DTU

Technical University of Denmark

Department of Mechanical Engineering

Annual Report 2001

Department of Mechanical Engineering

MEK

Department of Mechanical Engineering
Technical University of Denmark

ANNUAL REPORT 2002

We take pleasure in presenting you with this copy of the 2002 Annual Report of the Department of Mechanical Engineering (MEK) at the Technical University of Denmark (DTU).

Best regards

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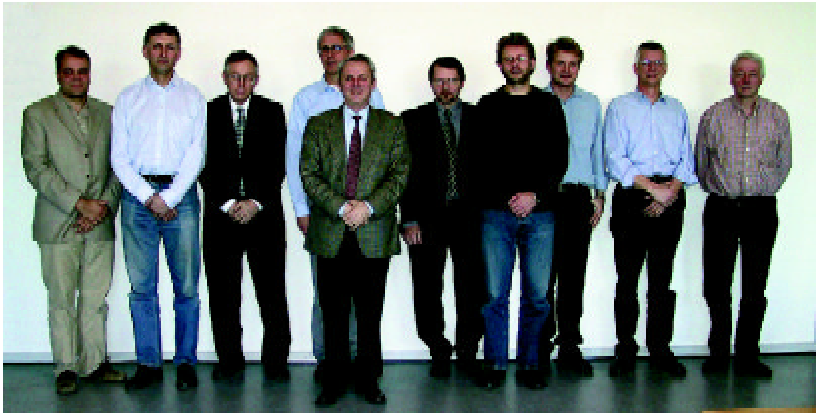
PREFACE

A high level of activity in the Department of Mechanical Engineering (MEK) characterized the year 2002, in particular by a strengthening of the educational side of our activities. In 2002 a new performance contract was negotiated with the Technical University of Denmark (DTU) for the period 2002 to 2004. This contract specifies goals for teaching, research and innovation.

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 MEK Leader Group. From left to right: Geo Clausen, Henrik Carlsen, Lars Hein, Viggo Tvergaard, Preben Terndrup Pedersen, Ib Misfeldt, Jens Nørkær Sørensen, Bo Cerup Simonsen, Peder Klit, and Jørgen Fredsøe.

As part of the ongoing development of the education and training given to future students at DTU, MEK has, together with the Department of Manufacturing Engineering and Management, been active in creating a new 5-year programme leading to a Master degree in engineering with special focus on Design and Innovation. This education is centred on MEK's strong research group within product development. We believe that product development and innovation is going to be centrally placed in future commercial competition and that our future candidates within this area will have a key role to play in the leading companies. The main focus of this programme is on activities relating to technical innovations. The students will gain an understanding of the basic requirements for establishing a business and ways to compete, based upon innovation. They will acquire skills related to the most important factors that influence the goals of: costs, quality, environment and lead-time and the education and training will focus on the creation of innovative technical solutions. To maintain the growth in the wind turbine industry that has taken place during the last 10-15 years, the industry and research institutions require an increasing number of engineers. Denmark is a leader in research, design, construction and manufacturing of wind turbines, holding 50% of the world market. Wind-generated electricity contributed more than 13% of the Danish electric energy consumption in 2000. It is on this background that MEK has established an M.Sc. programme in Wind Energy. The aim of this teaching programme is to educate highly qualified students and

combine topics from traditional civil, mechanical and electrical engineering. The Wind Energy teaching programme focuses on skills that qualify graduates for employment in the rapidly growing international wind energy sector, e.g. wind turbine manufacturers, utilities and research institutions.

In December a poster competition was organized for Ph.D. students at MEK. In total, 40 Ph.D. students participated. The jury consisted of CEO Peter Suun Petersen, MAN B&W; CEO Klaus Ostenfeldt, COWI; and Rector Lars Pallesen. The picture shows the Rector awarding the first prize, a travel grant, to René Hardam Christensen.

The research activities within MEK include the following core areas:

Solid Mechanics
Fluid Mechanics
Energy Engineering
Engineering Design
Maritime Engineering
Indoor Climate
Coastal and River Engineering

Selected activities within these research areas are mentioned in this annual report. Research at the Department is to a large extent financed by external funding. In 2002, 36% of the Department's activities were financed through national and international research contracts, contracts with national agencies, as well as with industrial companies. However, the national funding of energy-related research within the energy sector has seen a reduction during the report year due to the decision of the Danish Government to reduce national energy research programmes.

Preben Terndrup Pedersen
Head of Department

FEATURE ARTICLES

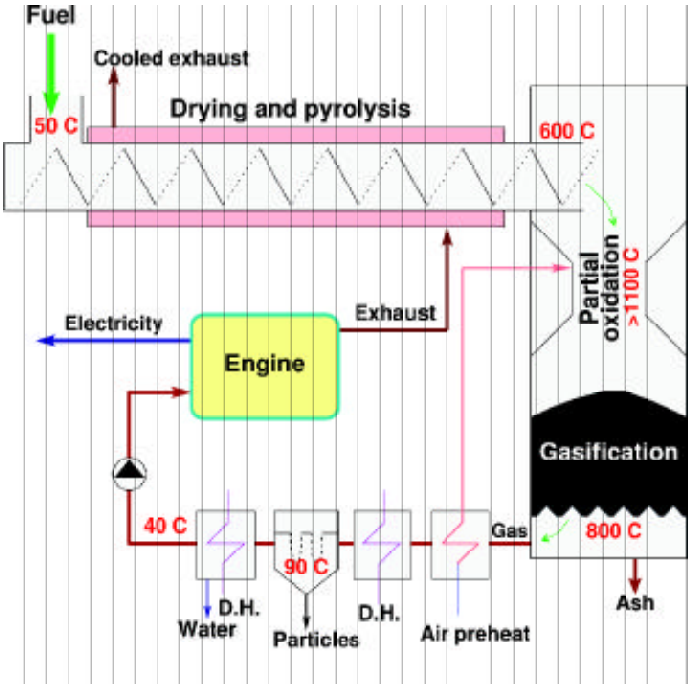
The Viking Two-Stage Gasifier

Energy Engineering

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.

Thermal gasification is a process whereby solid fuels are converted into a hydrogen-rich combustible gas that can be consumed by internal combustion gas 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.



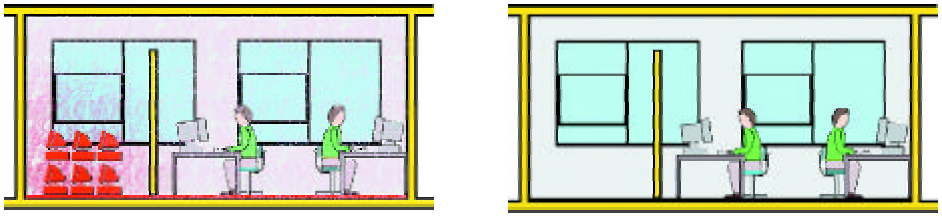
After 14 years of research, development and optimization, the newly commissioned Viking gasifier marks a breakthrough in thermal gasification. The plant is running automatically, fuelled by wood chips and feeding its gas to a gas engine. As the only known gasification plant, condensate from the gas is 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. Commissioned in August, the plant has been in power production for 780 hours during autumn 2002.

Personal Computers Pollute Indoor Air

Indoor Environment

The use of personal computers (PCs) in the indoor environment has increased dramatically in recent decades. The office environment and work habits have subsequently undergone great changes, leading to a substantial amount of time spent in front of a PC. At the same time, the number of complaints concerning headache, fatigue, etc. among individuals working with PCs has increased. Light, static electric fields and electromagnetic radiation emitted from the PC have been suspected of causing the complaints, but research to date has provided no conclusive support for these hypotheses. New research results from the International Centre for Indoor Environment and Energy show that the reason for the complaints among PC users can be air pollutants emitted by 3-month old PCs.

In these studies, human subjects were exposed to air polluted by chemical emissions from PCs that had been in use for 3 months. They performed typical office work using old low-polluting PCs so that their productivity could be measured, and assessed air quality and their health-related symptoms. The studies were blind, i.e. the subjects did not know to what they were being exposed. PCs consisted of a mini tower and a cathode-ray-tube (CRT) monitor.

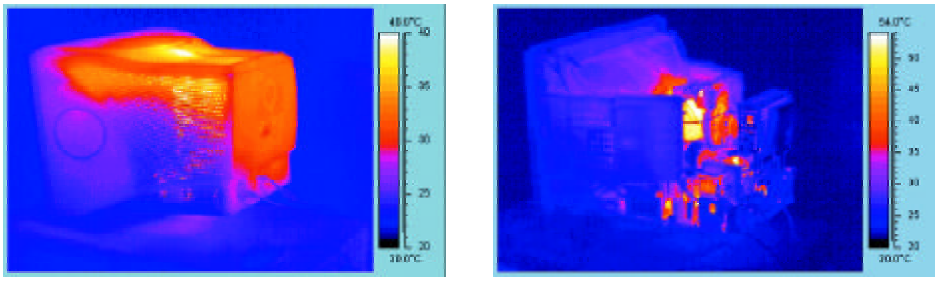


Experimental set-up with six 3-month old polluting PCs present or absent

The results showed that indoor air quality is significantly reduced in the presence of polluting PCs, that subjects worked nearly 10% less efficiently when polluting PCs were present in the office, and experienced more health-related symptoms, compared with the condition in the office when the polluting PCs were removed.

A large number of chemicals were emitted from PCs, and, although individually their concentrations were low, collectively they were enough to bother people. The main source of pollution is probably electronic components, especially those placed on the CRT monitor, as they operate at elevated temperatures which are the driving force promoting release of odorous compounds, plastic additives and flame-retardants.

The present results indicate that PCs may be an important, but hitherto overlooked, source of air pollution indoors, negatively affecting comfort and productivity of office workers. Although decreasing with time, the pollution emitted by PCs is still significant after one year, which is around 1/3 of the life expectancy of an average PC.



Thermographic view of a CRT monitor and its inner electronic parts

The results imply that ventilation in spaces with PCs, for example office buildings, call centres, internet cafes, data processing facilities and even some private homes, needs to be increased in order to handle the air pollution from the present stock of more than half a billion PCs worldwide. To lighten this pollution burden, future PCs should be reconstructed to minimize the emission of air pollutants. Local exhaust, cleaning of air or personalized ventilation can also be used to reduce the concentration of pollutants emitted by PCs.

New studies have already been undertaken to further evaluate and understand the impact of air pollution produced by PCs and other electronic equipment prevalent indoors on human health, comfort and productivity. In one of them, emission rates were measured from several popular brands of PCs, including CRT monitors and thin-film transistor (TFT) flat monitors, as well as TV sets. The results support the findings for PCs with CRT monitors and show that their emissions are much higher than emissions of air pollutants from PCs with TFT monitors and TV sets.

KAPPEL Propeller

Maritime Engineering

Shipping is the dominant form of transportation, carrying approximately 80% of world trade. This is because, despite air, road and rail, most of the long distance and a great deal of the short distance transportation is made by ships. This includes all kinds of goods, from highly industrial products, meat, and fruit to grain, ore, and oil.

Safe and efficient ships and sea transportation are essential for the modern world. These topics are dealt with in the Section of Maritime Engineering at the Department of Mechanical Engineering. One of the topics is propulsion of ships, in particular propellers. The propeller must transfer the power generated by the ship's engine into power to propel the ship with as little loss as possible. Worldwide, the total power installed in ships is approximately 6,800,000 kW and the annual fuel consumption is more than 7,000,000 tonnes. Even a relatively small increase in efficiency will mean a large saving in oil, accompanied by a similar reduction in the emission of exhaust gases.

The KAPPEL propeller is a new, innovative propulsor with higher efficiency than a conventional state-of-the-art propeller. Whereas traditional ship propellers have blades modelled on the basis of helical surfaces, the KAPPEL propeller has modified blade tips smoothly curved to the suction side of the blade. There is a parallel development within aircraft design where many modern aircraft, from high-performance jet liners to sophisticated gliders, have similar modifications of the wing tips in the form of winglets. These are separate lifting surfaces attached more or less perpendicular to the wings on the wing tips. Numerical methods, as well as experiments, show that the effect of winglets is to increase the lift-drag ratio of the wing.

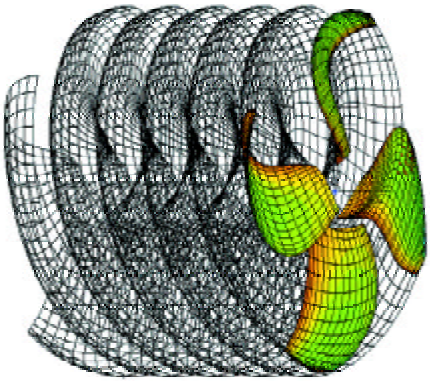
Aircraft have relatively well-defined design conditions such as climb, cruise and descent. The flow to the propeller is more complicated since the propeller works in the flow abaft the ship hull. This is in particular the case for single screw ships. At each revolution a section of a propeller blade will experience a highly varying inflow. This means that the pressure on the hull varies in time, giving rise to noise and vibrations in the ship. The pressure variation is exacerbated by cavitation, a phenomenon that occurs when the suction of the propeller locally evaporates the water.

One of the challenges of the KAPPEL propeller design was the optimization of the propeller with respect to efficiency. When modifying the geometry of the blade tip, relative to a conventional propeller, it was of paramount importance that the beneficial effects of the modified blade loading were annulled by the detrimental influence of friction on the relatively larger blade area in the tip region. This optimization was made on the basis of numerical fluid dynamics by which the flow field around the propeller was computed and hence the performance of the propeller. The calculations were complemented with model experiments. Further model tests were necessary to examine the interaction between ship hull and propeller, in particular the extent and time history of cavitation and the pressure field on the ship hull. On the basis of a vast number of calculations and comprehensive model testing, a design was developed for a 35.000 dwt product carrier.

A full-scale KAPPEL propeller for this ship was manufactured. It was tested at sea immediately after tests with the conventional propeller originally designed for the ship. Both sea trials took place in April, off the coast of Portugal, in good weather and under comparable conditions. The results confirmed the model test predictions that the improvement in efficiency of 4 per cent aimed at was

achieved. Furthermore, the pressure pulse level was slightly lower with the KAPPEL propeller than with the state-of-the-art comparator propeller.

KAPPEL propeller behind the 35000 tdw product carrier M/T Nordamerika of Dampskibsselskabet Norden, A/S



Numerical boundary element model of KAPPEL propeller.

The project was partly sponsored by EU and included: J.J. Kappel Marine Concept, Danish Maritime Institute, Department of Mechanical Engineering DTU, Stone Manganese Marine, Hamburgische Schiffbau-Versuchsanstalt Gmbh and Dampskibsselskabet Norden A/S. DTU was responsible for the theory and software of the design and optimization of the KAPPEL propeller.

Soil Liquefaction

Soft marine soils under high waves may undergo a process whereby the soil grains become completely free, and the water-sediment mixture, as a whole, acts as a fluid. This process is called liquefaction.

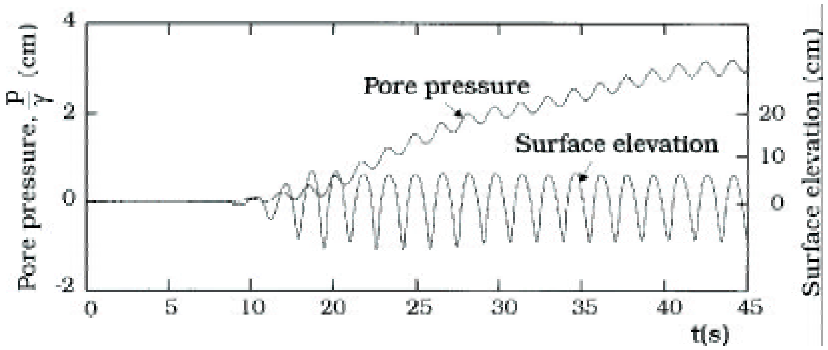
Under this condition, the soil (fine sand, silt) fails, thus precipitating failure of the structure. With the soil partially/completely liquefied, buried light pipelines may float to the surface of the seabed; heavier pipelines laid on the seabed may sink in the soil; offshore structures may settle; 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.

The key question here is: given the soil and given the waves, will there be any liquefaction potential/ risk for the soil supporting the marine structure, e.g. a pipeline, a gravity structure, a breakwater, a pier, a pile, or a scour protection structure? This question has stimulated research in the area of marine civil engineering over the past two decades.

Marine soil liquefaction is one of the areas covered by the Coastal and River Engineering Section in MEK. The following is a list of the topics studied under this theme:

- Sinking/flotation of pipelines and other objects in liquefied soil under waves.
- Liquefaction around a buried pipeline under waves.
- Influence of liquefaction (in partially/fully liquefied soil) on scour, another failure mode of structures.
- Liquefaction of soil under the rocking motion of a breakwater.
- Liquefaction of soil and resulting scour under the rocking motion of piles
- Numerical modelling of wave-induced liquefaction

The Section has also coordinated an EU research programme on this topic, namely Liquefaction Around Marine Structures (LIMAS), under the EU Framework Programme 5. The programme covers the period 2001-2004, and is undertaken by a consortium consisting of ten members, from academia and industry, from seven different European countries. The specific objectives of the programme are (1) to investigate the potential risks of failure of marine structures due to liquefaction; and (2) to prepare and disseminate practical guidelines, to be formulated from the present research programme, taking into consideration all state-of-the-art knowledge. Although the majority of the projects in LIMAS deal with wave-induced liquefaction, one project focuses on earthquake-induced liquefaction and its impact on coastal structures, with special reference to the 1999 Turkey earthquake. The following web address can be consulted for further information about the programme:
http://www.isva.dtu.dk/limas/limas.html



Pore-water pressure and surface elevation in a progressive wave in the laboratory in a water body.

Settlement caused by liquefaction at the Izmit Public Marina. Taken from Earthquake Spectra, 1999 Kocaeli, Turkey Earthquake Reconnaissance Report

New M. Sc. Programme on “Design & Innovation”

Engineering Design

In September 2002, DTU opened its doors to 60 eager students in the new M.Sc. programme “Design & Innovation”. Prior to this, a task force of ten colleagues from MEK and IPL had worked intensively for over a year to prepare this new education. Its scope is to further innovation and progress in the development of products, systems and services in industry and in society in general. The new education is intended to address the challenges of dynamic changes and new patterns of interaction, and to fill the need for innovative products and solutions, balancing a synthesis of technical and social aspects.

“Design & Innovation” is in itself an innovative addition to DTU’s educational profile, and should enhance our ability to attract more students. It is therefore interesting to look into the background and the motives of the new prospective students, and to learn whether a new group not hitherto attracted by the ordinary DTU education portfolio, even if fully qualified, has in fact been identified. A survey conducted by the Centre for Engineering Educational Development (CDM) at DTU shows that 70% of the students in “Design & Innovation” would not have selected to study at DTU had the new education not been available to them.

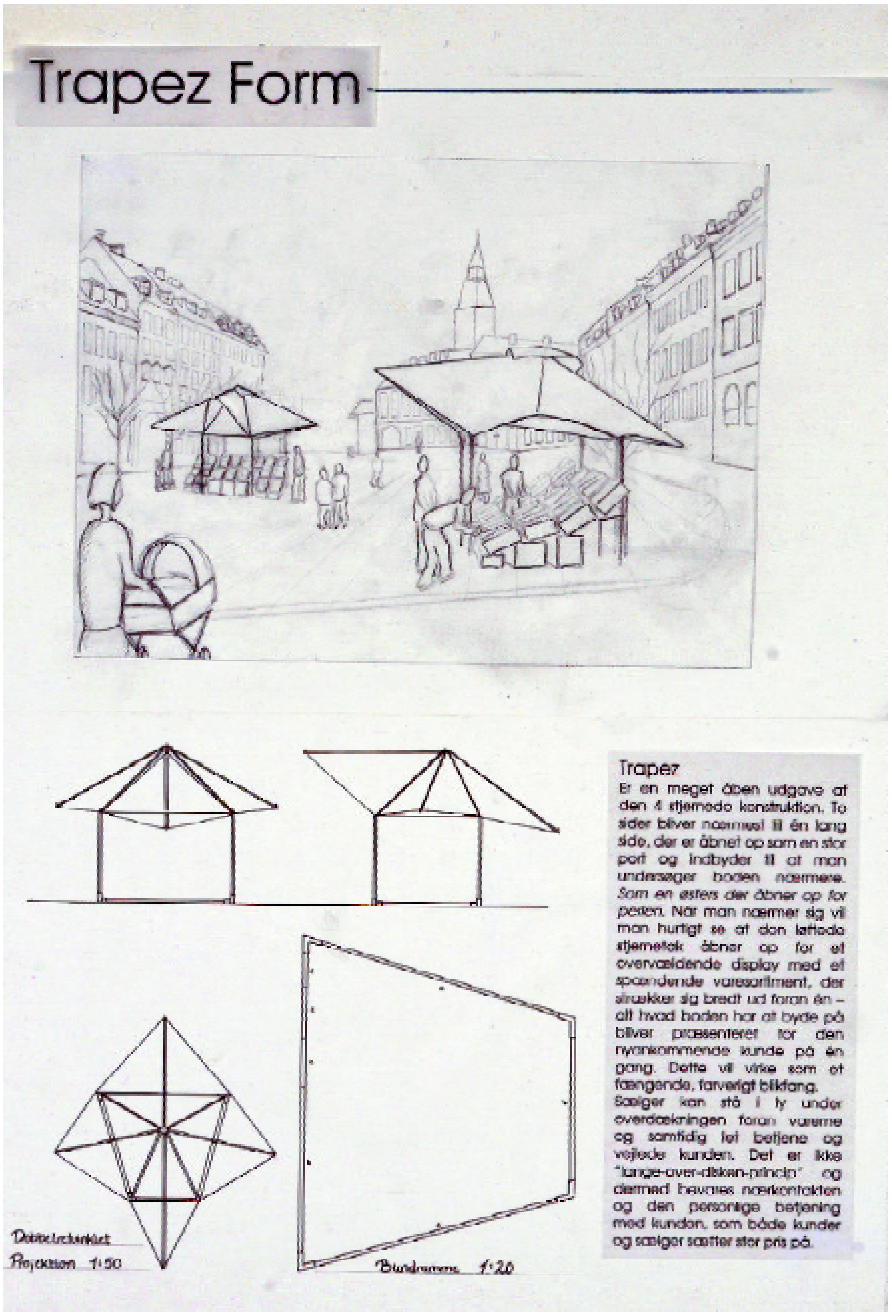
The new education is project-oriented and its aim is to develop the students’ creativity and ability to synthesize, through a confrontation with complex project tasks. The projects require engagement, professional insight, knowledge of methods, and good cooperation skills. Projects and cross-disciplinary learning is a unifying concept throughout the Design & Innovation education.

Throughout the year, a great effort has been invested in developing and practising the key feature of disciplinary integration, whereby the disciplines of basic engineering science are integrated into the more practice-oriented disciplines, in combination with constructive and motivating project work. Furthermore, care has been taken to monitor the extent to which the education matches the expectations of the students. Generally speaking, expectations have been met and even surpassed up till now, but of course certain challenges have arisen in implementation. Throughout our start-up period the new students, who have created a fine social network, have enthusiastically provided constructive criticism.

Many colleagues from MEK have participated in the conceptualization and coordination of Design & Innovation, to the benefit of both the students and the central group, the “design initiators”. It seems as if both students and staff are still very enthusiastic, and ready to continue developing the new programme. It is a good indicator that until now no students have left the group: all 60 students who set out in September 2002 completed the first semester successfully, and are now under way with the challenges of the spring semester. The group “design initiators” is currently finalizing the plan for the 3rd year, and for the concluding two M.Sc. years of Design & Innovation, and also finalizing the agenda for the supplementary research programme.

The illustrations in this text are taken from Design & Innovation’s first semester project work. The students were set the task of designing and building a scale prototype of a covered shelter for outdoor market salespeople in Copenhagen. These designs were based upon a detailed analysis of the social and technical needs of the users and the project is designed to combine the students’

newly learned skills in technical/perspective drawing, mechanics, materials selection and workshop techniques for model-making.



MAJOR RESEARCH ACTIVITIES

Research activities of the Energy Engineering Section

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Research

The main research topics are design, analysis and optimization of thermal systems, including power plants, refrigeration, district heating networks, engines (internal combustion and Stirling engines), emissions (engines, combustion and vehicles), fuels (alternative and conventional); biomass gasification plants, 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 being placed on process optimization, energy efficiency, and automatic control.

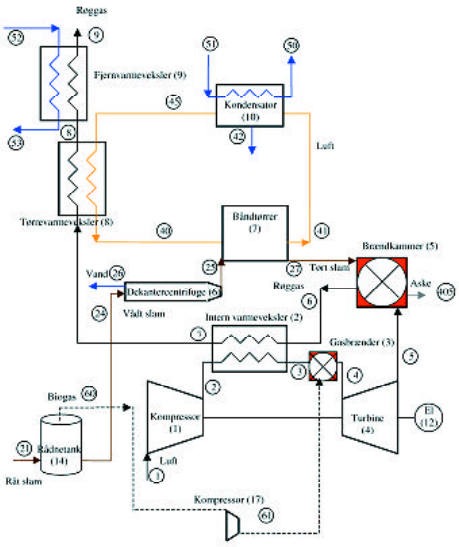
Gas turbines fired indirectly with biomass

The use of solid fuels for gas turbines has always been an interesting, but difficult, option. This combination will make it possible to use cheap fuels and still benefit from the advantages of gas turbines, i.e. high efficiency, low maintenance costs, and compact design. With the recent commercialization of microturbines, the scalability of gas turbines has been shown to be an added important advantage.

Conventional gas turbines require clean, fluid fuels for internal combustion. Therefore, gasification is currently the leading technology in the use of solid fuels such as coal or biomass, in gas turbines. However, these systems are quite complex and the gas produced requires a high level of cleaning.

In the present project, another technology, using indirect firing of a gas turbine (IFGT), has been studied, making use of high-level simulation tools. Plants

based on this technology have been operating on coal, mainly in Germany, during the period 1950-1980. However, due to low efficiency, the technology is not very interesting at present. An important result of the study is that an IFGT will be attractive for the treatment of wastewater, in respect of both energy and

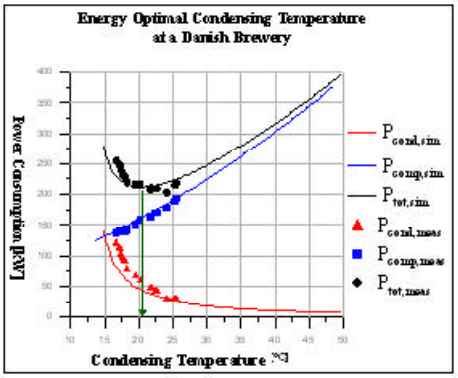


economy. An IFGT will convert the whole fuel into power and flue gas with similar efficiency to that of current technology. This differs from other technologies that do not convert the main part of the fuel, i.e., the water, and thus involve extra costs on transportation.

The research has been financed by the Danish Energy Agency, the Nordic Energy Research Programme, as well as the Process Integration Committee.

Energy-optimal capacity control and supervision of refrigeration systems

Through a project financed primarily by the Danish Energy Agency, a method has been established for operating intelligently with floating set-points in an integrated capacity control scheme of refrigeration systems.
The overall control problem (minimizing the total power consumption of active components, given temperature and cooling load) is translated into how to calculate so-called "energy-optimal secondary set-points". In practical terms, it is a matter of determining temperature of secondary coolants, of evaporation, and of condensation.
The secondary set-points are "paired" with the active component to which the process coupling is strongest. The dynamics of the controlled loops are tuned so as to diminish cross couplings. Another element influencing the energy operating cost is "precise diagnostics" – or lack of the same. It has been proven that the on-line use of rather simple energy balances can diagnose very precisely the airflow problems through coils, using existing instrumentation.
The university is assisted in this project (ESO) by the participation of a number of Danish companies.



Selected research topics

Simulation and process integration
Development of mathematical models and methods of analysis by numerical simulation.

Internal combustion engines
Modification of fuels and engines to reduce their emissions; application of new fuels and lubricants.

Stirling engines
Optimization of engine performance; operation on natural gas and renewable fuels such as wood chips and biogas.

Gasification
Virtually tar-free gas is generated from straw and wood chips for use in small gas-engine-based cogeneration plants.

Refrigeration

Substitution of CFC and HCFC refrigerants with natural refrigerants; energy optimization of domestic industrial refrigeration plants.

District heating

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

Power plants, combustor and boiler technology

Development of new or improved processes and computational tools to be used in the design and operation of power plants.

Research activities of the Solid Mechanics Section (FAM)

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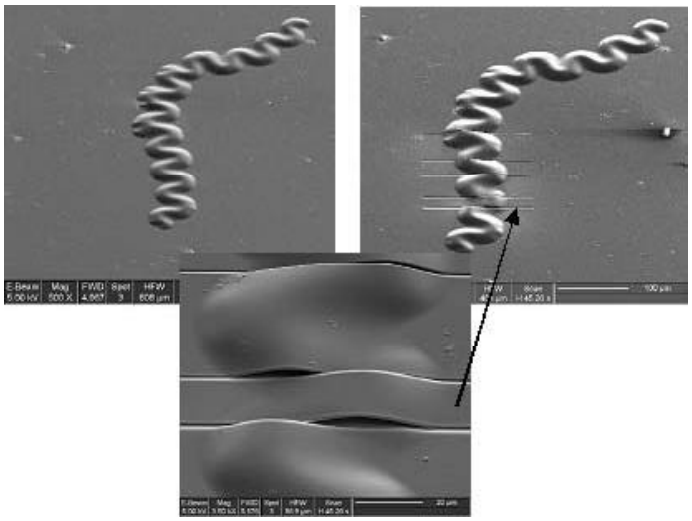
Main research topics concern the mechanics of materials and the strength and dynamics of structural components and systems. In materials mechanics the work includes basic development of material models for inelasticity and damage, as well as applications in the areas of fracture mechanics, delamination of thin surface layers and metal forming.
The structural mechanics area includes vibration analyses and advanced design using optimization methods. The design of MEMS (MicroElectroMechanical Systems), based on the Finite Element Method and topology optimization, has also become a major activity.

Delamination of thin films

The mechanics of thin film delamination is theoretically challenging and it has a wide range of applications from wear-resistant diamond-like-carbon (DLC) coatings on metal substrates to wireless electronic technology. Experimental observations of delamination modes in a DLC coating of a thickness of 123 nm are shown in the figure.



By means of the focused ion beam technique, cuts through the film are introduced, leaving the substrate unaffected. Measurements of buckling profiles around these cuts are used to extract the interface fracture toughness and the residual stresses in the film (in excess of 2 GPa in compression). In turn, measurements of buckling profiles for the uncut film, coupled with calculations for circular delaminations, show that the telephone cord delamination mode releases more energy than circular or straight-sided delaminations.
A theory for the causes of circular and straight-sided delamination that develops into the telephone cord delamination, and the mechanics involved in the propagation of this delamination, has been developed.

Designing bandgap materials and structures with optimized dynamic properties

The careful placement of several material phases in a multi-phase system (a material or a structure) can be used to create the so-called bandgap phenomenon. A bandgap means that gaps are present in the band structure for wave propagation in the system. In other words, there are certain frequencies for which waves cannot propagate - an effect that can be used to great advantage. Bandgaps may exist for periodic or near-periodic systems when the contrast between the properties of the involved materials is sufficiently large and they appear for both elastic/acoustic waves (phononic/acoustic bandgaps) and for electro-magnetic waves (photonic bandgaps). The purpose of this project is to apply advanced optimization techniques (topology optimization) to design improved bandgap materials and structures, and the project focuses on some promising directions with application areas appearing both in MEMS (MicroElectroMechanical Systems) for micro-size filters, resonators, and waveguides, as well as in larger structural components, e.g. for vibration isolation, sound-damping barriers, etc.

FREJA-project. Application of advanced material models for the analysis of metal-forming processes

Metal-forming processes such as sheet drawing and powder compaction have been studied using advanced material models. For sheet drawing, the grains and the orientation of the grains are individually represented in crystal plasticity-based analyses of the macroscopic stress response and development in surface roughness. In modelling powder compaction, both localization of plastic flow during compaction and sintering are studied. The focus for the sintering study has been on the 3D evolution of relative density and sintering stresses for spherical particles in body-centred cubic particle packing.

Selected research topics:

Design of microstructures for stability

Globally stable porous cell structures are designed using topology optimization and Floquet-Bloch wave theory.

Topology optimization for snap-through and bi-stability

Systematic design of bi-stable MEMS devices for switching and energy conservation purposes.

Non-local plasticity

Non-local plasticity theories are used to model size-effects in metals. Some of the areas investigated are metal matrix composites and crack problems.

Modelling of powder metallurgy processes

Localization of plastic flow in the form of shear bands in a porous metal undergoing compaction has been studied. Furthermore, the micro-mechanical behaviour of spherical metal particles during heat treatment has been analysed - a process known as sintering.

Dynamic effects of mechanical high-frequency excitation

Theoretical and experimental studies on the changes that strong high-frequency vibrations may cause to essential properties of mechanical systems, e.g. their equilibrium positions, natural frequencies, stability, stiffness, and friction properties.

Design for stiffness and strength with orthotropic materials

The combined design of density, orientation and boundary shape is optimized to obtain maximum stiffness and/or minimum elastic energy concentration.

Optimizing the acoustic sensitivity of fibre lasers

Designing a package enhancing or reducing the sensitivity of fibre lasers to acoustic vibrations.

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.

Effect of anisotropic plasticity on fracture

Crack tip blunting as well as failure by debonding from inclusions is analysed for different orientations of anisotropic axes.

Fatigue crack growth

The blunting-sharpening mechanism for crack growth under cyclic loading is studied in terms of a large strain numerical analysis.

Research activities of the Maritime Engineering Section (MT)

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The three main research areas are

- Hydrodynamics. Various aspects of the behaviour of waves and currents are modelled, for example the interaction of waves and currents at restricted water depth. Moreover, wave loads on ships and propeller hydrodynamics are dealt with.
- Solids and structures. Dynamic elastic behaviour is modelled as well as non-linear behaviour due to crack propagation, buckling and material plasticity.
- Risk and reliability. The aim is to determine risk profiles and failure probabilities for various systems in operation.

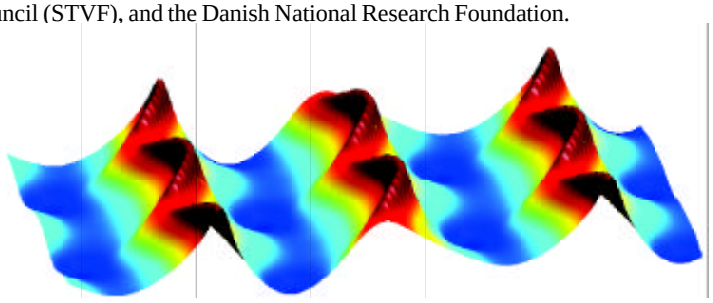
Onboard monitoring and decision support system for safe ship operation

Today focus is increasingly on safe and sustainable ship transportation of goods and passengers. While significant improvement can be made in the design phase, the role of the captain is of the utmost importance for safe, comfortable and efficient transportation. To assist the captain, accurate information on the current status and reliable predictions of the magnitude of motions and stresses within the next few hours as a function of sea state, heading and speed is very valuable. Thereby the possibility of sea sickness, lost cargo, fatigue damage in structural members and wave-impact loads may be minimized. In damage conditions following a collision, grounding or fire, the information on water inflow and ship stability is also of vital importance for the salvage of the ship and the rescue of the passengers.

Research at the Maritime Engineering Section on onboard systems concentrates on the development of robust and accurate models for the prediction of wave-induced loads on ships and on the formulation of proper interface and calibration models for the onboard measurements of motions and strains. The work is carried out partly within the EUREKA MONITUS project and partly under the Danish EFS project SeaSense.

Fully nonlinear water waves in deep and shallow water

A new theory for describing the dynamics and kinematics of fully nonlinear water waves has been developed at MEK. The theory belongs to the so-called Boussinesq family but in contrast to conventional formulations, which are restricted to weakly nonlinear shallow water phenomena, the new formulation is applicable for fully nonlinear waves in deep as well as in shallow water. The new theory is not a frequency domain formulation (such as e.g. Stokes theory and Stream function theory) and it is not restricted to a horizontal sea bottom. This makes the formulation very attractive e.g. for the description of the velocity and pressure profiles in nonlinear irregular waves. As a first practical engineering application, the model is at present being used to develop design criteria for offshore windmill foundations exposed to irregular waves in shallow water. Other more fundamental investigations include modelling the highest possible solitary wave; partial reflection from a rippled sea bottom; reflection and blocking of waves in opposing currents; 2D Benjamin-Feir instabilities in deep water waves; 3D horseshoe instabilities in highly nonlinear deep water waves (see Figure); and wave breaking in deep and shallow water. The research is supported by the Danish Technical Research Council (STVF), and the Danish National Research Foundation.



Selected research topics:

Waves
Behaviour of waves at restricted water depth or interaction with ships [117, 41]

Hydroelasticity of ships
Determination of wave-induced hull girder vibrations in stochastic sea-ways. [118]

Hydrodynamic loads on offshore structures
Application of a Navier-Stokes solver with free surface modelling for calculation of the loads on horizontal offshore structural members in the splash zone.

Propeller design
Development of methods for the design of optimal propellers. [123]

Dynamics and damping of structures and materials

Modelling of damping mechanisms [7,125] and radiation boundary conditions in infinite domains [34]

Residual strength of damaged sandwich panels

Prediction of delamination growth in sandwich structures by fracture mechanics or continuum damage mechanics.

Collision and grounding damage to ships

Modelling of collision and grounding frequencies, structural damage and the following consequences. Development of new crashworthy ship structures. [16, 50, 53, 46, 25]

Monitoring of structures and ships

Update stochastic load models, design models, operation procedures, and maintenance strategies by current statistical analysis of the simultaneous stochastic process signals.

Structural reliability methods applied to general technical risk analysis

FORM, SORM, and simulation combined with Bayesian network methods. [22, 21, 26]

Value settings in technical decision problems and public acceptance criteria.

Research activities for the Coastal and River Engineering Section

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Research

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, and 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 m^3 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 through 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 investigated to describe the conditions and risk of failure near the edge of the protection.

Selected research topics

Waves and scour around low crested structures

The wave climate and resulting scour around the roundhead of a low-crested offshore breakwater is investigated.

Scour in (partial) standing waves

The scour in front of a vertical breakwater is investigated by using a 3D flow description of reflecting waves.

The development of sandy spits

A theoretical and experimental investigation of the processes that govern the dimensions and shape of an accumulating sandy spit.

Sand waves in tidal current

A numerical investigation of the detailed morphological development of sand waves in a tidal current.

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.

Liquefaction

The wave-induced groundwater flow in silty sediments due to rocking of the structure, e.g. a monolithic breakwater element, and the resulting pressure build-up and eventual failure due to liquefaction.

Stability of graded armour layers

The pick-up of smaller units of armour blocks covered by larger blocks is studied in oscillatory flow and breaking waves.

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 LDA, PIV, stereo-PIV, LIF, and LSV.

Danish Academy in Wind Energy (DAWE)

DAWE is a new Ph.D. research school established in 2002 by the Danish Technical Research Council as a collaboration between DTU, Aalborg University, Risø National Laboratory and the Danish Hydraulic Institute. The secretariat of the school is located at MEK.

The overall goal of the school is to strengthen research in wind energy in order to maintain and strengthen the leading position held by Danish industry in this area. This will be accomplished by attracting the best students and internationally recognized guest researchers to participate in research projects within the field of wind energy. The goal is that 20-30 Ph.D. students will be involved in the research school and that the school will be the hub in a network covering all Ph.D. students in the wind energy area in Denmark. The school should eventually enhance the synergy and collaboration in research between the collaborating partners. Further information can be found at www.dawe.org.

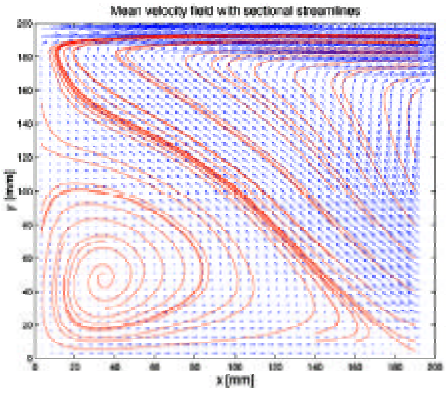
Laminar-turbulent transition

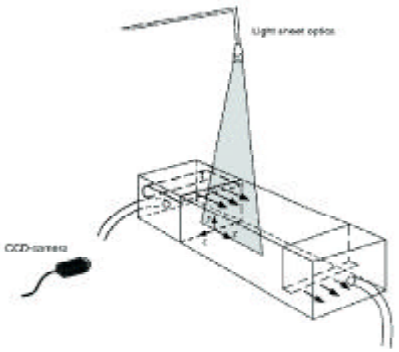
Flows are often neither fully laminar nor fully turbulent. Instead, an initially laminar flow undergoes transition and becomes turbulent only after encountering e.g. a structure. Especially for aerodynamic and turbo-machinery flows, transition is of great importance. Hence, correct modelling of the transition process is a prerequisite for determining “stall” for a wing. A range of transition types exists, of which the two extremes are called “natural”, and “bypass” transition, respectively. The first type is caused by small perturbations in the flow, while the latter is associated with free-stream turbulence and/or surface roughness. Transition in wind engineering flows and turbo-machinery

flows is almost always of the bypass type. Natural transition is theoretically well understood. Linear stability theory can be employed and the Orr-Sommerfeldt equations predict transition with good accuracy. Bypass transition is a very active area of research. Linear stability theory cannot be used, since the flow perturbations are not "small". Instead, semi-empirical relations are resorted to.

Flow in ventilated spaces

Local airflow, and heat and mass transfer within ventilated spaces are interesting from a fluid mechanical point of view because they involve recirculating flows and large turbulence intensities. Our ongoing research aims at an increased understanding of these characteristics. Experimentally, we consider mainly small-scale water models to obtain full-field information of velocity (LDA and PIV) and concentration (LIF) distributions. We use proper orthogonal decomposition (POD) to examine dominant flow-structures. Computationally, we use CFD to model, in full scale, the experimental set-ups. Also, we consider complex geometries (detailed human body) as well as complex physics (homogeneous and heterogeneous chemical reactions) that occur in indoor environments.
[62], [70], [158], [159].





Experimental fluid dynamics

Various fundamental flow cases are studied using optical measuring techniques, such as LDA, PIV and LIF. [43], [51], [58], [80], [132], [165].

Aero-acoustic modelling of turbulent flows

Models for noise generation and emission of turbulent flows are being developed. [149], [218].

Wind turbine aerodynamics

Various aspects of wind turbine aerodynamics are studied using state-of-the-art Navier-Stokes computations. [32], [63], [64], [94], [95], [109], [133], [150], [152], [195], [196], [201], [208], [214].

Database on wind characteristics

The database has been enlarged with four new categories of data: time series of wind characteristics and wind turbine responses, wind resource data and wind park data. [191], [198].

Dynamics and breakdown of vortices

New ideas for understanding vortex breakdown are tested and compared to experiments and numerical simulations. [49].

Biological flows

Solute coupled water transport in the small intestine is studied in a collaborate project with the August Krogh Institute. Ciliary sieving and pumping in suspension-feeding animals are studied in collaboration with the Marine Biological Research Center, University of Southern Denmark. [37], [39].

Research activities for the Indoor Environment Section

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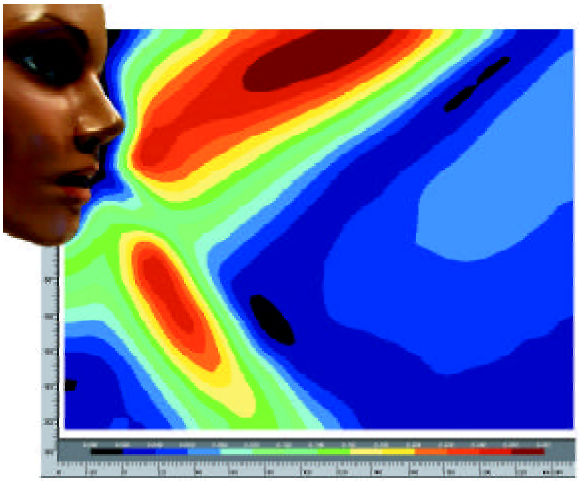
Research

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

Personalized ventilation systems

We are engaged in the development and optimization of personalized ventilation solutions, an approach that improves the air quality in the breathing zone of the occupants. This has great potential for reducing the overall outside air supply rate while improving occupant comfort, health and productivity. Initial studies on a prototype of a system showed very promising results. New, more efficient designs of systems for providing occupants with personalized air are being developed, based on both physical experiments and the most advanced measuring equipment (breathing thermal manikins, Particle Image Velocimetry, Laser Doppler Anemometry, etc.) and human subject experiments. An important aim of this research is the development and evaluation of strategies for coupling the personalized ventilation systems with total volume systems that will ensure the quality of the background indoor environment and minimize airborne transmission of infectious agents between occupants in both buildings and vehicle compartments.



Particles

Over 150 epidemiological studies have reported significant associations between outdoor airborne particle concentrations and excess mortality and morbidity even at moderate levels.
However, despite these well-established correlations between outdoor particle levels and health outcomes, there are no comparable studies showing such associations for indoor particles. Particles (both airborne and deposited) have traditionally been excluded from most indoor environmental research. We are addressing 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

Selected research topics

Indoor environments and human comfort, health and productivity [62, 70, 73, 74, 75, 87, 88, 89, 99, 105, 112, 148, 168, 185, 186, 187]
Buildings that make their occupants feel unwell are unacceptable. Extensive field and laboratory studies are ongoing to identify what makes healthy buildings.

Human response to low humidity [174]
Previous studies at the Centre have documented that low humidity improves perceived air quality in spaces. But how low a level of humidity is acceptable for humans?

Thermal comfort during thermal transients and during exposure to combinations of thermal parameters [20, 106, 110, 142]
In modern buildings very complex thermal conditions may occur and often these conditions change during the day. This research studies the effects on thermal comfort of thermal transients and combined thermal exposures.

New strategies for individual control of the environment [42, 92, 93, 122]
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.

Significance of sorption processes for indoor air quality
Sorption of chemicals on indoor surfaces may be a supplement to ventilation in striving to remove pollutants from the indoor air.

Combined exposures to several indoor environmental parameters [69, 173]
Development of models for the prediction of human response to simultaneously occurring loads from noise, the thermal environment and poor air quality.

Pollution sources in ventilation systems [96, 97, 170, 171]
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.

Research activities of the Engineering Design Section

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Research in the Section for Engineering Design and Product Development (K&P) is carried out in five key areas:

- Product Development
- Engineering Design
- Control Engineering
- Machine Elements
- Mechatronics

Our research covers both the object of product development (the product) and the process of product development itself. Product areas we focus on are largely from the mechanical, mechatronic, and electro-mechanical sectors.

Our research at K&P is very much synthesis-oriented with emphasis on innovation throughout the engineering design and product development processes. The use of laboratories and the MEK central mechanical workshop is thus essential, for both research projects and for student work. Furthermore, we collaborate extensively with trade and industry, testing research results in a professional business environment, and engaging staff from companies in educational activities at DTU. Typical partners from industry include major Danish companies such as Bang & Olufsen, Danfoss, Novo Nordisk, Oticon, and Nokia.

The Section is actively involved in the organization of a number of conferences and networking activities, including the international "Design Society" and "Norddesign", the national "Konstruktionsdagen" (conference on engineering design), "Produktudviklingsdagen" (conference on product development), "Mekatronikdagen" (conference on mechatronics) and an annual two-day conference on machine elements, "STATOIL-seminaret".

Selected research topics

Multi-product development

A focus on product platforms and modularisation as a means for 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.

Product development in distributed teams

The exploration of working patterns and results in team-working across large distances and cultural boundaries. This includes an investigation of both the obstacles and the new opportunities when working in globally-dispersed teams, leading to an understanding of the tools and methods required for such activities.

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.

Autonomous agricultural machinery

The environmental impact of agricultural production is very much in focus, while the competition demands high efficiency. Some 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 mechatronic and robotic expertise of the Section to the problem.

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 modern feature-based CAD system. The variant master consists of four elements: core models, variator models, rules and property models.

Design languages

The application of information technology plays a crucial role in achieving the industrialization of engineering design. The goal is to contribute to the next generation of CAD systems, focusing on the improvement of synthesis and documentation. To be able to synthesize in an 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 a 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 nonlinear systems. However, the majority of currently available control techniques suffer from being mainly applicable to linear systems. This makes these methods sensitive to nonlinearities. Of interest in this research are the problems involved in applying nonlinear control techniques in nonlinear mechanical systems. The nonlinear control methods include feedback linearization, variable structure control, adaptive control and fuzzy control.

Synopsis

This is a network project that has been funded for three years, and focuses on the establishment of a framework for integrated innovation in product system and service development, in collaboration with the Centre for Industrial Production (CIP) based at Aalborg University.

TEACHING PROGRAMME

MEK studies

MEK offers teaching programmes in the topics covered by the Department at undergraduate, graduate and Ph.D. levels.

The topics covered by MEK are mainly in the fields of mechanical and coastal engineering. The teaching programme is quite comprehensive, covering coastal engineering, naval architecture, material and structural mechanics, indoor environment, energy systems, fluid mechanics, engineering design and product development.

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

Teaching methods

A broad range of teaching methods is employed at MEK, i.e. lectures, 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 candidates attractive to industry.

For the bachelor students emphasis is placed on the use of commercial 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 departments IPL and MEK are responsible for most of the courses in the new curriculum.

The new study represents in several ways a renewal of the teaching methods at DTU. The students work in groups of 15 persons, and each group has its own room (home base). A significant part of the study is carried out as problem-based studies in the groups.

The traditional discipline-oriented teaching, which is common in other curricula at DTU, is in Design and Innovation substituted by problem-based teaching/learning.

It is foreseen that the experience gained from the newly established Design and Innovation curriculum will influence the “classic” curricula at DTU. The Center for Didactics in Engineering Education (CDM) at DTU is monitoring the learning processes to evaluate the “pros” and “cons” of the 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 the Department and the Department Study Board examine the evaluation results to see where improvements are required.

Generally the evaluation results are very satisfactory. The students are happy with the academic level and with the workload in the courses.

Pedagogic achievements – going from teaching to learning

The new curriculum in Design and Innovation
As mentioned above, the new curriculum in Design and Innovation is taught according to very modern pedagogic/didactic principles. As an example, a course in basic mechanics and materials is outlined below:

- The course considers a specific product, which is examined, described and analysed by the students. The disciplinary teaching is thereby substituted by problem-based learning.
- The teaching staff comes from different departments, thereby establishing the foundation for mutually beneficial teaching cooperation between departments.
- The knowledge gained by the students in this course is required in order to solve problems in project course work running in parallel, where students design a structure with both strength and functional requirements.

Course objective
The course objective is to give the students an understanding of the complex relations between the function, the geometry and the material in a product, taking into account also the manufacturing process. The students are introduced to the basics of mechanics and taught how to estimate the stiffness and strength of simple components. Furthermore, they are introduced to materials science as well as to methods of material selection for simple designs.

Teaching methods
Various teaching methods are adopted in the course, i.e. from lessons to laboratory experiments.

The lessons are well suited to give the students an overview of the main subjects. However, it is important that they are motivated to receive the lesson taught through specific problems related to a specific product.

The most effective learning takes place in group work.

Evaluation
At the end of the course the students must pass a written examination. In view of the renewal in teaching principles it may seem that the evaluation method is quite conservative. However, the curriculum of this course is of the outmost importance from a product safety point of view and it is important to ensure that all students have satisfactory knowledge in this field.

Teaching strategies

Based on the experiences gained in the Design and Innovation curriculum, other courses at MEK will be reshaped.

The B.Sc. curriculum, in particular, will be completely altered. A main objective is the use of problem-based learning.

Together with CDM, MEK is taking part in an initiative originating from a cooperative project between the technical universities in Sweden and MIT. The objective is to reshape the mechanical engineering curricula at the universities. The basic concept is problem-based learning in a form called CDIO (conceive, design, implement, operate). The CDIO concept is in many respects close to the teaching concept in Design and Innovation.

Development of staff pedagogic/didactic competencies

The cooperation between MEK and CDM on the B.Sc. Mech. curriculum includes coaching from CDM in the restructuring process of the courses. It is important that new initiatives be launched continuously so as to improve the quality of the teaching process.

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