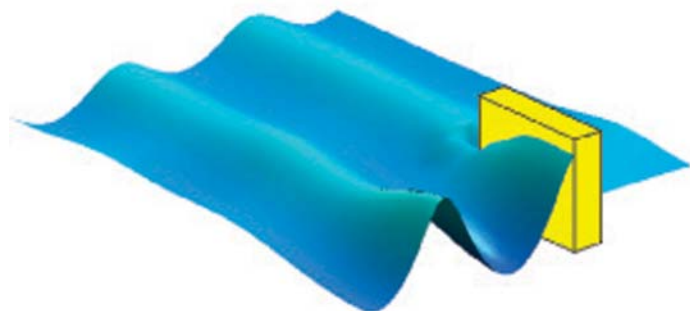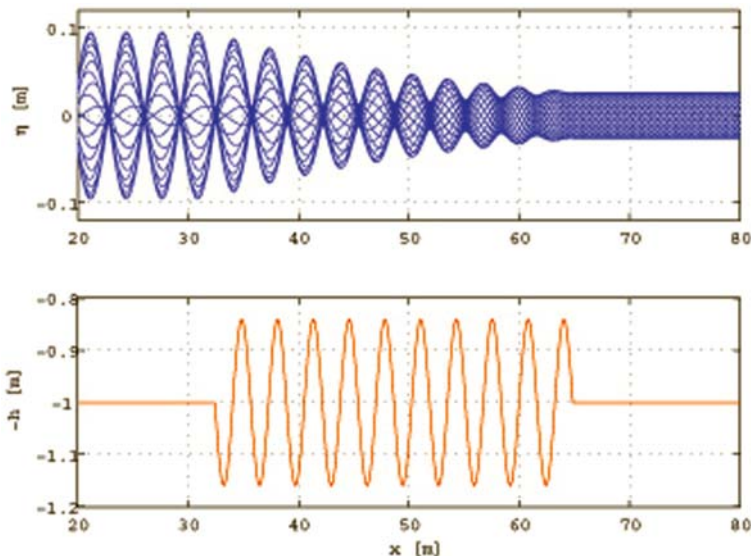

Figure 1.

Figure 2.
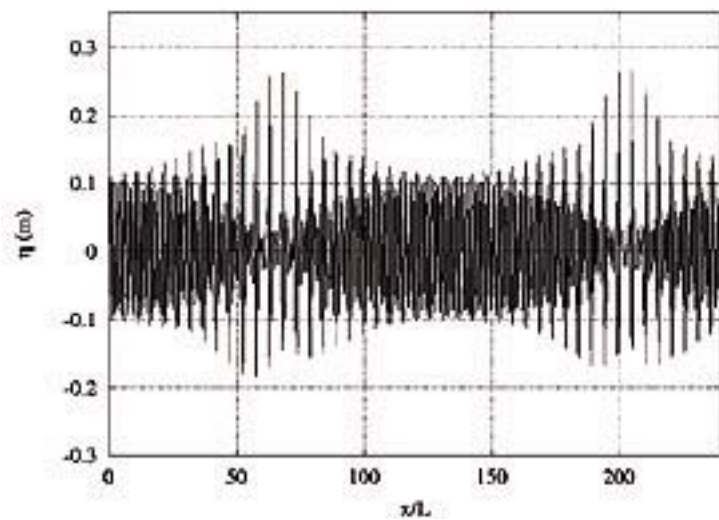
Figure 3.
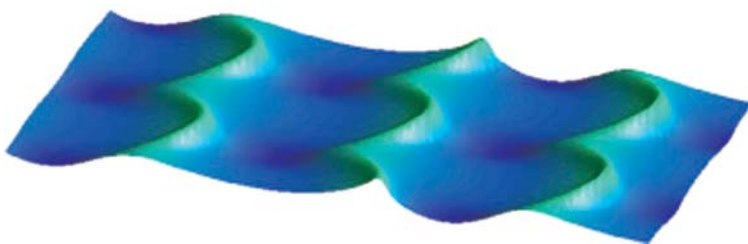
Figure 4.

bottom wave (Class I); b) two surface waves and two bottom waves (Class II); c) three surface waves and one bottom wave (Class III).

Instabilities of water waves

Non-linear waves travelling in deep water are exposed to different types of instabilities that may completely change their shape. A classic example is the two-dimensional Benjamin-Feir instability, which dominates for a wave steepness less than 0.1. During this process, energy is transferred from a carrier wave to two sideband frequencies and as a result we get a spatial focusing with a significant amplification of the wave height (see Figure 2). Another example is the three-dimensional McLean instability, which dominates for a wave steepness greater than 0.1. In this case we get systematic crescent or horseshoe patterns, which can frequently be observed on the sea surface or in tank experiments (see Figure 4).

ECOS 2003

Energy Engineering

One of the important MEK events in 2003 was the 16th ECOS conference. ECOS is the acronym for "Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems". The three-day conference in June/July was arranged by the Energy section at MEK in cooperation with the H.C. Ørsted Institute at the Copenhagen University (KU) and it attracted nearly 250 participants from all over the world. Primarily due to its situation close to the central part of Copenhagen with a wide range of hotels in all categories, KU was selected as the conference location.

The slogan chosen for this year's conference "Bridge to our Energy Future" is inspired by the fact that we live in a period of transition: a transition towards deregulated energy markets, towards renewable energy, towards distributed power generation, and towards a CO_2-neutral economy. This transition will occur over many years on a human time scale, but almost instantly on a geological time scale. Our natural resources are being consumed at a dizzying speed compared to the time required to accumulate the same resources. This worries many informed observers of both the industrial

and the developing worlds. Being here at this time in history and working in the field puts us in an enviable position of privilege and obligation to commit our efforts to the solution of these problems. It should also be mentioned that the choice of slogan of the conference has been inspired by the very extensive construction of bridges that has taken place in the Nordic countries in recent years.

The planning and preparations for the conference started in mid 2001 with fund-raising from industry and public sources. Having Professor Michael Moran as a visiting professor at DTU 6 months prior to the conference was invaluable. His favourite expression, the 6 P's, went something like: 'Prior Proper Preparations Prevent Poor Performance'!

From the 300 abstracts that were sent to the organizing committee, 200 papers were accepted for the proceedings and presentation at the conference. Review of the papers involved more than 100 persons worldwide, and all accepted papers were corrected based on comments from typically two or three reviewers. The day the proceedings came from the printer was a happy day – now there was something for

The persons involved!

Visit to the Avedøre Power Plant

all our guests, when they came to Copenhagen.

The conference was opened officially on a Monday with speeches from both our Rector, Lars Pallesen, and the Dean of Natural Sciences, KU, Henrik Jeppesen. The informal start was on the preceding Sunday, with activities such as a power plant visit (Avedøreværket) and a workshop (MATLAB). During the conference we had access at KU to four auditoria located around a central hall and a cafeteria, which was a perfect frame for the participants.

In retrospect: Is the spending of two man-years of work plus the spending of 1.3 mio. DKR for a three-day conference worthwhile? The answer is YES – definitely! It is very impor-

tant, however, to make sure that the financial risks are minimized and that the calendar is clear of all other possible time-consuming activities/events in order to avoid stress.

MAJOR RESEARCH ACTIVITIES

Research activities of the Energy Engineering Section

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The main research areas are analysis and optimization of thermal systems and components, including process integration and development. The focus is on utilization of biofuels, biomass gasification, engines (internal combustion and Stirling engines), emissions (engines, combustion and vehicles), fuels (alternative and conventional), refrigeration, power plants, district heating networks, energy storage and industrial process networks. Laboratory experiments, design and manufacture of pilot plants and field tests of existing systems are an important part of the research activities.

A general field of research is the development of mathematical models and analytical methods by means of numerical simulation, for the analysis of thermal systems and processes. Emphasis is placed on process optimization, energy efficiency, and automatic control.

Breakthrough for utilization of biofuels in small-scale CHP plants

An important activity in the Energy section is the utilization of biomass for Combined Heat and Power (CHP). Project activities include model-based control of plants for biomass, gasification of wood chips and other biofuels, and development of Stirling engines for small-scale CHP.

Gasification of biofuels

The Biomass Gasification Group (BGG) at MEK has built an automated thermal gasification power plant at DTU. The plant is fuelled entirely with CO_2-neutral biomass.

After 14 years of research, development and optimization, the newly commissioned Viking gasifier marks a breakthrough in thermal gasification. The plant is fuelled by wood chips and feeds its gas to a gas engine. As the only known gasification plant, condensate from the gas is clean enough to be accepted by standard biological sewage treatment plants. Dust and ash particles are collected by a bag filter and contain only traces of tar. Before the end of 2003 the complete plant had been in operation for more than 2000 hours in automatic mode.

Thermal gasification is a process whereby solid fuels are converted into a hydrogen-rich combustible gas that can be consumed by internal combustion engines, turbines, burners and possibly fuel cells. In this way, the corrosive ash content of the solid fuel is removed, allowing higher temperature conversion for heat and power production with a higher overall efficiency than would be possible by e.g. plain combustion of the biomass in a boiler.

The two-stage gasification process developed at MEK is unique in that it produces essentially no tar. Tar is formed during the initial heating of the fuel, converting it into char (pyrolysis). The toxic and sticky tar in the gas produced is a major challenge for most other gasification plants. With two-stage gasification, the process of pyrolysis and the process of gasifying the char have been separated in two reactors with an intermediate high temperature zone (>1100 °C) causing the tar molecules to disintegrate.

Stirling engines for biofuels

An efficient utilization of biomass for energy with a minimum of environmental impact can be obtained, if biomass is used for small-scale Com-

bined Heat and Power (CHP) production in smaller cities and villages close to biomass production sites, as well as in the wood processing industries. CHP plants based on Stirling engines have the potential to meet these demands.

Development in the Energy Engineering section is in front concerning Stirling engines for small-scale CHP using wood chips. A plant with a 4-cylinder Stirling engine and a nominal electric power output of 35 kW was put into operation in August 2002. At the end of 2003 the new Stirling engine had been running for nearly 7.000 hours with wood chips as fuel. In this period, the average availability of the pilot plant was more than 80%; in May and June 2003 it was even more than 92%. This result is a major breakthrough concerning Stirling engines for biomass and for small-scale bio-CHP in general.

Stirling engines are based on a closed cycle, where the working gas is alternately compressed in a cold cylinder volume and expanded in a hot cylinder volume. The heat input from the combustion of fuel is transferred from the outside to the working gas through a hot heat exchanger at a high temperature, typically between 950 K and 1050 K. The heat, which is not converted into work on the shaft, is rejected to the cooling water in a cold heat exchanger at 300 K - 350 K.

The development of the Stirling engine is based on detailed simulation of the cycle combined with numerical optimization of power and efficiency. The complex heat exchangers in the engine cycle must be optimized for heat transfer, frictional losses and internal volume, as all parameters have an impact on the overall performance.

The Stirling technology is now utilized as the basis for a new company that is funded in co-operation with DTU-Innovation.

Stirling engine ready for installation in a wood chips combustion system

Selected research topics

Simulation and process integration
Development of mathematical models and methods of analysis for energy systems and components using numerical simulation.

Internal combustion engines
Modification of fuels and engines to reduce their emissions. Application of new fuels with focus on utilization of dimethyl ether (DME) in diesel engines. Analysis of the influence of fuels and lubricants on emissions and wear. Energy consumption and emissions from transport. [3, 11, 39, 54, 68, 73, 74, 153, 244]

Stirling engines
Optimization of engine performance; component and process development, operation on natural gas and renewable fuels such as wood chips and biogas. [107, 232, 235, 236, 246, 247]

Gasification
Theoretical and experimental analysis of biomass gasification for use in small gas-engine-based cogeneration plants. [17, 31, 59, 105, 119, 158, 162, 207, 231, 234, 241]

Refrigeration
Indirect cooling and substitution of CFC and HCFC refrigerants with natural refrigerants. [4, 7, 52, 99, 183, 184, 185, 248]

Development of new or improved processes and process control for power plants by utilization of computational tools. Gas turbines and optimization of energy systems. [29, 97, 125, 142, 143, 211, 238, 249, 250, 252,253]

District heating

Field measurements of heat losses and operational optimization of distribution systems for district heating.

Research activities of the Solid Mechanics Section (FAM)

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Main research topics concern the mechanics of materials and the strength and dynamics of structural components and systems. In materials mechanics the work includes basic development of material models for inelasticity and damage, applications in the areas of fracture mechanics, delamination of thin surface layers and metal forming.

The structural mechanics areas include vibration analysis and advanced design using optimization methods. The design of multi-physics problems, based on the Finite Element Method and topology optimization, is a major activity.

Strange effects of strong mechanical high-frequency excitation

Theoretical and experimental studies on the changes that strong high-frequency excitation (HFE) may cause to the effective properties of mechanical systems, e.g. their equilibrium positions, natural frequencies, stability, stiffness, and friction properties. Three general HFE effects have been identified: Stiffening – an apparent chan-

ge in stiffness induced by HFE, Biasing – a tendency to move towards a state which does not exist or is unstable without HFE, and Smoothening – a tendency for discontinuities to be apparently smeared out by HFE. Examples include stabilization of unstable equilibriums of structures; a change of dry friction into apparent viscous damping; and transportation of objects (e.g. solid bodies or granular material; see figure). Convenient mathematical tools for studying such effects have been identified and used to predict and quantify them for a number of specific as well as quite general mathematical models of continuous and lumped mechanical structures. Topics under current investigation include the (mis)behaviour of feedback-controlled mechanical systems under HFE, and analytical methods for predicting average movements of rigid objects on the surface of vibrating structures, including consideration to impacts and friction. [12, 81, 80, 98, 103, 214]

Ductile fatigue crack mechanism

A basic mechanism for fatigue crack growth in ductile metals is the blunting-sharpening mechanism. Analyses of this mechanism have been based on highly simplified descriptions of deformations, e.g. in the form of two slip bands emana-
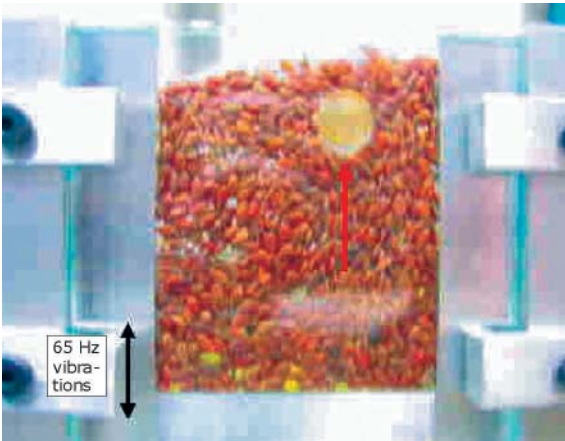
Example of a "strange" effect of HFE: in a few seconds the heavy brass disk travels from the bottom to the top of a container with much lighter linseeds, driven solely by 65 Hz vertical small- amplitude vibrations of the container.
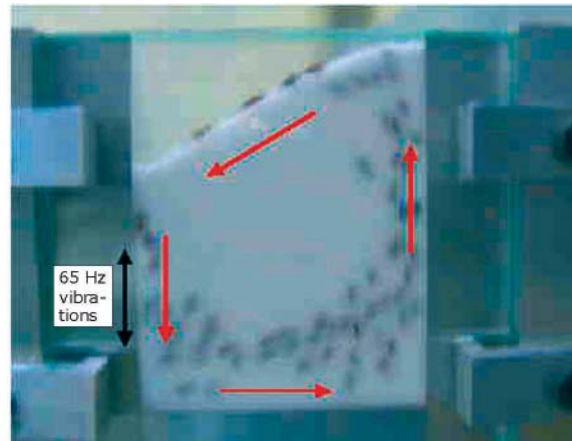
Starting with a salt-filled container with linseeds randomly distributed, imposed 65 Hz vertical vibrations of the container trigger a sloping salt surface, and the linseeds organize themselves into a stable structured motion counterclockwise along the container boundary.

ting from the current crack-tip. A detailed numerical solution of the blunting behaviour during the tension part of the cycle can be carried out by using finite strain plasticity. However, recent analyses have shown that mesh distortion develops so rapidly that the computation breaks down after a few loading cycles. Currently the problem is attacked by using remeshing techniques, which makes it possible to continue the computations during hundreds of cycles. These results show a transient behaviour during something like the first hundred cycles, developing towards crack closure in the unloading part of each cycle. These phenomena are studied for different values of the load ratio on the crack in a structural component.

PHONON-project: Topology optimization of bandgap structures

Bandgap structures are structures that inhibit wave propagation in certain frequency bands. Bandgap structures are potentially applicable in both mechanical and optical devices. Examples are photonic-crystal waveguides: possible building blocks of future optical circuits and processors and wave-reflecting structures: useful for noise insulation and vibration suppression. The research is focused on FEM-analysis and topology optimization of bandgap structures in order to improve the performance of such devices. Current research activities are:
1) Optimal design of a double 120-degree bend photonic-crystal wave guide with low transmission loss (fabricated and tested at COM/DTU).
2) Optimization of other pho-

tonic-crystal devices such as beam splitters and multi-plexers. [161]
3) Analysis and optimization of wave progagation and bandgaps for beam and plate structures. [38, 70, 160]
4) Optimization of eigenfrequencies in 2D structures.
5) Optimal design of acoustic devices. [205]
Link: www.topopt.dtu.dk/phonon

Powder metallurgy processes

Size effects in metal forming processes such as compaction of metal powder have been studied by use of a strain gradient plasticity theory, which has been generalized to also cover finite strains.

Micron Scale Plasticity

Strain gradient plasticity models are used to investigate size-effects in micron scale deformation of materials. Some

of the problems studied are necking of thin sheets, localization of deformation, and the effects of different higher order boundary conditions. [48, 49, 50, 181]

Analytical stiffness matrices with Green-Lagrange strain measure

Separating the dependence on material and stress/strain state from the dependence on initial geometry, we obtain analytical secant and tangent stiffness matrices for three node displacement triangles. [191]

Topology Optimization for incompressible flow problems

The topology optimization method is extended to include the design of non-linear flow problems and coupled fluid-structure problems. [204]

Optimization of acoustic sensitivity of fibre lasers

Design of packages for fiber lasers with enhanced or reduced acoustic responses. [155a]

Optimization of bi-refringence in Fiberoptic cables

Design of optical fibre cross-sections for maximum bi-refringence and pressure sensitivity.

Roller chain drive dynamics

Development of models of roller chain drives in order to analyse the dynamic behaviour of the system and the contact forces, especially in marine diesel engines. [191a]

Effect of anisotropic plasticity on fracture

Crack-tip blunting as well as failure by debonding from inclusions are analysed for different yield criteria and arbitrary orientations of anisotropic axes. [42, 170]

Application of advanced material models for metal-forming processes

For sheet drawing, crystal plasticity is used to analyse the macroscopic stress response and the surface roughness. [56, 57, 195]

Identification of material and friction parameters from deep drawing

A combined numerical and experimental method is used to estimate material and friction parameters from deep drawing experimental measurements. The combination of isotropic and kinematic hardening is assumed, and multiplicative decomposition of the deformation gradients is applied.

Research activities of the Maritime Engineering Section (MT)

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In general terms, the research topic of the Section is design, analysis and operation of large maritime and land-based structures under natural loads, such as waves and wind. The types of structure include ships, offshore structures, bridges, wind turbines and buildings. In connection with these structures, the main research themes are:

· *Hydrodynamics: Waves and currents and their interacion at re stricted water depths, wave loads on ships, flows and loads on ship propellers.*

· *Structures: Design and analysis of composite structures; damage tolerance of sandwich structures; dynamic elastic behaviour as well as non-linear behaviour due to crack propagation, buckling and material plasticity.*

· *Risk and reliability: Value-setting in technical decision problems and public risk acceptance criteria, risk evaluation of navigational equipment, consequence modelling, stochastic*

load and response modelling, risk- and reliability-based monitoring and inspection planning.

· Interaction: Evaluation of the performance of ships and large offshore structures subject to wind and wave loads involving not only elements of all three themes listed above, but also an under standing of the way in which they interact.
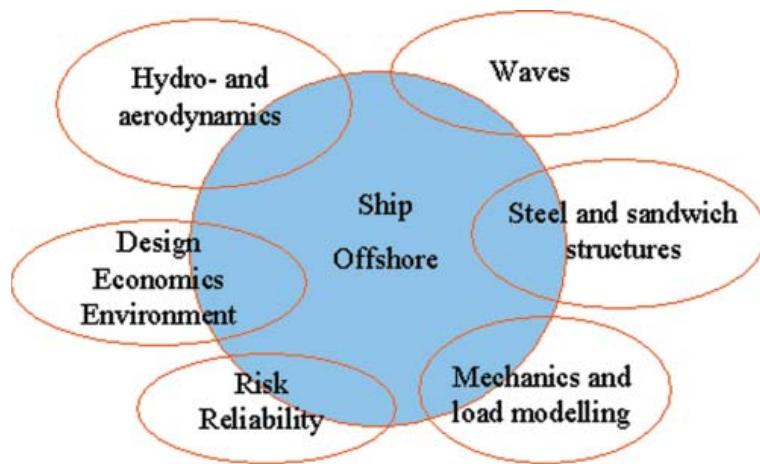
Crashworthiness

A new rational fracture criterion has been developed by the Department of Mechanical Engineering. This criterion was especially designed for analysis of the crashworthiness of ship structures and it was developed in cooperation with the classification societies Bureau Veritas and Germanischer Lloyd and with the Dutch research organization TNO under the EU project Crashcoaster.

The criterion has been applied by MEK to analyse the crashworthiness of two RoRo ships that are identical except for different side structures. One ship has a conventional side structure with a longitudinal bulkhead placed 3.35 m from the side plating. The other ship has an ice-strengthened side structure with a longitudinal bulkhead placed 1.75 m from the side plating. The main idea

is that the two structural layouts have the same energy-absorbing capability and therefore equal crashworthiness. The extra production cost of the ice-strengthened side structure will then be compensated for by a larger tank top area and therefore by the extra payload during the life cycle of the ship. In addition a more versatile vessel is obtained.
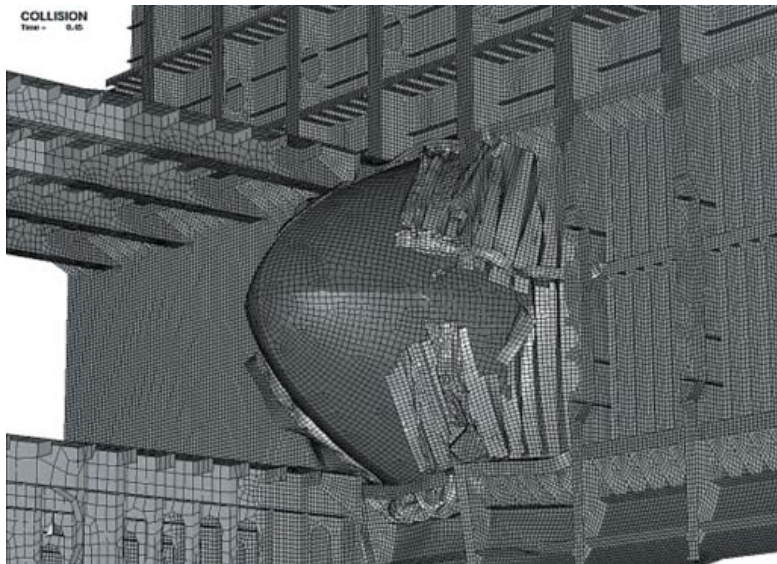
The final bow penetration of an ice-strengthened side structure of a RoRo vessel. A part of the main and longitudinal bulkhead is removed for illustrative proposes.

Numerical modelling of green water loads

Green water loads on moored or sailing ships occur when an incoming wave significantly exceeds the freeboard and water runs onto the deck. Excessive loads have resulted in severe damage on for instance floating production, storage and off-loading units (FPSO) and container ships. A numerical model (based on the Volume of Fluid method) has been developed and applied to study wave loads on a moored FPSO exposed to head sea waves. During a Ph.D. project two cases have been investigated: a fixed vessel in 2D and a moving vessel in 3D. Numerical results include the depth of water on deck and the resulting impact pressure on a deck-mounted structure. Very good agreement with experimental data has been found. The research has been supported by the Danish Technical Research Council (STVF) and the Danish National Research Foundation. [8]

Residual strength assessment of damaged FRP sandwich structures

Generally for shippin, as well as for other areas of the transport industry, the use of lightweight materials has been and will be steadily increasing. This is due to the persistent demand from both civilian and military operators of fast, light and profitable vessels.
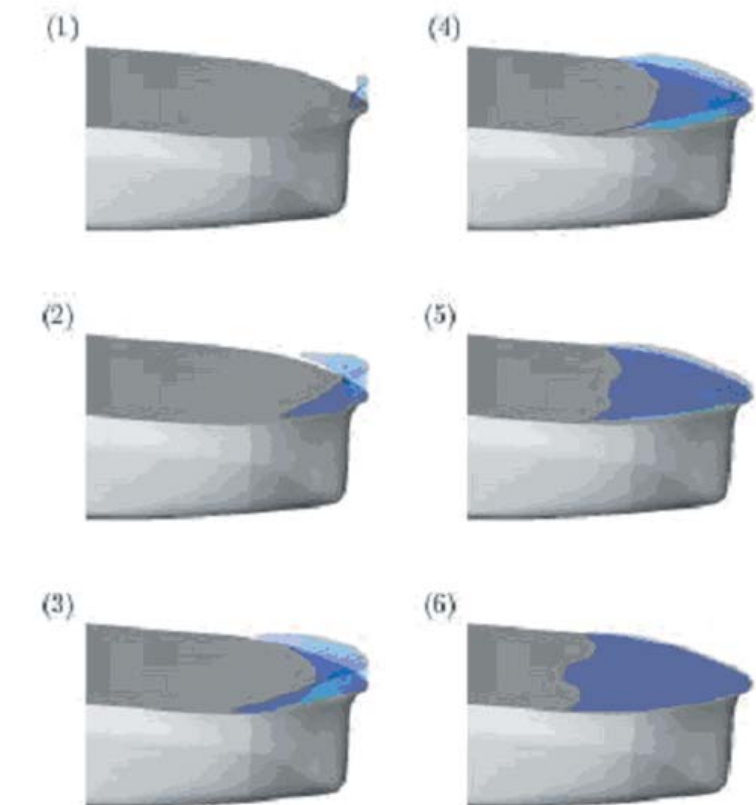
The basic knowledge and understanding of the structural behaviour of lightweight materials have not yet reached a level approaching that of conventional shipbuilding materials, such as steel and aluminium. Consequently, there is a strong need not only for validation and development of existing theories, but, especially in the area of damage tolerance, research into consequences, damage propagation and calculation of residual strength in composite sandwich structures with in-service damages and/or production flaws. Especially

the debond damage, where the glue interface between face and core is lost in a certain area of the panel, is of high interest.

Research at the Maritime Section is focused on developing a finite-element-based calculation tool able to predict the residual strength of debonded sandwich panels, taking into account crack propagation and using fracture mechanical routines. The finite-element tool has been developed in a 2D and 3D version and is verified through three large-

Left: A Standard Flex 300 of the FLYVEFISKEN class. Right: Bottom panel with circular debond, failed in pure compression and tested in the strength laboratory at DTU

scale test series carried out at the strength laboratory at DTU. The research is a part of THA-LES 3.23 Inspection and Repair of Naval Ships (saNDI), and the aim is to use the models developed at MEK to produce vessel-specific inspection manuals for the Nordic navies. [120, 121]

Onboard monitoring and decision support system for safe ship operation

The main objective of this project is to develop systems that can contribute towards a higher operational safety for ships. This is paramount for passenger transport but also for transportation of containers and other cargo. [148]

Estimation of ship motions using closed-form expressions

Closed-form expressions for the frequency response functions for the wave-induced motions of monohull ships are derived with a semi-analytical approach. With the expressions it is possible to make quick estimates in the conceptual design phase or in decision-support systems. [159]

Springing of monohull ships

The resonant 2-node hull vibration excited by an unsteady pressure field (denoted as springing) is influenced by the hull natural frequency and specific sea conditions. A second-order hydrodynamic theory, including the incident pressure field from the second-order bi-chromatic wave field, is developed. Non-linear cross coupling terms due to the interactions between directional wave systems are shown to amplify the high frequency springing response. [208]

Damping of structures

The calibration and efficiency of concentrated dampers on structures are being studied. A simple asymptotic formula has been obtained for damping of the vibration modes, predic-

ting the maximum attainable damping from the frequency increase that would result from locking the damper. A number of specific results have been obtained for damping of cables. [166, 47]

Design and analysis of propellers

High-efficiency ship propellers of the KAPPEL type are being investigated. This includes calculation of blade loads for structural assessment of the structural design. A technique similar to hydrodynamic analysis of propellers was also used for analysis of flows over planing boat hulls. [116, 90]

Numerical modelling of tidal bores with emphasis on the Hangzhou Bore

An implicit finite difference formulation of the non-linear shallow water equations has been developed to allow for the treatment of tidal bores and hydraulic jumps. This model has been applied in a case stu-

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dy of the tidal bore in Hangzhou Bay and Qiantang River. The model results are shown to be in very good agreement with field data.

Wave reflection in connection with ripples and trenches

A systematic study of Bragg scattering and reflection from trenches has been conducted. A Boussinesq formulation has been extended to rapidly varying bottom variations and wave transmission/reflection has been studied in connection with mega ripples, submerged bars and trenches. Analytical solutions have been derived and compared with model results.

Collision and grounding damage to ships

Modelling of the influence of equipment and navigators on collision and grounding frequencies, structural damage and their consequences. [71, 72, 58, 14, 100]

Stochastic response characteristics of ships and structures

Models have been developed for prediction of the characteristics of the response of ships and structures exposed to random loads, e.g. from wind and waves. [61, 62, 196, 89, 23, 24]

Monitoring of structures and ships

Update of stochastic load models, design models, operation procedures, and maintenance strategies by Bayesian updating using the simultaneous stochastic process signals. [150]

Formulation of acceptance criteria for oil spills

A rational criterion for public risk acceptance of the pollution of the environment has been formulated. This NRWI acceptance criterion has been applied to an oil spill sample. [33]

Research activities for the Coastal and River Engineering Section (VB)

Head of Section:
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Teaching and research on hydrodynamics comprise the interplay between nature and man's intervention, for example river regulation, coastal structures, the influence of large construction works on the environment, dispersion of effluent wastewater, hydrodynamic forces on structures and their response. The research is often aimed at gaining a better understanding of the physical processes (e.g. turbulence, suspension of sediment or wave breaking); it involves development and application of numerical models and experimental work in the basin and flumes of the 2500 m3 hydraulic laboratory. The research has been focused on subjects related to sediment transport and morphology and to structures.

Sediment transport and morphology of rivers and coasts
For coasts, the hydrodynamic studies deal with waves and turbulence in the surf zone,

wave-driven currents and exchange processes. Sediment transport under strongly transient conditions and the resulting morphological changes is studied experimentally and by modelling. Topics include the morphological development of longshore bars and of sandy spits and bed forms in the coastal area. The results of the research are used as the basis for improved engineering tools for the design and understanding of coastal protection structures, beach nourishment schemes, harbours and navigation channels.

For rivers, the morphology of bed forms is investigated by numerical modelling. The research also involves the effects of structures on the river morphology and study of the detailed three-dimensional flow and sediment transport pattern in straight and curved rivers.

Offshore and coastal structures The flow around slender structures in waves and currents, the hydrodynamic forces and the response of the structure are studied experimentally and with modelling. The local erosion around structures under different hydrodynamic conditions has been studied extensively in laboratory experiments and by use of numerical three-dimensional flow models developed in the Section of Fluid Dynamics. Scour protection in the form of loose stones has been investi-

gated to describe the conditions and risk of failure near the edge of the protection.

Selected research topics

The development of sandy spits
A theoretical and experimental investigation of the processes that govern the dimensions and shape of an accumulating sandy spit, including comparison with field data.

Sand waves in unidirectional and alternating current
A numerical investigation of the detailed flow and sediment transport field and the morphological development of sand waves in a unidirectional and an alternating tidal current with special emphasis on the amplification of wave height in a tidal environment.

Wave boundary layers and coherent structures
Wave boundary layers are central for several processes near the seabed such as turbulent mixing of mass and momentum; frictional dissipation; sediment transport; exchanges of chemicals and organisms between seabed and the main body of the water, etc. Wave boundary layers are studied both experimentally and theoretically. A major experimental project has recently

been launched in our oscillating water tunnel, to study coherent structures in a wave boundary layer. From the experiments, three kinds of coherent structure are identified: small-scale longitudinal streaks; transverse vortex tubes; and turbulent spots, the latter being of particular interest. These structures can be considered to be the building blocks of turbulent boundary layer processes. [25, 32]

Liquefaction of marine soils
Fine, granular marine soils (such as fine sand / silt) may be liquefied under the action of waves, thus precipitating failure of the supported structure. With the soil liquefied, buried pipelines may float/sink; offshore structures may settle; large individual blocks (such as those used for scour protection) may penetrate into the seabed; sea mines may enter into the seabed and eventually disappear. Liquefaction caused by waves is a major research area in our Section and will continue to receive emphasis in future years.

Stability of scour protection work
Rock dumping is one of the methods widely used for scour protection. When such a rock (armour) layer is exposed to flow, the sand underneath will be agitated by the flow turbulence. When the flow velocity exceeds a critical value, the

sand will be sucked from between the armour blocks. This is a threat for the stability of the armour layer. The suction removal of base sediment in scour protection works exposed to various flow conditions such as waves, combined waves and current and breaking waves is under study.

Morphology of longshore bars

Numerical modelling of the hydrodynamics, sediment transport and bed development to describe the evolution of a longshore breaker bar and the development of alongshore irregularities due to the presence of a river etc.

Projects

EU projects:

LIMAS: Liquefaction around marine structures

DELOS: Environmental Design of Low Crested Coastal Defence Structures

HUMOR: Human Interaction with Large Scale Coastal Morphological Evolution

Danish Technical Research Council:

Coasts and Tidal Channels

Computational Hydrodynamics

Research activities of the Fluid Mechanics Section (FM)

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Applied research topics focus on two main areas: aerodynamics of wind turbines and flow-related industrial process equipment. More fundamental research in fluid mechanics includes laminar-turbulent transition, aero-acoustics, rotating flows, room convection, and biological flows. In computational fluid mechanics (CFD) we use both in-house developed and commercial codes, and in experimental fluid mechanics

(EFD) we use mostly optical methods, such as Laser Doppler Anemometry (LDA), Particle Image Velocimetry (PIV) and related techniques.

CFD computations of flow and heat transfer around a seated human body

A database (http://www.ie.dtu.dk/manikin) containing a detailed representation of the surface geometry of a seated female human body was created from a surface scan of a thermal manikin (minus clothing and hair). The radiative heat transfer coefficient and the natural convection flow around the manikin were calculated using computational fluid dynamics. Results were compared to published data and to measurements by particle image velocimetry. The agreement was generally

Eksperimental work on a model of a climate chamber

good and variations across the manikin well predicted. The uniqueness of the present work is twofold: (1) the geometry of the computational manikin has all surface features of a human being; (2) the geometry is an exact copy of an experimental thermal manikin, enabling detailed comparisons between calculations and experiments. [76, 77, 78, 220, 229]

Computational aero-acoustics (CAA)

Noise has become an issue of increasing importance for environments. Current research is focused on aerodynamic noise generated from fan systems, pumps, wind turbines, etc. In order to predict broadband noise, a non-linear aero-acoustic model is being further developed on collocated grids. The model has been applied to gust problems to simulate turbulent flows subject to stochastic and time-dependent inflow. Furthermore, a general semi-empirical model is being developed for predicting noise from wind turbines. This model serves as a tool for designing wind turbines with low noise blades. [67, 202]

Simulation and control of vortex dynamics using proper orthogonal decomposition

A low-dimensional model is constructed and used for analysing bifurcations occurring in a swirling flow in the lid-driven cavity. The cavity is further equipped with a rotating rod that serves to control the flow. Proper Orthogonal Decomposition (POD) is utilized to extract a limited amount of data characterizing the flow. The modes resulting from the decomposition form a basis in the phase space on which a Galerkin projection of the equations of motion can be performed. By
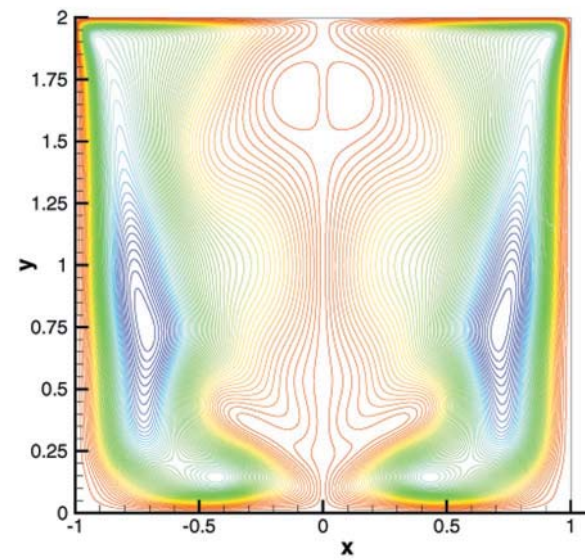
Vortex breakdown of swirl flow in cylindrical cavity

carrying out such a procedure one obtains a low-dimensional model consisting of a reduced set of Ordinary Differential Equations (ODEs) which models the original equations. The model is employed as a means to control the appearance of recirculating bubbles, usually referred to as vortex breakdown. [37, 40, 45]

Experimental fluid dynamics

Various fundamental flow cases are studied using optical measuring techniques, such as Laser Doppler Anemometry (LDA) and Particle Image Velocimetry (PIV). [9, 41, 152]

Jet in cross-flow

Detailed measurements of a jet in cross-flow have been reported. The data are being analysed for local flow structures using Proper Orthogonal Decomposition (POD). [93]
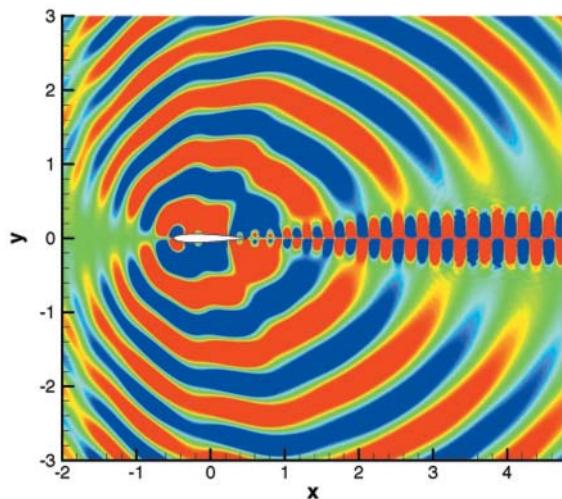
Pressure waves generated from airfoil

Electrostatic precipitator (ESP)

The ESP is the most efficient device for removing particles from large volume flows of flue gas from power plants, chemical works, etc. In the ESP, suspended particles become electrically charged from the Corona process and are drawn to grounded collector plates. In the project the combined flow and electrostatic problem is analysed both numerically and experimentally.

Database on wind characteristics

During 2003, the wind database has been enlarged with wind farm, SODAR and wind turbine response measurements. A meteorological measurement project has been initiated near Sisimiut, Greenland for recording wind resource data, which is also available through the wind database. [239, 240, 242, 243]

Nordtank measurements system at Risø

A 500 kW wind turbine located at Risø, Denmark has been instrumented for simultaneously measuring meteorological parameters, electrical power and structural loads (see www.vinddata.dk/nordtank/). The measurements are used primarily in the wind energy education programme and e.g. for validation of new computer codes.

Wind turbine aerodynamics

Various aspects of wind turbine aerodynamics are studied using state-of-the-art Navier-Stokes computations. [2, 3, 21, 22, 36, 88, 132, 156, 176, 194, 203, 210]

Biological flows

Solute coupled water transport in the small intestine is studied in a collaborative project with the August Krogh Institute. Ciliary sieving and pumping in the suspension-feeding of animals are studied in collaboration with the Marine Biological Research Center, University of Southern Denmark.

Artist's impression of flow structures around airfoil

Research activities for the Indoor Environment Section

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The Indoor Environment Section constitutes the core of the International Centre for Indoor Environment and Energy, established in 1998 on the basis of a 10-year contract between the Danish Technical Research Council and DTU. The Section's interdisciplinary research programme aims at developing design criteria and innovative technical solutions for the creation of healthy, comfortable and productive indoor environments that satisfy human requirements at low energy consumption. Many research projects involve exposure of human subjects to single or multiple indoor environment parameters and subsequent observation of the effect on their comfort, health and productivity.

Allergies and indoor environments

Allergies are increasing worldwide. The causes are not known, but changes in the quality of the indoor environment are among the main suspected causes. The Centre is addressing these issues in extensive ongoing epidemiological studies on the home environment and health effects among, especially, small children. The studies are conducted in Sweden and Bulgaria, in order to increase the study power by studying extremes. The studies are aimed at generating hypotheses on why people are becoming ill in buildings, with special emphasis on exposures due to "dampness", building materials, ventilation, pets and electronics. Significant findings that are extremely important for society have already been scientifically published (effects of pet-keeping and of ventilation), and more will appear during 2004. Findings are planned to be tested in carefully controlled human exposure studies in DTU's indoor environment chambers.
[20, 128, 129, 154]

Low indoor air humidity

In cold climates, outdoor air can hold very little moisture in wintertime, so indoor air humidities become low in the absence of artificial humidification. Humidification requires a great deal of extra energy and increases condensation on cold interior surfaces, for example where outdoor walls are imperfectly insulated or heated. This has been found in practice to increase mould growth and related health problems, but

there is a widespread belief, reflected in international standards and national building regulations, that dry air is harmful, and some countries have quite unreasonably high minimum indoor air humidities in their regulations (such as 40%RH). The Centre is developing new criteria for low indoor humidity in buildings, and also in aircraft cabins, where the outdoor air at cruising altitude is always in the region of -50ºC and thus extremely dry. Very little subjective discomfort seems to be caused by low humidity, even though objectively measured skin moisture and tear-film quality were both found to be reduced to less than about 20% RH, as expected. What was unexpected was that the performance of office work seems to be reduced at very low indoor humidity. The mechanism for this effect is being investigated. [144, 167]

Selected research topics

Indoor environments and human comfort, health and productivity

Buildings that make their occupants feel unwell are unacceptable. Extensive field and laboratory studies are ongoing to identify what makes buildings healthy. [227]

New strategies for individual control of the environment

People are different and have individual preferences regarding the indoor environment. Strategies and technical systems are developed to accommodate these differences through individual control of the microenvironment near a person. [131, 175, 200, 228]

Pollution sources in ventilation systems

We are rethinking how air shall be handled in tomorrow's buildings. This includes the role of HVAC components in air-handling systems, of ducts and of the air distribution system. [117, 178, 209]

New methods for air cleaning

The use of photo-catalytic air purifiers may decrease the requirements for outdoor air supply to a building. Extensive testing is ongoing.

Chemical transformations

Chemical transformations may significantly alter indoor air quality. Chemical reactions occur both in the air and on indoor surfaces, including the surfaces of air filters in HVAC systems. The research activities include human exposure studies to assess the importance of various chemical reactions. [60, 91, 92, 225]

Particles

The Centre is addressing important and neglected questions such as the role of indoor particles for perceived air quality, SBS symptoms and productivity; the design and operation of ventilation systems to limit unwanted exposure to airborne particles; and the indirect impact on occupants of particles deposited on surfaces or collected on filters [215, 221, 226]

Research activities of the Engineering Design Section

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The research activities of the Engineering Design Section (K&P) are carried out in five key areas:

> **Product Development**
> **Engineering Design**
> **Control Engineering**
> **Machine Elements**
> **Mechatronics**

Our research covers both the object of design (the product) as well as the process of design and development. Product areas are machines, mechatronics, and electro-mechanical products.

Research at K&P is very much synthesis-oriented, with emphasis on innovation throughout the engineering design and product development processes, making the utilization of laboratories and of the MEK central mechanical workshop essential. Furthermore, we collaborate extensively with trade and industry, testing research results in a professional industrial environment, and engaging staff from companies in educational activities for

our students. Target industries are major Danish companies such as Bang & Olufsen, Lego, Danfoss, Novo Nordisk, Oticon, and Nokia.

K&P is actively involved in the organization of a number of conferences and networking activities, including the international "Design Society" (organizers of the ICED conferences) and "Norddesign". K&P hosts the national "Konstruktionsdagen" (conference on Engineering Design), "Produktudviklingsdagen" (conference on Product Development), "Mekatronikdagen" (conference on Mechatronics) and "Seminar om Smøreteknik" (a two-day conference on lubrication) in cooperation with the Scandinavian company Statoil.

Selected research topics

Eco-design

The integration of an environmental strategy in every stage of the manufacturing organization, from top management to the details of the product development process, requires a detailed and coordinated effort. This research area focuses on both the analysis of the process and the actual integration of tools and techniques into the product development activity, in order to effect positive environmental change at the right stages of the product's developing profile. This area also

covers research into innovation in Product Service Systems.

Research into the development

and use of platforms and modularization as a means of multi-product development, i.e. product development with planned utilization of previous and forthcoming product variants (re-use and pre-use), as well as planned variety and commonality of product families. The research also covers applications of the Product Family Master Plan (PFMP) methodology.
Product variant master design Many manufacturing companies are expanding their product range by producing variants to suit individual customers.

The goal of this research is to identify a variant master or a template that can serve as the basis for designing customer-specific variants in a modem feature-based CAD system. The variant master consists of four elements: core models, variation models, rule models, and property models.

Autonomous agricultural machinery

The environmental impact of agricultural production is very much in focus, while the competition still demands high efficiency. Many years ago, weeding was done manually, without the use of pesticides. With the development of an autonomous agricultural vehicle with sensors for weed detection, it will again be possible to avoid the use of pesticides. The development of autonomous agricultural machinery explores this challenge through applying the mechatronics and robot expertise of K&P and collaborating partners to the problem.

Design languages

The application of information technology plays a crucial role in achieving the industrialization of engineering design. The goal of K&Ps research into design languages is to contri-

bute to the next generation of CAD systems, focusing on the improvement of synthesis and documentation. To be able to synthesize in interplay seems to require the existence of design languages that allow the designer to "spell" a design solution formally in such a way that properties can be derived from the design model.

Evaluation and decision in design

The development of a Designer's Workbench has shown the need to enlarge and refine the theoretical foundation in the area of evaluation and decision in design. The goal of the project is to create the theoretical basis for the development of computer tools within the Designer's Workbench concept, in order to support the engineering designer in decision-making.

Modelling and control of non-linear dynamics systems

Most mechanical systems are actually non-linear systems. However, the majority of currently available control techniques suffer from being mainly applicable to linear systems. This makes these methods sensitive to non-linearities. Of interest in this research are the problems involved in applying non-linear control techniques in non-linear mechanical systems. The non-linear control methods include feedback linearization, variable structure control, adaptive control and fuzzy control.

Synopsis

A network project focusing on the establishment of a framework for integrated innovation in product system and service development, funded for three years since 2002. It is carried out in collaboration with the Center for Industrial Production (CIP) at Aalborg University.

The research framework SPACES

K&P has formulated a research framework (handlingsplan) SPACES, jointly with the Department of Manufacturing Engineering and Management. The individual projects that will be launched under SPACES in the forthcoming year 2004 are: Management of design processes; Effectiveness in product development; Integration of industrial design and engineering design; Innovation in ECO design; Innovation strategies and development arenas; and Competencies, learning and knowledge in design. The goal of SPACES is to lead to a national centre for Innovation and Product Development to be established at DTU.

TEACHING PRO-GRAMME

Peder Klit

MEK studies

MEK offers teaching program-mes and courses at under-graduate, graduate and Ph.D. levels.

The teaching programme is quite comprehensive and co-vers coastal engineering, naval architecture, material and structural mechanics, indoor environment, energy systems, fluid mechanics, engineering design and product develop-ment.

DTU offers two separate tea-ching programmes in enginee-ring in parallel. One is the 3.5-year B.Eng. programme and the other is the 5-year M.Sc. programme. MEK is responsible for a considerable amount of the curriculum in mechanical and energy engineering as well as in design and innovation.

Teaching methods

A broad range of teaching met-hods is employed at MEK, i.e. lessons, classroom teaching, course work, project work and laboratory experiments.

A number of our courses utilize computer analysis, simulations and CAD/CAM-modelling. Using the newest computer-based tools is given high priority, partly to provide students with

the most updated knowledge and partly to make our candi-dates attractive to industry.

For B.Eng. students emphasis is placed on the use of com-mercial software, while master students are trained in the use of advanced development tools.

The new curriculum in Design and Innovation

In 2002 a new curriculum in Design and Innovation was established at DTU. The de-partments IPL and MEK are re-sponsible for most of the cour-ses in the new curriculum. The experience gained so far with the new programme is very po-sitive. Also in 2003 the number of applicants to the programme exceeded the number of pla-ces. DTU has attracted stu-dents who would have studied elsewhere if it were not for this new programme.

Evaluation of the teaching programme

All the courses are evaluated through DTU teaching intranet. The aim is to obtain input from which further improvements in the courses can be made to the mutual benefit of teachers and students. As part of the evaluation process, the head of department and the depart-ment study board examine the evaluation results to see where improvements are required.

Professor Peter Friis Hansen,

MEK, has developed a very ef-ficient computer program that presents the evaluation results graphically, giving a very good overview.

Pedagogic achievements – go-ing from teaching to learning

A new curriculum was introdu-ced for the B.Eng. programme in mechanical engineering. The curriculum structure and the pedagogic/didactic idea were developed with inspiration from the CDIO initiative, which originates from a cooperative project between the technical universities in Sweden and MIT. The project objective is to reshape the mechanical engineering curricula at the contributing universities. The basic concept is problem-based learning in a form called CDIO (conceive, design, implement, operate). DTU joined this pro-ject in 2002 and benefited from the project already in 2003 by utilizing the result in the new B.Eng. programme.

A further achievement in this new B.Eng. programme, wel-comed by many students, is the possibility of shaping the study to personal interests by combining optional courses in the last two semesters in the curriculum.

The new curriculum was de-veloped in close cooperation between the Department of Industrial Engineering (IPL) and MEK, and it is our hope

that this curriculum will be available for many years to come.

A new international master program

In 2003, MEK launched its second international master programme in Coastal and Maritime Engineering. MEK is internationally recognized for its research activities in these fields, making it an attractive opportunity for international students to study these subjects at DTU.

The other international master programme in Wind Engineering has recorded an increasing interest in the programme from international students. In 2003, 20 international students signed up for the programme.

Teaching efficiency

The teaching staff at MEK has been reduced during the last couple of years, mainly owing to retirements, and at the same time the number of students at the department has increased due to the above-mentioned new teaching programmes. This has given a significant increase in the earning of student credits per teaching staff member. It is appropriate here to praise the staff for this effort, because the teaching quality at the same time has been kept at the required high level.

Teaching staff flexibility

Because of the above-mentioned reduction in staff, the new programmes and the increased intake of students on our courses, many staff members has been challenged to take up new teaching activities. Again it is appropriate to praise the staff for its willingness to meet this challenge.

The DTU study administration

During the last couple of years, the study administration at DTU has introduced several new computer-based administrative tools that can be operated by the departmental administrative staff. This has improved both efficiency and quality of the administrative work at the department significantly and promoted cooperation and smooth running in the daily routine.

Basic

Applied Mechatronics
Dimensioning and Strength 1
Dynamics and Vibrations
Electrical Engineering
Electronic Design
Energy
Energy Systems
Engineering and Physiology
Engineering Design (Problem Solving)
Fundamentals of Engineering Thermodynamics
Introductory Computer Science
Mechanics
Mechatronics Engineering Design
Non-Linear Modelling and Analysis of Structures and Solids
Object-oriented Design and Programming
Principles of Naval Architecture and Offshore Engineering
Products and Documentation
Shape and Colour. Basic course in Product Design
Simulation of Energy Systems
Strength of Materials
Strength of Materials 2
Structural Materials, Mechanical Properties and Applications
Technology Analysis: Product, Company and Society
Thermodynamics, Fluid Mechanics and Basic Energy Technology
Yacht Performance - Theory and Practice

Intermediate

Advanced Fluid Mechanics
Applied Hydrodynamics for Civil Engineers
Applied Programming (Mechanical Engineering.)
Basic course in Fuel Cells
Basic Fluid Mechanics
CAD/CAM
Design of Energy Systems
Dimensioning and Strength 2
Dynamics
Dynamics of Machinery
Economic and Environmental Performance of Transport Systems
Energy Production and Air Pollution
Experimental Mechanics
FEM-Light (applied finite element modelling)
Heat Transfer
Heating, Cooling and Air Conditioning
Hydrodynamics - Minor project
Industrial Placement
Internal Combustion Engines and Transport

Loads and Global Response of Marine Structures
Machine Elements
Mechanical Engineering Design
Mechanical Vibrations
Mechanics and Materials
Meet the World of Technology
Motion Control
Power Plants
Product Design and Documentation
Product Development
Programming and Automation
Risk and Decision Analysis
Ship Design
Strength of Materials 3 (Fiber Laminates)
Structural Dynamics
Thermodynamic Modelling
Visualisation
Voluntary Trainee Service at a Steel Ship Yard
Wind Turbine Technology and Aerodynamics
Workspace Design

Advanced

Advanced Vibration and Stability Analysis
Computational Coastal Hydrodynamics
Computational Fluid Dynamics
Conceptualisation
Design and Analysis of Plated Structures
District Heating and Energy Systems
Eksperimental Fluid Dynamics and Data Interpretation
Experimental Methods in Fluid Mechanics
FEM-Heavy
Fluid Power - Hydraulic and Water Hydraulic Control
Fluvival and Marine Sediment Transport
Indoor Climate
Innovation in Product Development
Life Cycle Engineering
Linear and Nonlinear Wave Dynamics
Load and Response Analysis of Structures
Marine and Hydraulic Structures - Minor project
Marine Structures
Plasticity and Fracture Mechanics
Projects in Wind Turbine Aeroelasticity
Refrigeration
Robotics
Structural Reliability and Load Modelling
Theoretical Ship Hydrodynamics
Tribology of Machine Elements
Turbulence Theory
Ventilation and Climatic Systems

Arsen Melikov

P. Ole Fanger, *Gliwice*

Preben Terndrup Pedersen

Bjarne W. Olesen

Awards

Arsen Melikov: Fellow of American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Chicago, 25 January 2003

Arsen Melikov : Honorary Member of Bulgarian Society of Heating, Refrigerating and Air Conditioning (BULSHRAE), Sofia, 16 February 2003

P. Ole Fanger: Honorary Member of Bulgarian Society of Heating, Refrigerating and Air Conditioning (BULSHRAE), Sofia, 16 February 2003

P. Ole Fanger: Honorary Doctor, Silesian University of Technology, Gliwice, 11 April 2003

P. Ole Fanger: Honorary Professor of Tianjin University, China, Tianjin, 10 October 2003

P. Ole Fanger: Honorary Doctor, Technical University for Civil Engineering Bucharest, Bucharest, 16 December 2003

P. Terndrup Pedersen: Appointed member of The Norwegian Scientific Academy.

P. Terndrup Pedersen: Awarded Donald Julius Groen Prize by The Institution of Mechanical Engineers in UK

Bjarne W. Olesen: Awarded the Medal of Honour from the German Engineering Society (VDI-TGA), Düsseldorf, 10 October 2004

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