Department of Mechanical Engineering

DTU

Annual Report 2005

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Preface - MEK 2005

The year 2005 was a successful and busy year for the Department of Mechanical Engineering (MEK) at DTU. A major occurrence was the establishment of an Advisory Group consisting of high level representatives from leading companies.

Several researchers at MEK received prestigious international awards for their work in 2005. We achieved our targets for general performance parameters such as number of students, student satisfaction, number of journal publications, number of citations etc.

To determine if our targets were set at the highest possible levels, we compared the number and impact of our publications with related figures from leading university departments of mechanical engineering in Europe. The comparison confirmed that our achievements are of international standard.

The main objective of MEK is to conduct teaching and research in mechanics, energy systems and design tools. The Department is responsible for essential parts of the B.Sc. and M.Sc. programs in Mechanical Engineering, Civil Engineering, and Design and Innovation at DTU.

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

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

Within the design and product development areas MEK develops procedures for design of industrial products ensuring safety, economical viability, environmental impact, aesthetics and durability are taken 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 at MEK during our fifth year of existence.

Preben Terndrup Pedersen

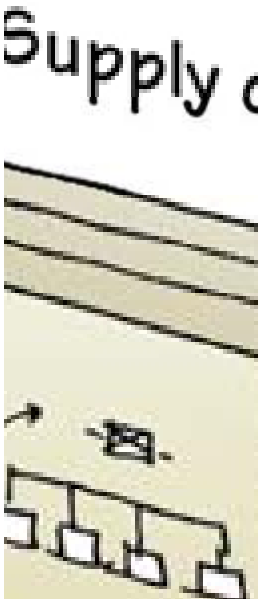
Head of Department

Feature Articles:

Risk Analysis of the Navigational Safety

Indoor Environmental Quality Affects the Performance of Schoolwork by Children

Profitable Sales, Development and Production of Customer Specific Products



Pollution of the marine environment caused by oil or chemical spillage from ships is always subject to considerable public attention. Often the incidents imply significant socio-economic losses as a consequence of loss of fishery, loss of tourism, loss of wild life and flora, loss for the immediately affected persons, and general loss of unspoilt natural environments. It is evident that any society strives to limit the impact of these losses on the affected communities as much as possible within the economical boundaries. This is done partly by reducing the frequency of the occurrence of the marine in-cidents and partly by limiting the consequences when the unwanted event has ocurred.

The best and most economic safety initiatives are those which provides the greatest loss reduction compared with the monetary expenditure. To identify these initiatives maritime authorities use risk analysis. By risk is understood the expected loss over time. Thus the evaluation of risks requires the assessment of both the frequency with which unwanted events occur and the assessment of the resulting consequences from the unwanted event. Defining risk as the expected loss allows the risk analysis to become an integrated part of the economic decision analysis that balances expenditures and benefit, thus allowing owner and community to evaluate the economical trade-off by investing in safety directly.

Undoubtedly, the navigational risk will change in the future: the composition of traffic and the number of vessels are likely increase and hence, everything else equal, increase the frequency of unwanted events; navigational equipment will improve and hence lower the frequency. Other important factors are: size and speed of vessels, condition of buoyage, and conditions of ships (single hull vs. double hull tankers). It is not obvious in which direction the resulting future navigational risk exposure will develop. It is therefore important that local navigational and maritime authorities carefully perform risk analyses be-fore deciding which new navigational safety initiatives to employ.

History of maritime safety

Sailing in an often hostile marine environment has always been a risky activity for mankind. Today the vast majority of all transport of goods is done by ship, and the volume of goods which goes on a single ship is very large. It is obvious that, when marine incidents occur, the consequences which follow may also be significant. Although the public in general acknowledges the importance of the shipping, the perception of the marine industry is highly affected by the infrequent but very tragic casualties, which sometimes occur. This has resulted in the public perception that the marine industry over time

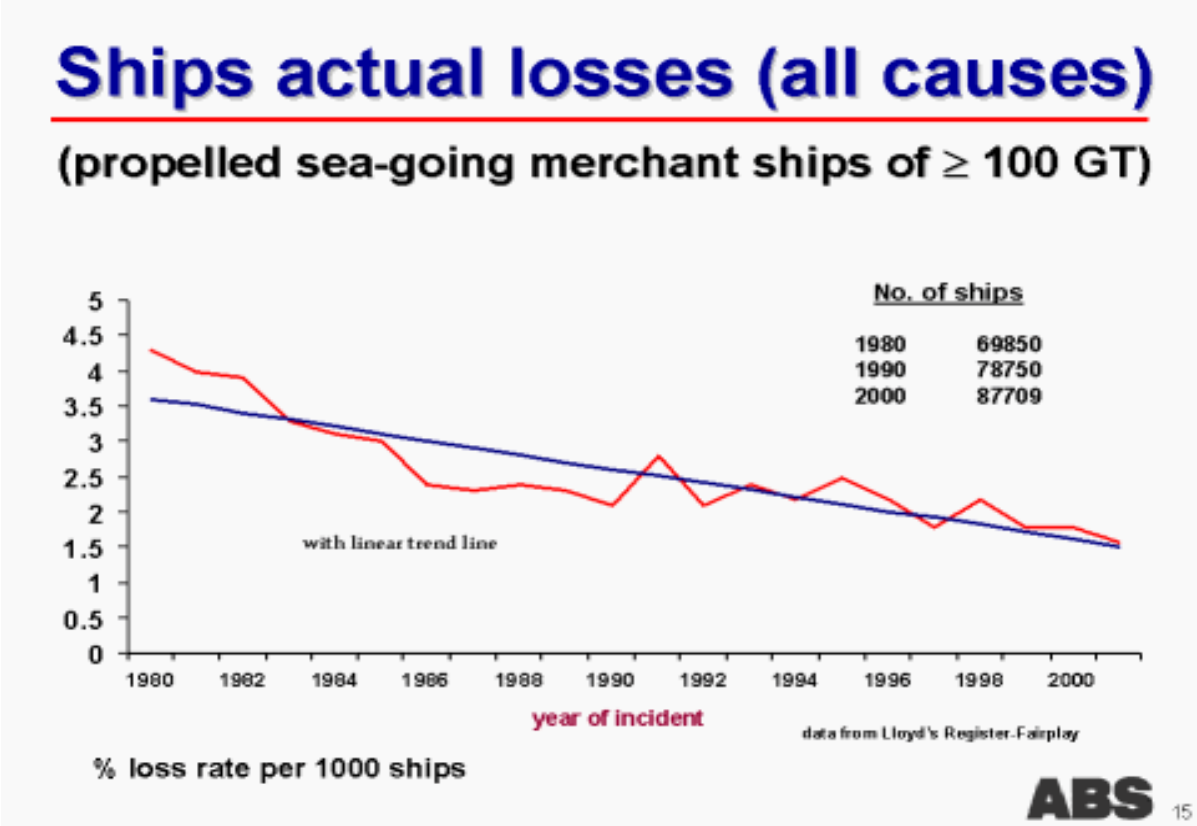


Figure 1. Worldwide percentage loss rate per 1000 ships for the period from 1980 to 2003.

has become more risky. However, statistics clearly shows that over the past two decades the marine industry has reduced the number of incidents.

From Figure 1, combining the loss rate per 1000 ships with the increase in number of vessels, the total number of lost vessels worldwide has decreased by 58%. This reduction can partly be attributed to improvements in navigational equipment, better training of crew, improved standards of ships and their manoeuvrability, improved layout and marking of routes.

Similarly, Figures 2 and 3 shows that both the number of registered oil spills and the amount of oil spilled have decreased over the past three decades. Although the recent *Erika* and *Prestige* incidents have gained considerable exposure in the media, the intensity of the public outcry does not reflect the seriousness of the incident measured relatively to previous oil spills.

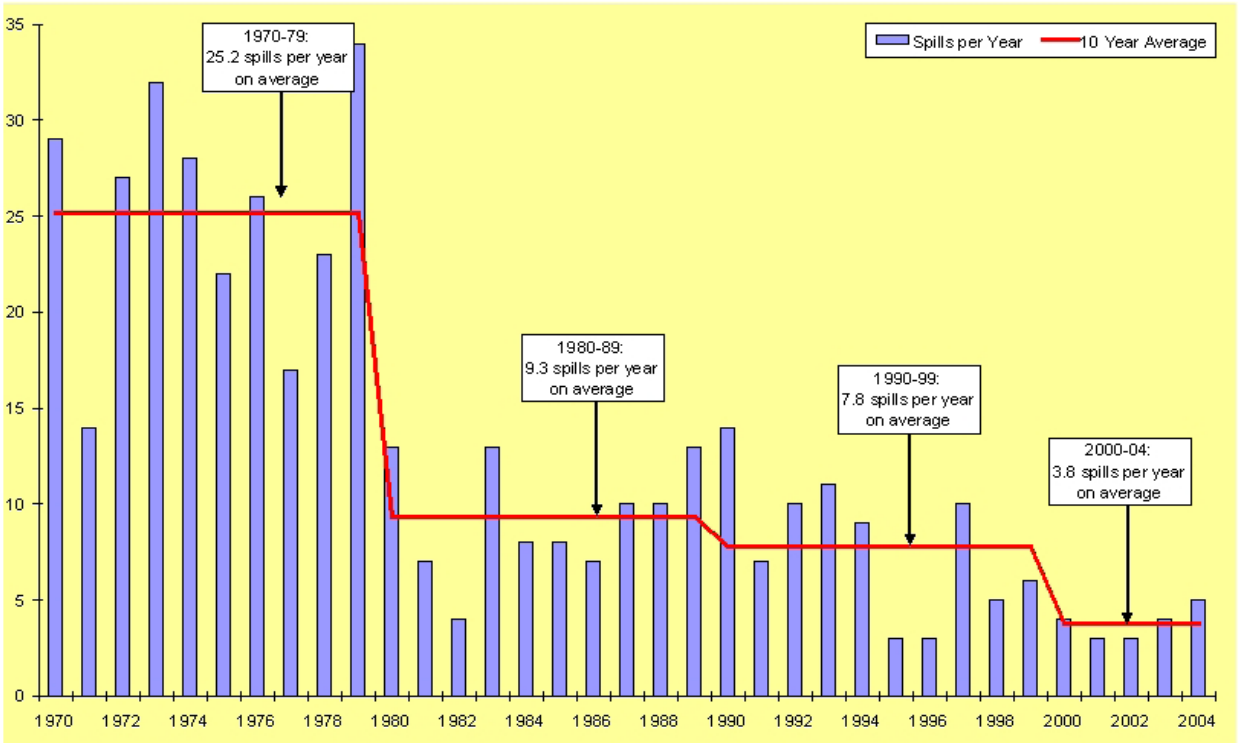


Figure 2. Number of oil spills over 700 tonnes (ITOPF: www.itopf.com).

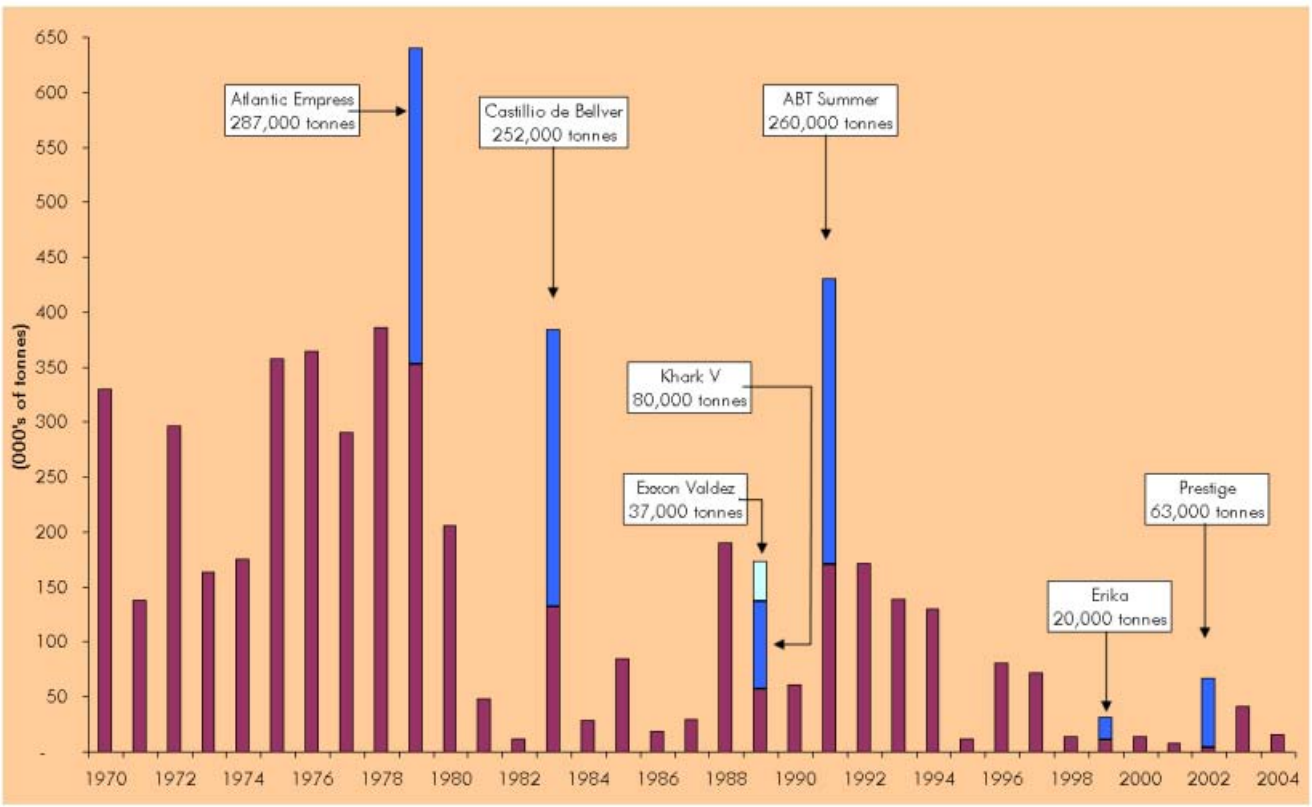


Figure 3. Amount of oil spilled as a function of time (ITOPF: www.itopf.com).

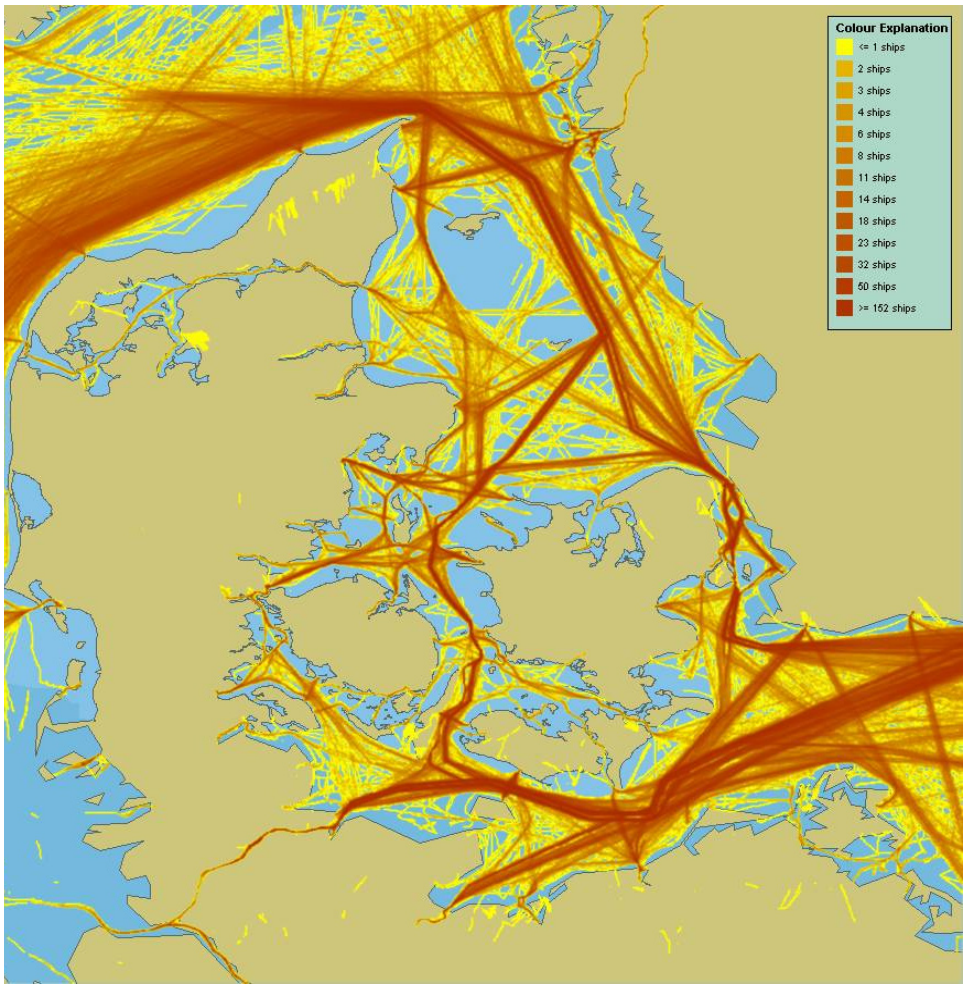


Figure 4. Routes in Danish Waters. Taken from the Royal Danish Administration of Navigation and Hydrography's AIS-server.
Source: GateHouse.

Applying risk analysis

To perform an analysis of the risk related to ship-ship collisions and grounding requires a calculation of 1) the frequency of occurrence of collision or grounding and 2) the resulting con-sequences following these events. The former requires modelling of:

- routes
- traffic composition and distribution on ship types operating on the routes
- grounds
- the captain's failures of reacting in time

The calculation of the consequences requires calculation of:

- structural damage following ship-ship collision or grounding
- oil outflow, for example
- cost of oil spill or other consequences

Presently the majority of ships are equipped with AIS (Automatic Iden-tification System). For the Danish waters, the Royal Danish Administration of Navigation and Hydrograph gather these signals and store them in a database.

These data are valuable for understanding more precisely how the vessels are sailing in a given area and what the traffic composition actually is. Based on one day of registered AIS data Figure 4 presents an intensity plot of the number vessels in Danish waters.

As an illustration the col-lision frequency involving oil tankers operating in the Great Belt has been calculated on the basis of year 2000. All main routes and crossing traffic have

been modelled. The first objective is to calculate the risk related to oil spill for the Great Belt. This is done by calculations in the GRACAT simulation computer program (GRounding And Collision Analysis Toolbox, http://www.skk.mek.dtu.dk/Software/GRACAT.aspx), developed at the Technical University of Denmark from 1998 to 2001. The software con-sists of a frequency analysis module, a dama-ge analysis module, a consequence analysis module and a risk mitiga-tion module. In the risk mitigation module, risk profiles for the calculated consequences can be calculated.

The probability of a col-lision between an oil tanker and one of the vessels ope-rating in the route area and the probability distribution of the oil outflow is calcu-lated by a Monte Carlo simulation procedure. At each collision the energy available for crushing the structure is calculated and the size of the resulting structural damage is ob-tained. It is assumed that a damaged compartment leaks all its oil into the sea if the damage extends below the water line. If the damage is only above the water line, only the oil above the lower edge of the hole is leaked.

Collision probabilities and associated oil out-flow distributions are cal-culated for operations in the Great Belt. Thereafter the distribution for the total oil spill is obtained by weighing the oil spills from the individual vessels with their frequency of travelling in the area. The calculations show that a collision in the Great Belt is estimated to occur once per 59 years and the probability of fracture is estimated to 0.93. Not all collisions will result in fracture, and fewer will result in an oil spill. The fleet of tankers consists of a mixture between single and double hull tankers (first row of the table), only single hull tankers (second row) and only double hull tankers (third row).

It is seen that the move from single hull to double hull structures reduces the frequency of having oil spill from one per 84 years to one per 190 years. It is also seen that the expected spill increases. This is due to the changed tank configuration of small and large sized oil tankers. A small single hull tanker will typically have a central bulkhead, whereas its double hull counterpart will not. For large tankers it is similarly seen that the two-tank across in the double hull tanker replaces a three-tank configuration in the single hull. For midrange tankers there is a general tendency of the double hull tanker having smaller tanks than its single hull counterpart. ■

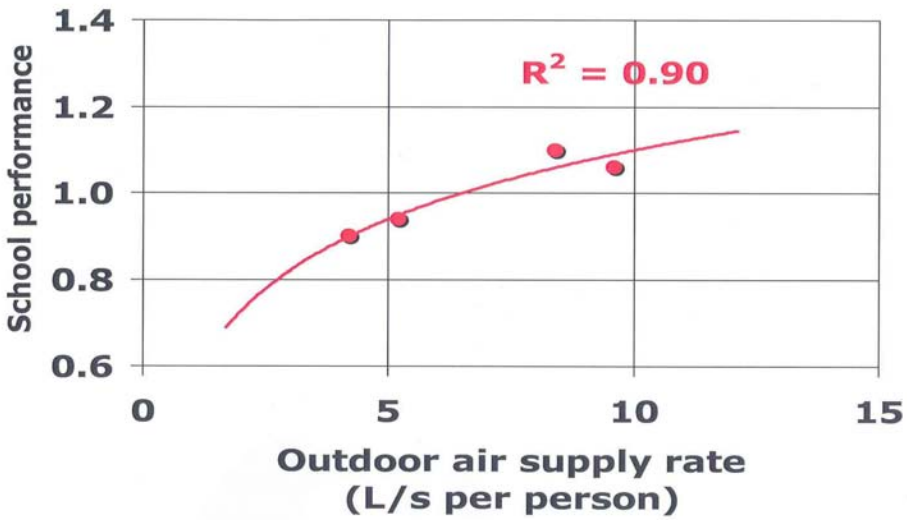
Hull structure	P[Spill]	Frequency spill	E[Volume | Spill]	E[Cost | Spill]	Annual risk
Single and double	0.54	109 y	4971 m3	56 M€	0.5M€
Single	0.70	84 y	4233 m^3	51 M€	0.6 M€
Double	0.31	190 y	7302 m^3	76 M€	0.4M€

Indoor Environmental Quality Affects the Performance of Schoolwork by Children

Poor indoor environmental quality (IEQ) in office buildings can reduce the performance of office work by adults. While it is well documented that IEQ in schools is both inadequate and frequently much worse than in office buildings, there is little direct evidence that classroom performance is being negatively affected. Inadequate ventilation is one of the most common problems identified in schools, causing increased levels of carbon dioxide and other pollutants, and reducing indoor air quality. There is often no adequate temperature control in classrooms, which especially in warm seasons may result in increased temperatures. New research results from the studies carried out at the International Centre for Indoor Environment and Energy show that reducing classroom temperatures and increasing outside air supply rate improve the performance of schoolwork by children [107, 115, 147, 151, 167, 197, 205, 206, 215, 216, 217].

In these studies five independent field intervention experiments were carried out in six identical classrooms in an elementary school in Denmark (Fig. 1). In three experiments carried out in late summer and in winter, the outdoor air supply rate per child was increased from about 3 L/s to 10 L/s, while in two experiments carried out in late summer the temperature was reduced from about 25°C to 20 °C. The outdoor air supply rate was increased using the existing mechanical ventilation system while temperature was reduced by either operating or idling split cooling units

Figure 2. Performance of schoolwork as a function of outdoor air supply rate.



installed in the classrooms. For each condition, tasks representing up to eight different aspects of schoolwork, from reading to mathematics, were performed by 10 to 12-year-old children. The tasks were selected so that they could have been a natural part of an ordinary school day. The tasks were presented to children by their teachers. Both teachers and pupils were blind to the interventions. No changes to the lesson plan or normal school activities at school were made, so as to ensure that the teaching environment and daily routines remained as normal as possible.

The results of the experiments show that an increased outdoor air supply rate and reduced air temperatures significantly improved the performance of many tasks, mainly in terms of how quickly each pupil worked, but also for some tasks in terms of how many mistakes were made. It is clear that errors and rate of work are being negatively affected by poor air quality and raised classroom air temperatures. The results show that doubling the outdoor air supply rate improved the performance of schoolwork by about 14.5% (Fig. 2), while reducing classroom air temperature by 1°C improved performance by about 3.5%.

The present studies indicate that improving indoor air quality in classrooms by increasing the outdoor air supply rate, and reducing classroom temperatures in hot weather by cooling, can substantially improve the performance of a wide range of tasks characteristic of schoolwork, from rule-based logical and mathematical tasks requiring concentration and logical thinking to language-based tasks requiring concentration and comprehension. The present results clearly demonstrate that air quality and temperatures in classrooms are very important factors in the learning process and should, together with teaching materials and methods, be an urgent educational priority. In efforts to conserve energy and money over the past decades, the possibly negative effects of poor

environmental conditions in schools have often been neglected and today working conditions are often much worse in classrooms than they are in the offices where adults work.

Improvement of school education has a high priority in most countries and the present results should provide a strong incentive to improve education by improving the mediocre IEQ that is all too frequently found in schools today. This should not only be a priority for the Danish School Authorities. Although Danish pupils were used, the present results can be generalized to other countries in Europe and the USA because classroom conditions and the level of education and educational programs in Denmark are quite similar to those in other developed countries. ■

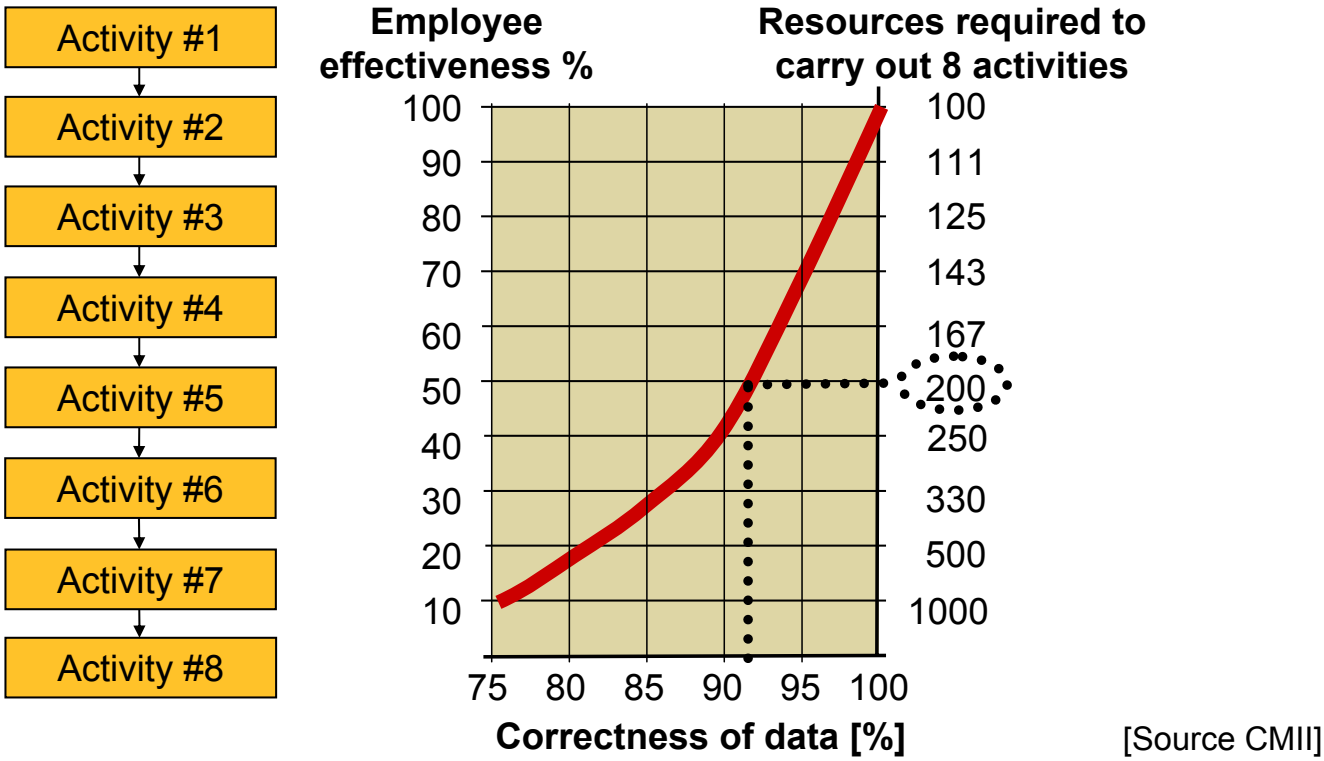
Profitable Sales, Development and Production of Customer Specific Products

Many companies main reason for existence is the ability to sell, develop, manufacture and deliver competitive customer specific products. Examples of customer specific products are refrigeration systems, power plants, pressure transmitters, frequency converters, valves, speaker systems, intelligent housing controls etc. The customization of products often leads to increased complexity in nearly all the functional areas within a company. Some of the main challenges which affect profitability from the perspective of sales, engineering and production in these companies are:

Challenges in Sales: The assortment is difficult to communicate to customers, which often means that the customers will specify products which have not been sold, designed and produced before. There is a saying that "if you do not tell the customer what you have – he will explain what he wants". This means that the possibilities of guiding customers into products which already exist in the company are very limited. When a product is sold, the specifications of what exactly has been sold are often unclear, leading to disturbance in the down stream activities, i.e. design, production logistics etc.

Challenges in Engineering: Often both the product assortment and IT systems grow in complexity in such a way that each project will be difficult to complete on time and budget with expected quality. The product assortment will often have a "spaghetti" structure meaning that the subsystems are coupled in such a way that if one subsystem is changed, it will affect other subsystems. Seen from the IT viewpoint, Bill of Material and other documentation will also grow in complexity and contain severe errors.

The Institute of Configuration Management has within the framework of CMII estimated how



[Source CMII]

correctness of data influences resource consumption. The diagram above shows the correlation between correctness of data and resources necessary for carrying out the activities shown in the left part of the diagram.

The diagram shows that if correctness is 92%, the estimated resource consumption is 200 compared to 100 resources if data were 100% correct. The implication is that, if a company has 92% correctness of data then 50% of all employees are doing non value adding activities.

Challenges in Production: The many new variants to be produced are often based on specifications, e.g. Bill of Materials and drawings which are not error free. This makes it difficult to obtain a proper flow and quality level in production, purchase and delivery. Sometimes flexibility of the production system does not match the areas in the product assortment where variety is needed.

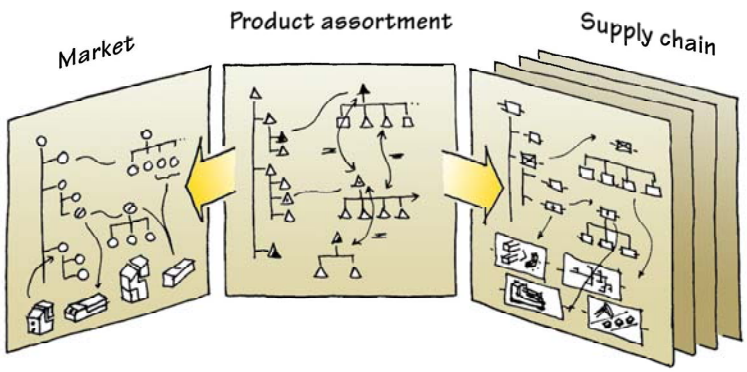
Challenges in the Interplay between sales, engineering and production: Often there will be several iterations between the above functional areas which makes it even more difficult to handle the whole chain from customer to production and delivery efficient and effectively. Product structures are transformed in several IT systems, which each have their own individual structures. This makes development and order execution complicated and errors are introduced. A consequence of the above is that nearly all activities within these companies become projects and is done ad hoc in individual projects. There is a serious risk that more long term development of products is jeopardized which affects the long term competitiveness.

How to handle the challenges?

There are several ways to handle the above challenges. In general there seems to be two ways which are either reducing the complexity or handling the complexity. Examples of means of reducing the complexity are modularization, standardization, platforms of products, product data and business processes. Examples of complexity handling means are introduction of Configuration, Product Life cycle Management, Enterprise Resource Planning and modern CAD systems. In many cases the best results are achieved by a combination of complexity handling and complexity reduction means.

One of the research areas within the MEK's section of design and product development has been complexity reduction by harmonization and alignment of product structures across sales, engineering and production. This is supported by means of a so-called Product Family Master Plan (PFMP), shown below. It is based on Theory of Technical Systems, Theory of Domains and Object oriented modelling. These three theories form a strong base. Theory of Technical Systems explains the structure and behaviour of artefacts. Theory of Domains explains synthesis processes. Object oriented modelling describes structure and behaviour of IT systems. The PFMP describes a product assortment and related IT structures seen from three points of views. These views are market, product assortment and supply chain/production.

The market view explains the product assortment seen from a customer point of view. This view makes it possible to judge which part of the product assortment creates value for the customers. The product assortment view explains the product assortment and variants including functionality of subsystems and modules. The production/supply chain view explains how the product is produced. One of the main benefits of application is that the product assortment becomes traceable from market to production and opposite. Reading the PFMP from the market viewpoint, it will be able to explain that a certain feature in the market view is realized by means of subsystems within the product assortment, which again is produced or created by a certain part of the supply chain. In practice generation of a PFMP often involves millions of data to be handled and therefore software which can extract part of the data from existing legacy IT systems (ERP, PDM, CAD etc) has



been developed by the MEK department.

Normally the PFMP is applied two times, i.e. for modelling the current state situation and for modelling the future state situation. So far the PFMP has been applied in more than 40 companies. One of them is York Refrigeration Denmark.

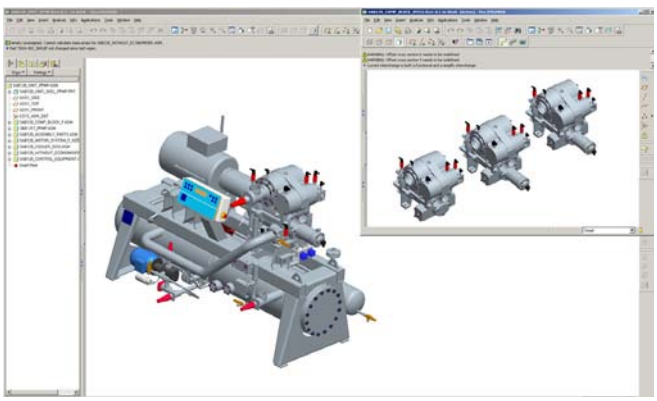
Case York Refrigeration

York Refrigeration is a global leader in development, manufacturing, and sales of refrigeration systems, which typically are used in cold storage warehouses, rinks, production sites, etc. An important business driver is customization, as each refrigeration system is tailor made to match the needs of the individual customer. Other important business drivers are state-of-the-art technology and short lead times.

Customized products are often associated with an ever increasing complexity of the product structures. YORK has also had this experience, and the consequences of this growing complexity include:

- Difficult transformation of an order into a Bill Of Material (BOM)
- Increased amount of resources spent on BOM maintenance
- Increased amount of resources spent on CAD maintenance
- Increased non conformity

To turn this development around, YORK decided to implement PFMP to manage all product structures across all major IT-systems, i.e. CAD, ERP, and PDM systems.



The president of York Denmark, Ole Mølby and Project Manager Thomas Frøslev states the following benefits from application of the Product Family Master Plan:

- "I am excited that product structures across the company have been aligned and harmonized – this will have significant bottom line impact"
- "We have developed a common language for all product families across the company"
- "Previously the same product might be defined in 20 different places. Today there is only one, the PFMP"
- "The foundation for success is good method (PFMP) and a top management team which fully support. Now York has both ffoundations in place" ■

Major Research Activities

Solid Mechanics

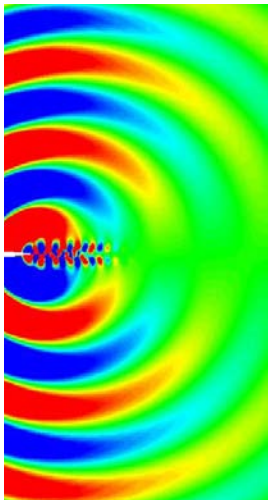
Coastal, Maritime and Structural Engineering

Indoor Environment

Fluid Mechanics

Energy Engineering

Engineering Design



Teaching Programme

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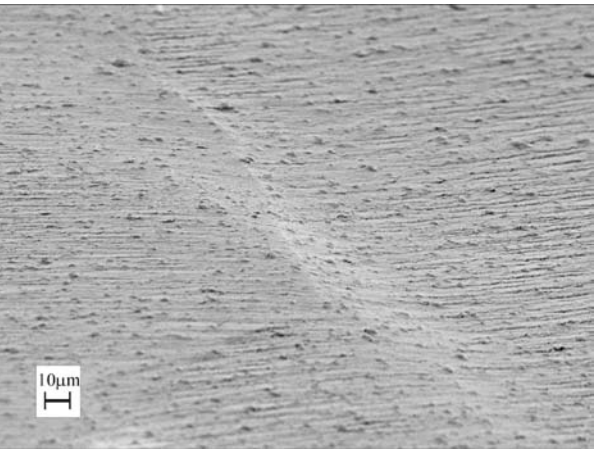
Research Activities of the Solid Mechanics Section (FAM)

The main research topics are the mechanics of materials and the strength and dynamics of structural components and systems, as well as machine elements and mechatronics. In materials mechanics the work includes basic development of material models for inelasticity and damage, size effects on material behaviour, applications to fracture mechanics and fatigue, micromechanics and metal forming.
The structural mechanics areas include vibration analyses 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.
The machine elements group works in tribology and on active vibration damping through magnetic acluators.



Scanning electron microscope image of the surface of an Aluminium specimen deformed in tension. A grain boundary is going from the upper left to the lower right.

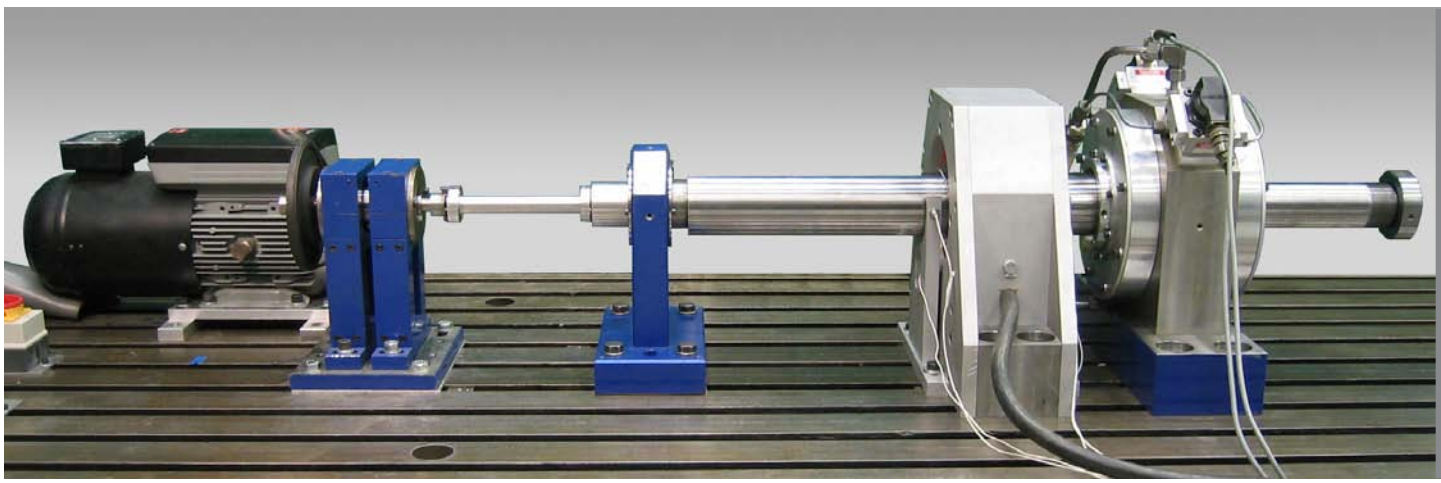
Surface roughening on the grain level

Surface roughening of polycrystalline metals is a common phenomenon observed in metal forming processes. Due to different crystallographic orientations of the grains, the grain boundaries are acting as obstructions to the motion of dislocations. This accumulation of dislocations at the grain boundaries can be modelled using a nonlocal formulation of a crystal plasticity theory. In crystal plasticity a quantitative description of plastic deformation is based on crystallographic shearing due to dislocation motion along specific slip systems. Such a theory has been formulated for finite strains and implemented in a finite element program. The formulation makes use of an energy potential at the grain boundaries depending on the accumulated crystallographic slip. Numerical simulations using the nonlocal crystal plasticity formulation are compared with experimentally observed results for Aluminium specimens deformed in tension.

Intelligent active magnetic bearing

An increasing number of industrial turbomachines are already built with active magnetic bearings (AMB) but the potential of the AMB has not been fully exploited yet. AMBs have been used as a simple bearing, and not as an integrated identification and diagnosis tool. To fully exploit AMBs one must think of them as both an actuator and a bearing, capable of not only supporting the rotating shaft but also capable of exciting the shaft with predefined signals. This unique feature facilitates measurements of input-output (displacement and force) relations and leads to novel approaches in identifying crucial rotor parameters. An intelligent AMB is being developed with the aim of aiding the accurate identification of damping and stiffness coefficients of active lubricated journal bearings. [55, 182, 183, 207]

4 pole active magnetic bearing, capable of generating forces up to 2000 N.



Active magnetic bearing and active lubricated bearing test rig.

Selected research projects

Mixed mode interface crack growth

Current studies include the influence of anisotropic plasticity under plane strain conditions. Also mode 3 effects are incorporated in debonding analysis. [198, 199, 200]

Eigenfrequency optimization of fibre reinforced plates using optimality criteria and mathematical programming

Composite plates are designed in order to maximize the performance with respect to eigenfrequencies. The plates are considered to be laminates where the individual plies consist of orthotropic material. The design task is the orientation of the orthotropic material in each element of the discretization and the ratio between the amounts of material put in the two directions of the fibre-net. [171]

Particle debonding in anisotropic materials

Debonding failure in plastically anisotropic materials containing rigid particles is investigated numerically using a unit cell approach. Different particle shapes and orientations (geometrical anisotropy) as well as non-uniform interfacial strength are considered. [34, 159]

Surface roughness in anisotropic materials

Surface instabilities and surface roughness of a free surface is analyzed during severe straining of anisotropic materials. At the very bottom of the surface troughs high strains arise, which can result in shear fracture propagating deeply into the material.

Size effects in anisotropic sheets

A viscous material model is proposed in which both a material lenght scale as well as plastic anisotropy enters. The model is used to predict necking of sheets.

Vibro-impact analysis by discontinuous transformations and averaging

Many near-elastic vibro-impact problems can be conveniently solved by discontinuous transformations combined with averaging. A general technique for this is developed, and applications illustrated for simple harmonic oscillators, self-excited friction oscillators with stops or clearances, and a particle bouncing on a vibrating gravity. [64a]

Aeroservoelasticity of wind turbines

Theoretical studies on the structural dynamics of wind turbines, focusing on the interaction between aeroelasticity and control, and the possibilities in using active control to reduce fatigue loads on wind turbines.

Large deformations of polymer materials

The mechanical behaviour of polymers can be analysed using a more complicated, non-linear material model than the well-known elastic-plastic material models describing the deformation of metals.

Synthesis and topology optimization of optomechanical systems

(EURYI-project)
Modulation, dispersion and polarization of light are controlled by mechanical means such as external pressure, thermal stress and surface acoustic waves. [7, 24, 27, 143, 144]

Topology optimization in fluid dynamics

Micro and macro devices involving fluid flow are optimized for pressure loss, prescribed velocities and diffusion. Examples are micro-fluidic devices, mixers and bipolar plates for fuel cells. [134]

Topology optimization with pressure loads

Through a new incompressible elasticity formulation using mixed finite elements it is possible to use the standard topology optimization approach to solve problems with design dependent pressure loads. Design examples include lids, submerged structures and water containing dams.

Topology optimization of photonic building blocks

Applications may be in future ultra-compact integrated photonic components. Several bends and splitters in photonic crystals and wires have been designed and tested experimentally [7, 26, 27, 64, 144, 154]

Topology optimization of elastic and acoustic wave-propagation - the PHONON project

New optimized material and structures have been developed for control of waves and vibrations, utilizing the bandgap effect. Examples are acoustic mufflers, bending waves in beams and plates and highly dissipative structures [24,143]

Topology optimization for acoustic-structure interaction using a mixed FE formulation

A new topology optimization method for acoustic-structure interaction structures has been developed. The mixed displacement/pressure formulation is used to interpolate between different governing equations without the need for an explicit boundary representation.

Analysis of cracks in big Diesel engines

A program to model two dimensional crack growth based on the Boundary Element Method (BEM) has been developed. The program is used to study crack propagation in a piston crown. A method to correct the crack extension direction is also included. In order to analyse three-dimensional crack propagation in existing Finite Element Models of the big Diesel engines a method, which combines the BEM and the Finite Element Method, is considered.

Active vibration control of rotor-blade systems

The active control of blade vibrations via active bearings is investigated both theoretically and experimentally. The feasibility of controlling blade vibrations via bearings is depending strongly on the patterns of blade mistuning and on the significance of the dynamic coupling amongst rotor and blades. [54, 56, 114]

Active lubrication for eliminating instability in rotating machines

The active control of lateral dynamics of flexible rotating machines via active lubricated bearings is investigated theoretically as well as experimentally.

The control system design of such bearings is a multidisciplinary task involving rotor dynamics, fluid dynamics and control theory. [55, 182, 183, 207]

Thermoelastohydrodynamic lubrication applied to heavy loaded rotating machines

Hydro-generators of water turbines weighting several hundred tons are normally supported by thrust bearings with many tilting-pads. The minimum oil film thickness is one of the most important design parameters and depends on the lubrication mechanisms, lubricant properties, structural and thermal deformations of collar and pads. [139]

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Research activities of the Coastal, Maritime and Structural Engineering Section (SKK)

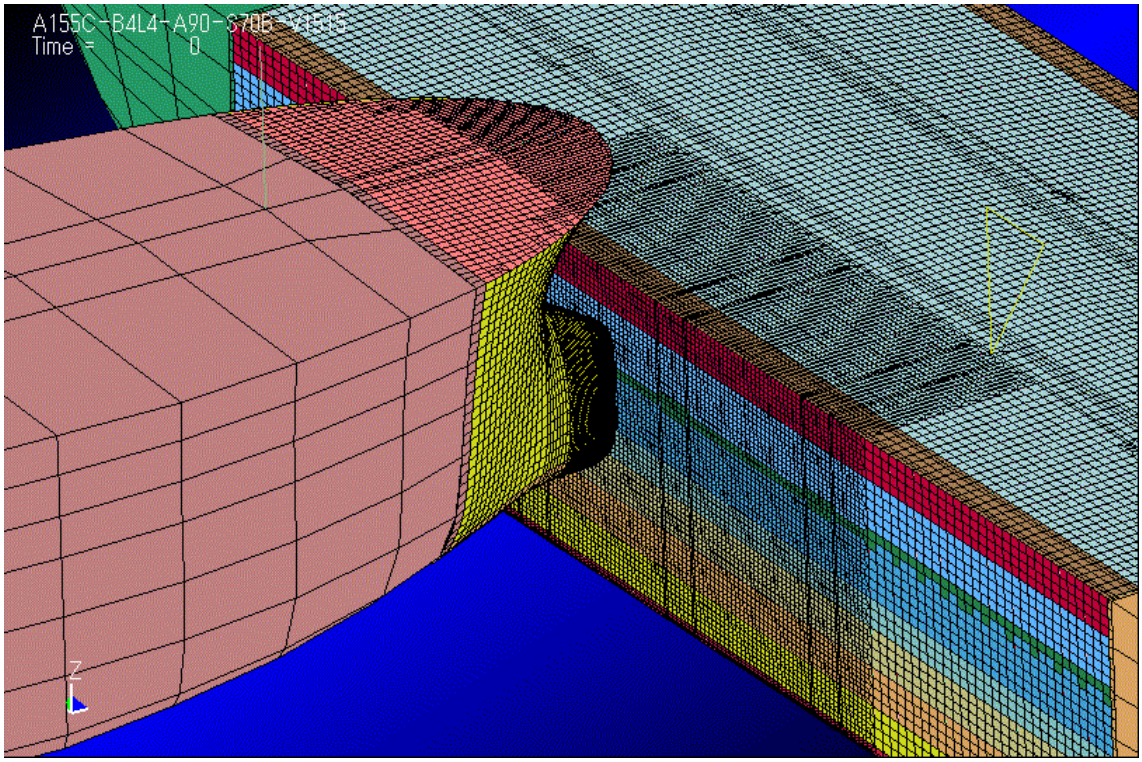
The research topics of the Section include design, analysis and operation of large maritime, coastal and land-based structures under natural loads, such as waves and wind.

The main research themes are:

- Hydrodynamics: Waves and currents and their interaction at restricted water depths, wave loads on ships, offshore and coastal structures, flows and loads on ship propellers.
- Structures: Design and analysis of structures; structural damping; composite structures; damage tolerance of sandwich structures.
- Risk and reliability: Risk acceptance criteria, risk evaluation, stochastic load and response modelling.
- Sediment transport and morphology of rivers and coasts: Waves and turbulence in surf zones, wave-driven currents and exchange processes, riverbed forms, effect of structures on river morphology.
- Interaction: Performance of ships and large structures subject to wind and wave loads and their interaction with the environment. Decision support systems.

Ship Collisions

According to statistical analyses, ship collisions and groundings are responsible for about half of all ship losses and for about 70% of all polluting events caused by shuttle tankers. So collisions and groundings are major risks to the safety of ships. A disastrous oil spill from a struck oil tanker has become one of the major problems in view of conservation of maritime environment. So far double hulls have been introduced to reduce the consequences of collision



and grounding events. But it is still a fact that collision accidents involving struck double hull tankers result in oil spills. One example from the Danish waters is the collision accident involving the double hull oil tanker "*Baltic Carrier*" in Kadetrenden a couple of years ago. Therefore, there are good reasons to study procedures to minimize the consequences of ship collision accidents.

In order to further reduce the oil spill from struck oil tankers, research is being performed at MEK on the effect of buffer bulbous bows. Relatively soft buffer bows absorb part of the kinetic energy of the striking ship before penetrating the inner hull of the struck vessel and they result in smaller load intensities on the struck vessel. The specific purpose of the present project is to verify the effectiveness of a prototype buffer bulbous bow structure in ship-ship collisions as compared with that of standard bulbous bows.

Comprehensive numerical analyses will be performed for buffer bow designs and the results will be compared to experimental results.
The experiments on buffer bows have been carried out at the Structures Analysis Group at National Maritime Research Institute in Tokyo, Japan under the supervision of Mr. Yasuhira Yamada. At present Mr. Yamada is on leave from a position as chief researcher at the National Maritime Research Institute to work on the project at MEK. The project itself is part of a major Japanese national research project and Mr. Yamada's expenses here in Denmark are paid by the Japanese Government. [209, 89]

Selected research topics

Estimation of impulsive wave-induced loads on a FPSO

The effect of impulsive loads like slamming and green water on deck on the wave-induced bending moment is estimated by a semi-analytical approach. These loads can be due to bow flare slamming, bottom slamming or green water. The results are given in closed-form expressions and the required input is restricted to the main ship dimensions. The formulas make it simple to obtain quick estimates in the conceptual design phase and to perform a sensitivity study of the variation of the ship's main dimensions and operational profile [5a, 146].

Hydroelasticity of marine structures

The hydroelastic response equations of a floating plate with large deflections in multidirectional irregular waves are established, and a solution method in the frequency domain is discussed including extreme value statistics. A very large floating structure is chosen as an example. The numerical results show that the membrane forces have an influence on the vertical displacements and the bending moments. [13]

Conditional second order short-crested water waves applied to extreme wave episodes

A derivation of the mean second order short-crested wave pattern and associated wave kinematics, conditional on a given magnitude of the wave crest, is presented. The analysis is based on the second order Sharma and Dean finite water wave theory. A comparison with a measured extreme wave profile, the Draupner New Year Wave, shows a good agreement in the mean, indicating that this second order wave can be a good identifier of the shape and occurrence of extreme wave events. [28, 145]

Wave height distribution observed by ships in the North Atlantic

The analysis of almost 25.000 observations of the wave height from ships in the North Atlantic shows that the encountered wave height distribution is significantly lower than the distribution provided by the classification societies for structural assessment. It is seen that for higher waves the crews avoid sailing in following sea and as expected the speed is decreased in higher waves. There is, however, still a relatively high probability that the ship will maintain its service speed even in relatively severe sea. The distribution derived could be used to incorporate the effect of weather routing in a long term analysis of the wave loads on a ship. [88]

Springing of ships

Significant springing vibrations in ships have recently been measured in a large ocean-going bulk carrier. In this project it is shown that the springing response depends strongly on second order (sum frequency) terms involving cross-coupling terms from the combined wind- and swell-driven wave system. The agreement with measured springing responses is found to be greatly improved when these second-order cross-coupling terms are included. [2, 67a]

Service performance of ships

A simple method has been established for the

evaluation of the service performance of ships. Input data collected daily on board are adjusted to correspond to a well-defined condition which is full load, service speed and no wind or waves. This makes a comparison between different ships and between different voyages for the same ship possible. The procedure has been applied to two 35,000 dwt product carriers, fitted with different propellers, over a period of approximately two years. Difference in performance due to different propellers has been found. [4, 74].

Non-linear wave modelling

Numerical models of highly non-linear waves in the coastal environment have been developed. The purpose is to achieve a better understanding of the dynamics of these and their interaction with coastal bathymetries and structures placed in the offshore and coastal environment. The main tool has been a finite difference based solution to a set of extremely accurate Boussinesq equations. [6, 35, 72].

Wave interaction with fixed structures

This PhD project focuses on implementing a Discontinuous Galerkin Finite Element Method (DG-FEM) for solving the Boussinesq equations. This solution provides full flexibility in terms of both the geometry and the local order of the numerical solution and allows the treatment of (wall-sided) structures of arbitrary form in plan. [21, 141]

Combined numerical/physical modelling for coastal waves problems

This project has developed a new unified wave generation theory which allows the physical wave tank to be enclosed in a larger numerical domain to combine the advantages of both modelling tools. As a spin-off, the new generation technique turns out to be vastly superior to existing methods for generating highly non-linear periodic waves in physical wave tanks.

Wave-instabilities in 2D and 3D

Oscillating crescent waves are considered, arising from three-dimensional (class II) instabilities of steep plane waves. Their selection can be explained from a conventional stability analysis, when effects of a finite-width tank are taken into account. Furthermore, the numerical Boussinesq-type model has been used to investigate the longterm evolution of doubly-periodic short-crested wave instabilities. Results reveal that the evolution in these cases is qualitatively different than the classical evolution in a single horizontal dimension. For example, even in weakly non-linear cases, the combined evolution results in a quasi-recurrence cycle that is asymmetric, in contrast to the related two-dimensional case for plane waves. [22, 219]

Generation of non-linear short-crested waves in deep water

A numerical investigation has been made, which demonstrates that the observed unsteady features (e.g. bending wave crests, dipping at the centerline, and pronounced modulations in the propagating direction) are in fact due to release of spurious free first harmonics, arising from the neglect of third-order components in the three-dimensional (physical) wave generation.

Third-order theory for irregular waves

A new third-order theory for bi-directional bi-chromatic water waves has been developed. For the first time this theory allows an assessment of the non-linear interaction of two directional wave trains of different amplitude and frequency in arbitrary depth. Although the theory only considers two interacting wave trains, the expression for the amplitude dispersion is generally valid for a random number of interacting waves, as these interactions should be treated on a two-by-two basis. The new theory has been successfully applied to a variety of non-linear phenomena related to wave resonance. [227]

EPCOAST (Exploitation and Protection of Coastal Zones)

EPCOAST is a 3-year (2005-2008) Research Frame Programme financed by the Danish Research Council for Technology and Production Sciences (FTP, Forskningsrådet for Teknologi og Produktion). This research program is being undertaken jointly by DTU (Danish Technical University); and DHI Water & Environment. The programme includes 1) coastal processes due to organized vortices and 2) morphological modelling. [53, 61, 62, 192]

More information can be obtained from the project website: http://www.epcoast.mek.dtu.dk

Experimental and numerical investigation of seabed and stone protection interaction

Scour is one of the failure modes of coastal and hydraulic structures. Stone cover has proven to be an effective measure for scour protection in most engineering problems, including the design of wind farms. The objectives of this research are (1) to study the processes related to scour protection and seabed interaction, and (2) to put into practical use the knowledge to be advanced from this research. Experiments are conducted in the current/wave-flume facilities of the Hydraulic Laboratory of the Coastal, Maritime & Structural Engineering Section. For the numerical investigations, a three-dimensional general-purpose flow solver, EllipSys3D, will be coupled with a morphologic model to simulate several related cases. [65]

Stone protection in/on a liquefiable soil bed

When the seabed sediment is fine the seabed soil can be liquefied under large waves. Two special cases are under investigation: (1) stones are dumped over a backfill to protect the backfill against scour; and (2) stones are dumped on a pipeline lying in a trench and the trench is backfilled with the native soil to protect the pipeline against fishing gear etc. The objective of the present investigation is to study/disclose the actual

processes regarding the interaction between the stone protection layer and the soil, and on the basis of this, make recommendations for the use of stone protection in engineering practice. [193]

Wave boundary layers over a stone-covered bed

Wave boundary layer over a bed with large roughness, simulating stone/rock/armour block cover on the sea bottom, is studied. The roughness elements used in the experiments are stones ranging in size from 1.4 cm to 3.85 cm in one group of experiments and regular ping-pong balls measuring 3.6 cm in the other. The orbital-motion-amplitude-to-roughness ratio at the bed is rather small, in the range O(0.5-5). The mean and turbulence properties of the boundary-layer flow are measured. Various configurations of the roughness elements are used in the ping-pong ball experiments to study the influence of packing pattern, packing density, number of layers and surface roughness of the roughness elements.

Damage and imperfection tolerance of fibre reinforced composite structures

In this project prediction of in-service damage and production imperfection tolerance of fibre reinforced polymeric composite structures, especially debond damages in sandwich structures, is considered. Future extensions will include improving damage tolerance by taking advantage of non-linear phenomena growth of debonds in foam cores sandwich structures under cyclic loading. Imperfections on the buckling capacity of composite shells in wind turbine blades will also be investigated. [5a, 40, 111, 137, 142, 148, 161]

Placement and efficiency of dampers on structures

A general method for placement and calibration of dampers has been developed [Main & Krenk, J. Sound Vib., 2005]. It is based on a discrete model of the structure as obtained e.g. by the Finite Element Method. The damped mode of vibration is assumed to be a combination of the free vibration mode and the corresponding mode in which the dampers have been

locked. For special structural elements like cables the two-component representation of the damped modes can be carried out in closed form, leading to a simple design oriented format. This format is used in the de sign of major new bridges. [31, 36]

Optimal calibration of tuned mass dampers

A complete analysis of the classic Tuned Mass Damper (mass supported by a spring) has been performed and it has been demonstrated that the optimal damping is about 15% higher than the classic value. The new results and theoretical results for the use of multiple dampers on flexible structures have been used in the initial design phase of the new Langelinie Footbridge in Copenhagen, currently under construction. [153]

Numerical computation of dynamic response of structures

A new algorithm for numerical computation of the dynamic response of structures with 4'th order accuracy – in contrast to the 2'nd order accuracy of the classic algorithms – has been developed for linear structural dynamics. It has excellent high-frequency behaviour and by eliminating unintentional dispersion effects introduced by most discrete models it is ideal for wave propagation problems in solids, e.g. ground and structure borne vibrations. It has also been demonstrated that the classic high-frequency improvements can be obtained as special cases of a new formulation in which artificial damping is introduced via a first order filter [32, 152].

Research activities for the Indoor Environment Section (IK)

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The Indoor Environment Section constitutes the core of the International Centre for Indoor Environment and Energy, established in 1998 based on a 10-year contract between the Danish Technical Research Council and DTU.
The section's interdisciplinary research program aims at developing design criteria and innovative technical solutions for the creation of healthy, comfortable and productive indoor environments which 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

Aircraft cabin simulation studies

The indoor environment in aircraft cabins is studied in a simulated section of an aircraft cabin with 21 seats constructed inside a climate chamber. In previous experiments (Strøm-Tejsen et al. 2005a, b; Sun et al. 2005) the benefits of increasing the outside air supply rate and of operating available types of air cleaners in the return air stream were examined. In 2005 the research continued with exposing subjects to four simulated flights, each lasting 11 hours, in a 2x2 design in which outdoor supply rate was set to two levels and an air cleaner was either operated or idle at each outside air supply rate. It was found that more symptoms of distress were indeed reported in the last 4 hours of an 11-hour simulated flight than in the first 7 hours. The symptoms were more effectively alleviated by operating the air cleaner than by increasing the outside air supply rate by an amount which in turn would cost $20M per aircraft in increased fuel consumption during its service life.
The latest experiments investigated whether the high

Physiological measurements performed inside the cabin.

levels of ozone encountered at 10km altitude, which typically leads to gate-to-gate average cabin ozone concentrations of 80 ppb, is responsible for some or even all of the negative symptoms reported by passengers and cabin crew. The analysis of the data obtained in these experiments is still in progress, but it is already clear that ozone can be responsible for many of the symptoms commonly reported by passengers and cabin crew. This suggests that the lower levels of ozone encountered in buildings at ground level may be responsible for some indoor air problems. If later experiments at the Centre lead to the conclusion that this is true, ozone elimination may become part of an innovative and energy-efficient use of air cleaners in return air as an alternative to increased ventilation rates. [190, 191, 194, 211]

Human subjects performing simulated office work during the exposure in the climatic. chamber

New energy efficient concepts for the cooling of buildings

There are different approaches to reducing the energy consumption when controlling the climate in buildings. These include the use of water-based radiant cooling systems which may also utilize the building's thermal mass combined with night cooling or heating, or cooling by pipes embedded in floors, walls or ceilings (slab heating or cooling).

The energy-saving advantages of such systems are high water temperatures for cooling and low water temperature for heating. This will increase the efficiency of the cooling systems (chillers, heat pumps) and the potential for using renewable energy sources such as ground heat exchangers, evaporative cooling, adsorption heat pumps etc. Besides by using the storage capacity of the building the peak loads can be reduced and a major part of the energy use can be transferred to night time. Such systems are often associated with

indoor temperatures which drift somewhat during the day. In an experimental study we are investigating the influence of temperature drift on the occupants comfort, health and productivity, based on which recommended limits for temperature drifts will be established. The Centre has been involved in several building projects (New Bangkok Airport, Operaen) using this technology. Through an EU-ASIA program the Centre is involved in a demonstration project in Malaysia, where the concept will be used in a zero-energy office building. At the same time we will be involved in a Danish demonstration project supported by PSO funding. [42, 43, 83, 84, 85, 169]

Allergies and indoor environments

Asthma and allergies are increasing worldwide. The causes are not known. Changes in the quality of the indoor environment are amongst 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 (Dampness in buildings and health study, Selma study, Day care centre study), Bulgaria (Allhome study) and Singapore, and are planned in Taiwan, and Tianjin (China), in order to increase the power of the study by studying extremes. The studies are aimed at testing and generating hypotheses on why people are getting ill in buildings, with special emphasis on exposures due to “dampness”, building material emissions, ventilation, pets and electronics. Significant and community-wise highly important findings have already been published in scientific publications (effects of plasticisers - phthalates in indoor dust, pet-keeping and of home ventilation rate), but more results will be available during 2006. Some of the findings are tested in controlled human exposure studies in DTU’s indoor environment chambers. [8, 9, 10, 11, 38]

Selected research topics

Indoor environments and human comfort, health and productivity

Buildings which make their occupants feel unwell are unacceptable. Extensive field and laboratory studies are ongoing to identify what makes buildings healthy. [8, 9, 10, 11, 37, 42, 43, 97, 107, 109, 130, 131, 140, 147, 157, 167, 168, 169, 170, 190, 191, 197, 205, 206, 211, 213, 215, 216, 217, 230, 232, 236, 237, 238]

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. [37, 44, 57, 220, 226, 231, 252, 253]

Pollution sources in ventilation systems

We are rethinking how air should 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. [110]

New methods for air cleaning

The use of a regenerative desiccant rotor may decrease the requirements for outdoor air supply to a building. Extensive testing is ongoing. [129, 151, 186, 194, 234]

Combined exposures to several indoor environmental parameters

Development of models for predicting human response to co-occurring loads from e.g. noise, the thermal environment and poor air quality. [115]

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. [19, 38, 99, 108, 180, 208]

Particles

The section is addressing important and neglected questions such as the role of indoor particles in 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. [195]

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Research activities of the Fluid Mechanics Section (FM)

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, biological flows and the wetting and slippage of fluids at nanoscale.
Fundamental research in material science includes studies of materials under nanoscale confinement.
In computational fluid mechanics (CFD) we use both commercial codes and codes developed in-house. In experimental fluid mechanics (EFD) we mostly use optical methods, such as Laser Doppler Anemometry (LDA), Particle Image Velocimetry (PIV) and related techniques. [41, 44, 51, 52]

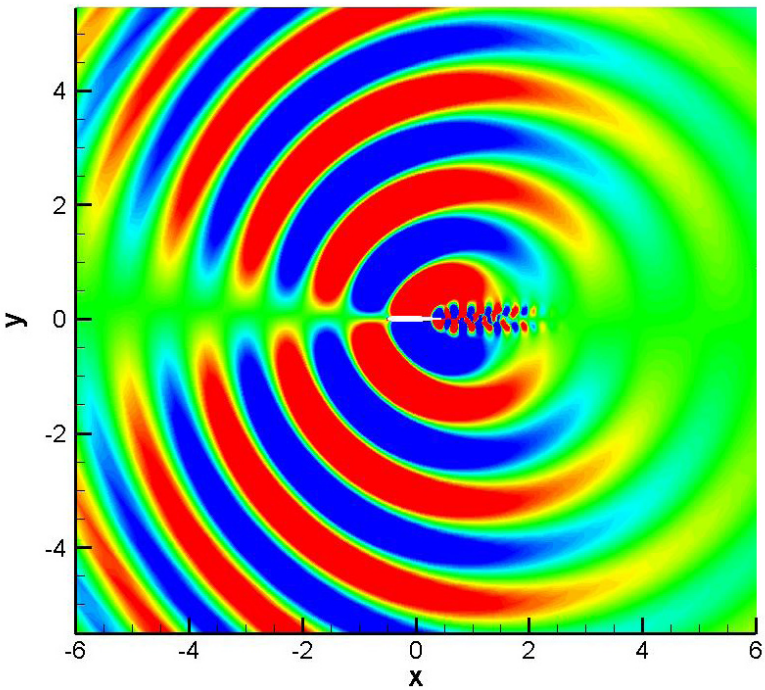

Figure 1. Propagation of acoustic pressure waves.

Selected research topics

Noise from wind turbines

Noise is an important issue in today's wind turbine designs. In order to predict broadband noise, various non-linear aero-acoustic models are being developed. Current research is focused on aerodynamically generated noise from flow past wind turbine blades. The main part of the research project is sponsored by the Danish Independent Research Council (FTP). Figure 1 shows the propagation of acoustic pressure waves from the flow past a NACA0012 airfoil at 0 degree angle of attack an at Re=20.000 [71, 100]

Investigation of Vortex Generators

A project funded by DSF (Danish Strategic Research Council), which was initiated in 2005, where the flow

induced by vortex generators will be studied mostly experimentally but also numerically. A benchmark of the flow past a bump mounted with vortex generators will be created in order to validate various numerical schemes for computing the flow. The flow will be thoroughly measured using Particle Image Velocimetry (PIV) and Laser Doppler Anemometry (LDA).

Wind turbine aerodynamics

Research on wind turbine aerodynamics has for many years been one of the main activities of the Section. Various aspects are studied using state-of-the-art Navier-Stokes computations and blade-element/ momentum (BEM) techniques. In the past year the work has been focused on further development of the BEM technique, especially with respect to 3-dimensional and unsteady effects, and the understanding of vortex dynamics in the wake. A joint Mexican/Danish PhD project was initiated were the onset of turbulence will be estimated in order to further improve the accuracy of CFD based flow models of flow past a rotating wind turbine blade. [58, 59, 91]

Database on wind characteristics

During 2005 the wind database has been further enlarged with more wind data and wind turbine response measurements. Still a number of investigations are based on wind field measurements extracted from the wind database data. [25, 78, 79]

Modelling the flow in wind farms with special emphasis on wake effects

With the development of wind energy evolving towards large wind farms with many wind turbines in a small area and often arranged in a line or a grid, many new national and EU funded projects have been granted to investigate the disturbance of the incoming flow to a single wind turbine rotor from all the other upwind wind turbines. As a standard it is so far allowed to assume an increase in the general turbulence intensities calculated by some relatively simple formulas. Several of the new projects focuses on a more realistic de-

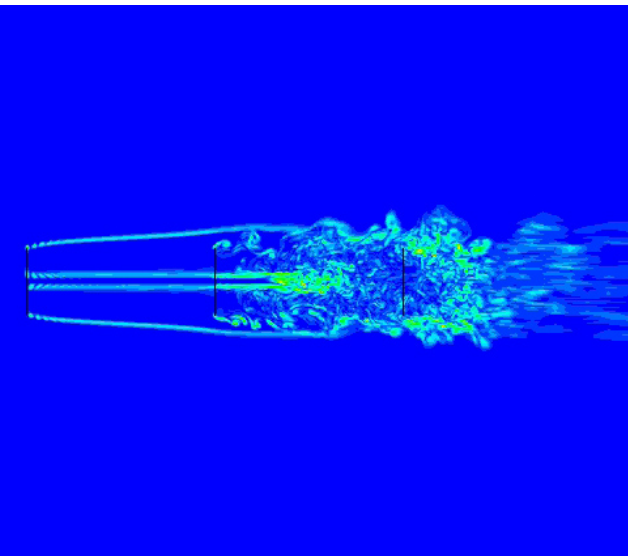

Figure 2

scription of the real inflow using e.g. CFD to model the influence of the flow past each turbine. Figure 2 shows how the flow past the three first turbines in a row aligned with incoming wind breaks up into something similar to turbulence. When the turbines in addition are yawed as shown in Figure 3, also the tip vortex from the upwind turbine is hitting the downwind turbine causing a severe pulse loading on the blades of the downwind turbine every time a blade is passing a tip vortex. [96]

Thermodynamics of nanomaterials

Our understanding of the thermodynamic behaviour of materials is largely based on experimental data acquired from the bulk material.
Large deviations from bulk properties are well known, e.g. the melting point of solid particles is reduced as the size of the particle reaches the nanoscale.
The research project is focused on the influence of confinement on the thermodynamic properties of nanoparticles.
The work is conducted with ETH Zurich and the Paul Scherrer Institute, Switzerland.

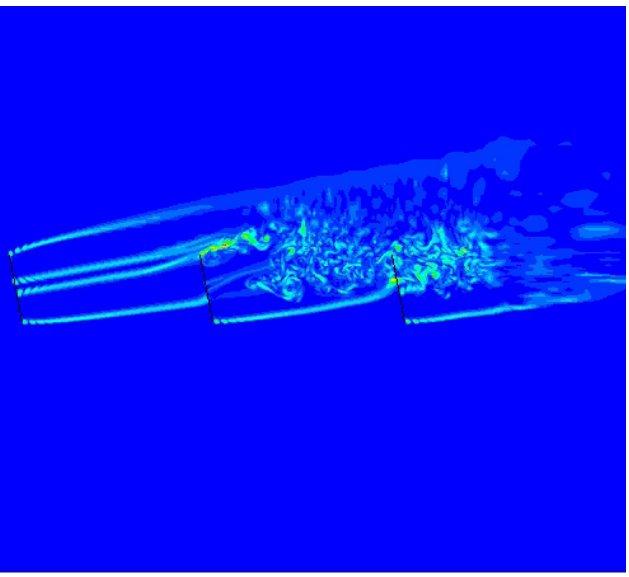

Figure 3

Multiscale simulations

The numerical simulation of nanofluidic devices often requires an atomistic description to capture the non-bulk behaviour of the individual nanoscale elements. Coupling the nano device to the exterior microfluidic system using an all atomistic “direct numerical simulation” approach is computational prohibitive, and presents an inherent multiscale problem. The research project involves the coupling of atomistic molecular dynamics simulation techniques with continuum computational fluid dynamics methods.
The project is performed at ETH Zurich, Switzerland.

The static and dynamic behaviour of carbon nanotubes in water

Carbon nanotubes are novel structures with unique mechanical, electrical, thermal and chemical properties. As such they offer great promise of

application in nanotechnology and intense research has been devoted in the past decade to explore and quantify these possibilities. The present research project presents fundamental studies of carbon nanotubes immersed or transporting water.
The work is performed with ETH Zurich, Switzerland and NASA Ames Research Center, USA.

Development of parallel particle-mesh library

Particle methods are a powerful unifying formulation for the simulation of continuum and discrete systems. The grid-free character of particle methods is relaxed by the introduction of a mesh for the re-initialisation of particles, the efficient computation of the field equations, and the discretization of differential operators. The coexistence of meshes and particles presents a set of challenging parallelization issues which in the past have hindered the broader use of particle methods. The present research project addresses these key issues in the framework of a scientific library for large scale parallel simulations using particles. Prospect applications range from atomistic simulations, dissipative particle dynamics of mesoscopic systems, to smooth particle hydrodynamics and particle vortex methods for continuum fluid- and solid mechanics, to granular flow, plasma- and astrophysical applications.
The research project is conducted with ETH Zurich.

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Research activities of the Energy Engineering Section (ET)

The research in the Energy Engineering Section is divided in four main areas:

- Energy systems and power plants
- Internal and external combustion engine
- Refrigeration
- Biomass for power production

Energy systems and power plants include process integration and analysis and optimization of thermal systems and components with special focus on power plants. Biomass for power production is mainly concentrated on thermal gasification of biomass and utilisation of gasification gas in IC-engines. Main activities of the engine group is utilisation of alternative fuels in engines (internal combustion and Stirling engines) and emissions and new activities concerning large engines for ship-propulsion has been initiated during 2005.

Laboratory experiments, design and manufacture of pilot plants and field tests of existing systems are also 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. The Emphasis is placed on process optimization, energy efficiency, and automatic control.

Success for Hydrogen Vehicle in Shell Eco-Marathon

As a part of the CDIO (Conceive Design Implement and Operate) teaching program at the Energy Engineering Section students developed a prototype car driven by dimethyl ether (DME) instead of diesel in

The DTU Eco-car Team and "DTU Dynamo" in 2005.

a combustion engine. This prototype car took part in the Shell Eco Marathon at Nogaro Raceway in 2004 and was very successful.

However, the Section had further ambitions and it was decided to build a new car for 2005, DTU Dynamo, based on a fuel cell driven vehicle using hydrogen. Hydrogen is often mentioned as the future fuel for transportation. And indeed hydrogen is a suitable fuel for a vehicle engine. It can be used almost directly in the combustion engines of today and it can be applied to a fuel cell, which produces electricity for an electric motor.

"DTU Dynamo" was ready in time for the Shell race in 2005. It was an "Urban Concept" vehicle, which means that the vehicle can be approved for ordinary road application with minor modifications. For example

the driver must be able to sit upright in a chair as in ordinary cars, and the vehicle must have four wheels as well as front and rear lights. In other words the vehicle looks like a “real car”. On the other hand it is much heavier than the “prototype” vehicles “DTU Innovator” and “Spirit of Copenhagen”. “DTU Dynamo” weighs about 160 kg.

“DTU Dynamo” was an incredible success! The vehicle won the urban concept class and was without any doubt the most fuel-efficient vehicle - 671 km /litre of petrol equivalent. No other competitor got anywhere near this result and naturally it was a new world record in this class!

Selected research topics

Simulation and process integration

Development of mathematical models and methods of analysis for energy systems and components using numerical simulation. [23, 123, 124, 178]

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. New power train concepts for vehicles. [90, 103, 184, 187, 225a, 235, 243,]

Stirling engines

Optimization of engine performance; component and process development; operation on natural gas and renewable fuels such as wood chips and biogas. [212]

Gasification

Virtually tar-free gas is generated from straw and wood chips for use in small gasengine-based cogeneration plants. [103, 104, 222, 223]

Refrigeration

Indirect cooling and substitution of CFC and HCFC refrigerants with natural refrigerants.

Power plants, combustor and boiler technology

Development of new or improved processes and process control for power plants by utilization of computational tools. [177]

District heating

Field measurements of heat losses and operational optimization of distribution systems for district heating. [12, 75, 76, 80, 98]

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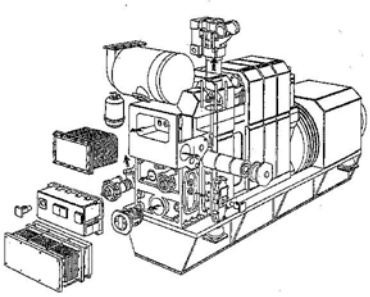


K&P research covers the nature and composition of mechanical and mechatronic products and systems.

Research activities of the Engineering Design Section (K&P)

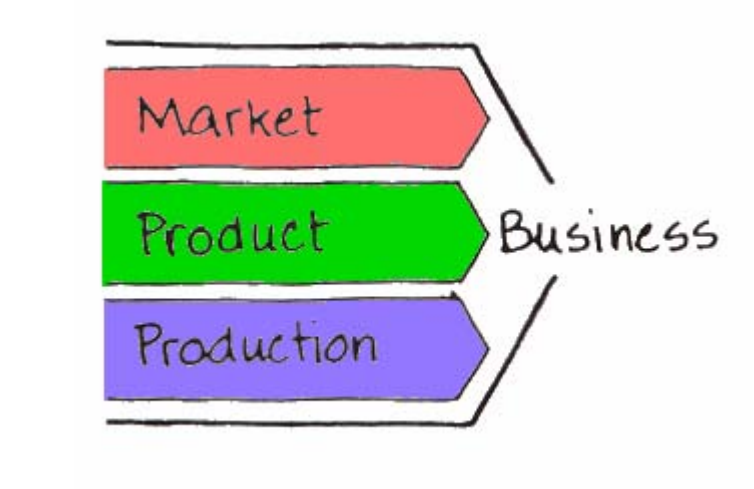
The research activities of the Engineering Design Section (K&P) focus on four key areas:

- Product Development
- Engineering Design
- Control Engineering
- 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 highly synthesis oriented, with emphasis on innovation throughout the engineering design and product development processes, making the utilisation 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 include major Danish companies such as Vestas, Bang & Olufsen, Lego, Danfoss, Novo Nordisk, York, and Nokia. But K&P also cooperate closely with a number of small and medium size enterprises.

K&P is actively involved in the organisation of a number of conferences and networking activities, including the international 'Design Society' (organisers of the ICED conferences) and 'Norddesign', and K&P are hosting the national 'Produktudviklingsdagen' (conference on Product Development), 'Mechatronics Day'' (conference on Mechatronics) and 'Seminar om Smøreteknik' (a two day conference on Lubrication in cooperation with the Scandinavian company Statoil). Also, K&P are organising a series of workshops on innovation and product development under cipu (the Centre for Innovation in Product Development).



K&P research also covers the synthesis oriented processes of innovation, engineering design and product development, leading to products and systems.

Selected research topics

The Design and Innovation Research School

Primo 2005 the research school Design & Innovation was established as a formalized cooperation between SDU, AUC, KU, DTU and Risø. The school integrates social and material dimensions of design, focusing on technological systems.

The cooperation was defined in a proposal for constitution and the application for quality support and funding to Forskeruddannelsesudvalget (FUU, the Danish Board of Education of Researchers). The research school is closely related to cipu (the Centre for Innovation in Product Development) through similar research profiles and through the use of cipu's workshops as meeting point for students and supervisors.

During 2005 the cipu workshops "Our future depends upon…" have created very promising corporate contacts. A further application for grants primo 2006 and a stronger formalisation of the research school are in the pipeline.

The DTU summer school 2005 on engineering design research, hosted by Malta University. The summer school is held every year - up till now 350 PhD's have joined the school.

Information systems for engineering design

In order to design proper information systems for

engineering designers, it is important to understand how the engineers enrich their knowledge base during the design process, what motivates their queries for information, which strategies they use and what issues influence their information seeking behaviour. This research is based on a series of empirical studies carried out with engineering designers and intends to draw specifications for proper information systems to support conceptual design. [179]

Engineering design knowledge

Engineering Designers spend around a quarter of their time searching and providing information. The aim of the research is to develop tools to improve the engineering design process and engineering design products. The research focus on understanding the use of knowledge and experience in engineering design through the use of empirical studies carried out in industry. Current research projects include an understanding of engineering designers' competencies and how they may change in the future as well as the development of ontology for indexing design knowledge. The research also investigates the impact of change on a product. [3, 101, 102]

Conceptualisation

The early synthesis activities in a product development project are very important because the product's competitiveness is built in – or left out – during the conceptual phase. In the current situation of globalization and customers requesting products satisfying not only needs but also supporting or signalling the customers attitude and perception of value, it has become more and more important for companies to develop innovative and attractive products. Danish companies are now recruiting concept developers or concept engineers.

The traditional understanding in design methodology literature that the goal of the concept phase is to synthesise a solution principle is no longer adequate. In the recent years we have engaged in the development

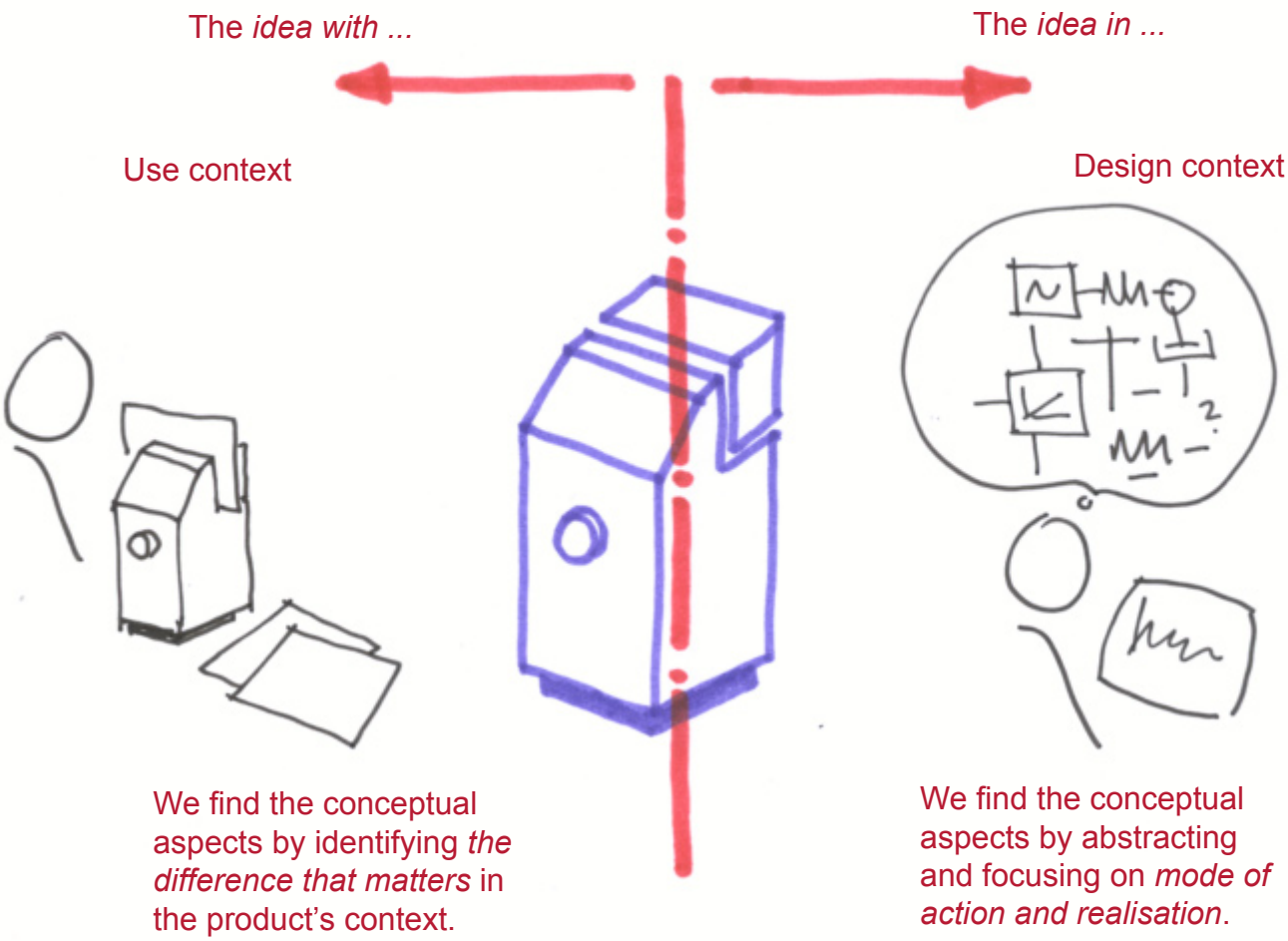


Figure 4. The design concept has to articulate two ideas: the idea with and the idea in.

of new knowledge of conceptual designing and design concepts. We have focused on the research questions: What is a proper understanding of a need? What is the nature and content of a design concept? What is a rich and sound design concept description? Furthermore, we have broadened our perspective from a technical understanding to include the socio-technical aspects in the concept activities.

We have proposed an enhanced understanding of design concepts based on two elements. Firstly, the concept for a new product may be seen from two sides, a need/market-oriented and a design/realisation-oriented. The need/market-oriented side explains the conceptual new way the design solves its task; this is the *idea with* the concept. The design/realisation side explains how the concept creates the necessary functionality and structural realisation for doing so; this

is the *idea in* the concept. Secondly, what is seen as conceptual depends upon what is already created in the actual area concerning solving the task or concerning the principles or design of the artefact. Thus, a concept has to articulate *a difference that matters* in the product's context.

Based on the enhanced design concept understanding we are currently developing a mindset for innovation, and we see the need to develop models to carry and articulate the *idea with* during the product development process. [135, 181]

Product service system design

A number of theories describe the necessary improvements in global environmental performance in order to maintain status quo in our eco-systems. These theories are far reaching in their ambitions and it is not immediately apparent how we can achieve, for example, a factor 20 improvement in our environmental performance.

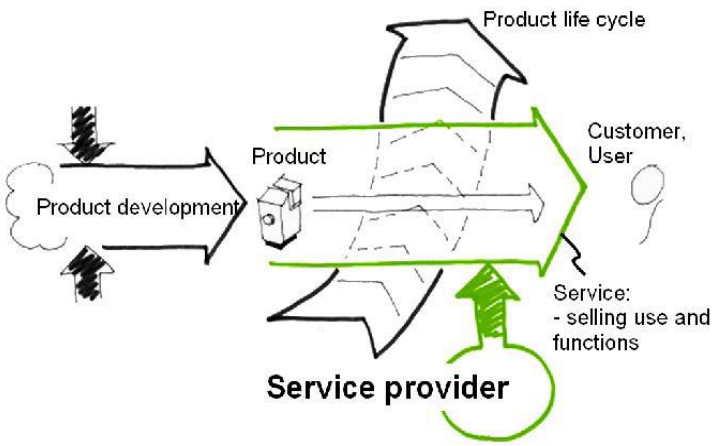


Figure 5. The approach of Product Service System Design is introducing a new dimension of Integrated Product Development - the result of this is a new mindset.

One attempt, however, has recently emerged, which combines the product as an artefact with the service which the product provides to the user. Through the combination of these two facets, the company retains ownership of the physical artefact and instead provides what the customer really wants – the actual functionality from the product. This enables a series of potential improvements to the product's performance throughout its lifecycle.

A shift in focus to product service system design and development could provide the lift required for industry to overcome the barriers to considering environmental and sustainability issues in current product development processes. We have introduced an approach to environmentally conscious design focusing upon *service* as the design object, and this approach seem to support the

creation of radical environmental effects.

Platform based product development

The main characteristic of platform development is a division into a preparation phase (development of the platform) and an execution phase (application of the platform). Experience from several companies and state-of-the-art literature shows that platform development is a means to achieve a quantum leap in company performance. Seen from a practice point of view there are also several challenges, which have to be dealt with in order to successfully implement platform based product development. Seen from a theoretical point of view, design theories are only valid for individual products and have to be expanded to cover product families and assortment. Some of these are targeted in the research in the section. Research in platform based product development focuses on:

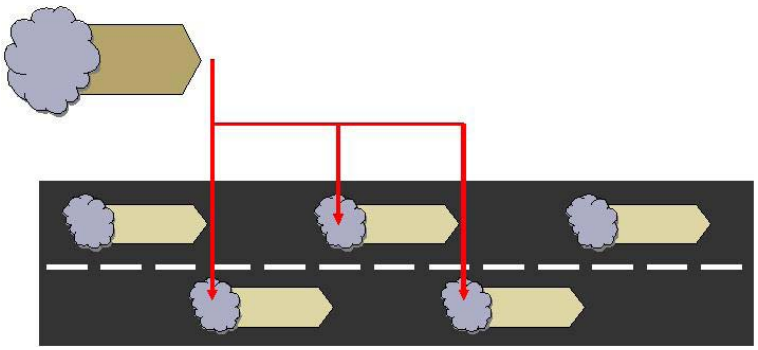


Figure 6. Platforms and modularisation as a means for multi-product development.

- Modelling of architectures, modules and interfaces
- Documentation of platforms by means of PDM systems
- Creating the foundation for decisions concerning scope and contents of platforms by means of business case principles
- Modelling and diagnosing product assortments
- Multi level road mapping

Autonomous agricultural machinery

The environmental impact of agricultural production is very much in focus, while a competitive market demands high efficiency. Many years ago, weeding was done manually without the use of pesticides. The development of an autonomous agricultural vehicle with sensors for weed detection will once again allow weeding without pesticides. The development of autonomous agricultural machinery explores this challenge by applying the knowledge of mechatronics and robotics at K&P and collaborating with external partners.

Figure 7. The cipu workshops “Our future depends upon…” gathered a large corporate following in 2005.

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 nonlinearities. The areas of interest in this research project are the challenges 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.

The research framework SPACES and the cipu centre

K&P has formulated a research framework (handlingsplan) SPACES, jointly with the department of Manufacturing Engineering and Management. The individual projects which are being launched under SPACES 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. SPACES aim to establish a national Centre for Innovation in Product Development (cipu) at DTU with a number of research institutions as partners. Currently K&P are at the head of the interim board at cipu and K&P are coordinating the concerted actions at DTU in relation to cipu.

Teaching Programme

Studying at MEK

MEK offers teaching programmes and courses at undergraduate, graduate and Ph.D. levels.

The teaching programme is very comprehensive and covers coastal engineering, naval architecture, material and structural mechanics, indoor environment, energy systems, fluid mechanics, engineering design and product development.

A reform of higher education programmes, known as the Bologna Process, was initiated at DTU in 2004. Mutual recognition of foreign qualifications is the core of the Bologna collaboration. The recognition facilitates mobility for persons with a higher education and makes further education in other European countries possible. Therefore the original 5-year master degree is being replaced by a 3-year B.Sc. degree followed by a 2-year M.Sc. degree to allow students to movement easily between countries.

Consequently, DTU now offers three separate teaching programmes in engineering in parallel. The 3.5-year B.Eng. programme, the 3-year B.Sc. programme and the 2-year M.Sc. programme.

MEK is responsible for a considerable part of the curricula's in mechanical and energy engineering as well as in design and innovation.

New teaching facilities

Prior to 2004 MEK's sections were scattered all over campus. During 2004 all the staff relocated to three adjacent buildings. New teaching facilities were established in former laboratories in the buildings and the classrooms were equipped with up-to-date teaching equipment.

The relocation has proven very successful from the

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Four students on the first semester course in Product Analysis and Communication are examining the motor for a lawn mower.

perspectives of both students and teachers. The distance between classrooms and staff offices has decreased and the degree of utilization of the facilities has increased considerably, creating an atmosphere of activity and enthusiasm.

During 2005 the teaching facilities were further improved. In two classrooms all seats were equipped with PCs, allowing the students to make simulations, analysis, modelling etc. during lectures. A new laboratory for the B.Eng. course in automation was equipped with the latest programmable controllers, making it possible for the students to simulate and to build real automation systems.

Teaching methods

A broad range of teaching methods is employed at MEK, i.e. lessons, classroom teaching, coursework, projects and laboratory experiments.

A number of our courses utilize computer analysis, simulations and CAD/CAM-modelling. Using the latest computer-based tools takes high priority, partly to provide students with the most up-to-date knowledge and partly to make our candidates attractive to industry.

For B.Eng. and B.Sc. students emphasis is placed on the use of commercial software, while M.Sc. 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 feedback from the new programme is very positive.
In 2005 the number of applicants for the programme exceeded the number of places. Thanks to this new programme, DTU has attracted students who would otherwise have studied elsewhere.

Hands-on with big machines ...

Evaluation of the teaching programme

All courses are evaluated through DTU teaching intranet. The aim is to obtain input which is used to improve courses to the mutual benefit of teachers and students. As part of the evaluation process, the head of department and the department study board examines the results of the evaluation to see where improvements are required.

Professor Peter Friis Hansen, MEK, has developed a very efficient computer programme, which presents the evaluation results graphically, giving a very good overview. The continuous monitoring of the quality of teaching has proven very fruitful. Other departments at DTU are now utilizing the software in their evaluation process.

Learning achievements - from teaching to learning

A new curriculum was introduced in 2003 for the B.Eng. programme in mechanical engineering. The curriculum structure and the pedagogic/didactic idea were inspired by the CDIO initiative, which originates from a project from 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).

A further achievement in the B.Eng. programme, welcomed 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.

International master programmes

MEK has two international master programmes, “Wind Energy” and “Coastal and Maritime Engineering”. Both programmes have attracted a considerable number of students. 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.

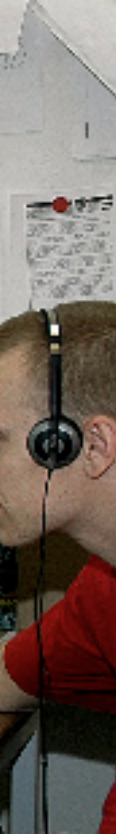
Heads-on - students of Design and Innovation in deep thoughts

Teaching efficiency

The number of students at the department has increased over the last few years due to the new teaching programmes. This has lead to a significant increase in the earning of student credits per member of teaching staff. Thanks to staff efforts, this has happened while the quality of the teaching has improved.

The DTU study administration

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



MEK Administration

MEK is a large department employing about 40 administrative staff. The Department was relocated, starting in 2004, to 3 adjacent office buildings with connected laboratories. The physical relocation of the employees into the new office space was completed by end 2004. In 2005 a major challenge has been the reorganization of technical and workshop support for the department, as well as some administrative services.

A number of smaller workshops were combined into a new MEK workshop. The workshop is located in two large laboratory halls, which were converted to a modern workshop with facilities for manual and automated mechanical treatments. The workshop includes a well-equipped room, where students can work with mechanical treatment.

Classrooms were established simultaneously with the office space in 2004. The majority of the classrooms are situated in the office buildings, but four new larger rooms were created in one of the former laboratory buildings.

During 2005 one additional room has been modernized and converted into a combined classroom and project laboratory. This laboratory is specifically created to support CDIO (Conceive, Design, Implement and Operate) related teaching. A smaller laboratory for mechatronic laboratory work has also been established.

Simultaneously with the modernization of the physical framework for employees and students, the administration is continuously working to improve the service offered to the employees.

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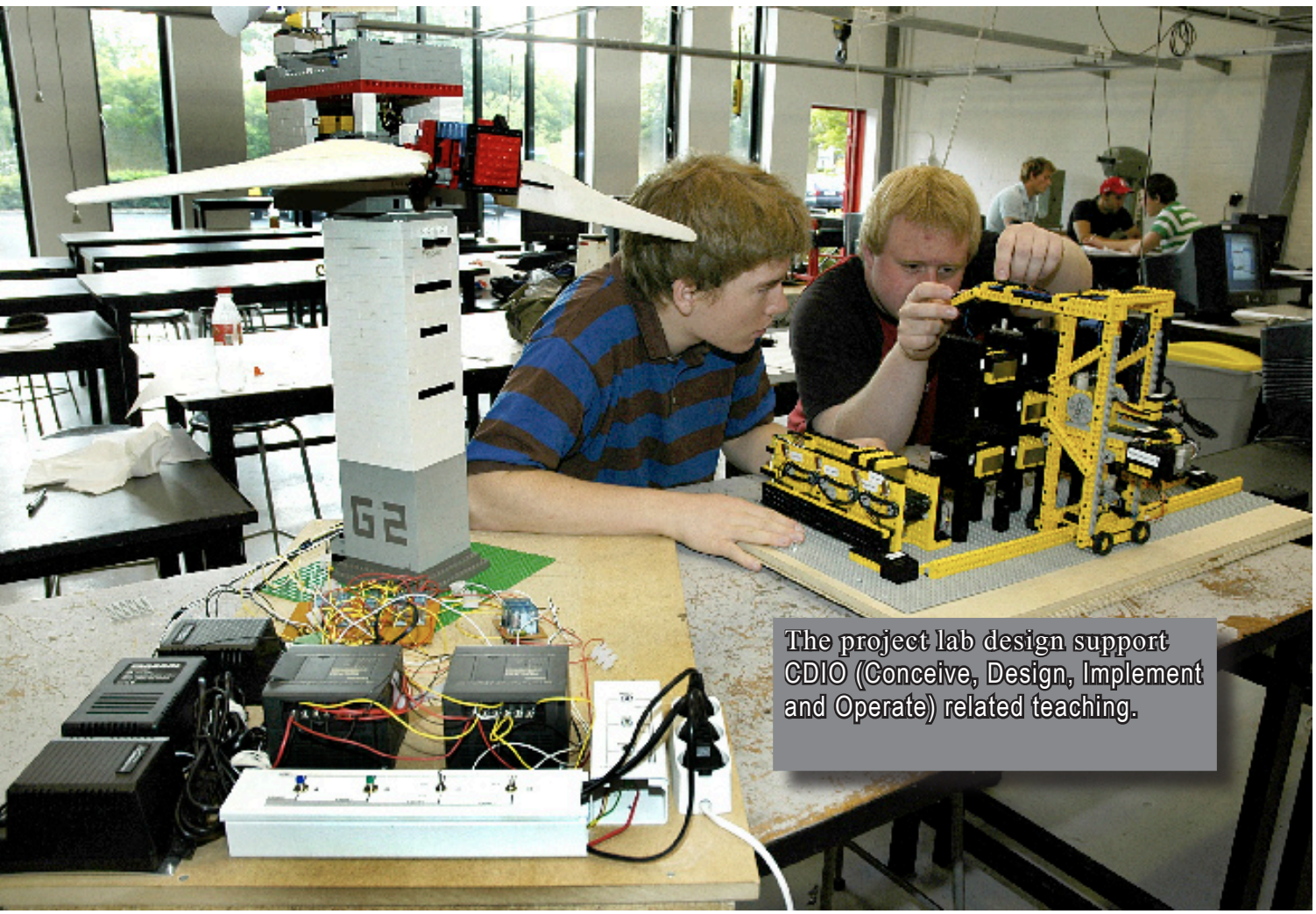
Students at work in a MEK workshop

Workshop and office space for workshop staff - here a member of staff is advicing students.

During 2005 the area undergoing the most significant changes was the accounting support.

The MEK administration is continuously involved in the general improvement of the DTU administrative workflow. MEK participated in pilot projects and work groups within accounting, electronic document management, information databases etc.



The project lab design support CDIO (Conceive, Design, Implement and Operate) related teaching.

Awards

Staff

Publications

Abstracts:

New theory claims when applied to the Mathematical models normal distribution as a function of the

However,

Awards

Finn Conrad: JFPS International Symposium, Distinguished Service AWARD
In honour of outstanding contribution to the JFPS International FLUID POWER 2005
Signed President Shiyern IKEO
Tsukura, Japan, November 10, 2005

Finn Conrad (right)

P. Ole Fanger: Honorary Member of the Society of Danish Engineers, IDA, Copenhagen, Denmark, March 8, 2005

P. Ole Fanger: Honorary Doctorate, Syracuse University, USA, May 15, 2005

P. Ole Fanger: Birch & Krogboe Prize 2005 (250.000 DKK) “for groundbreaking research of great importance for society”, Copenhagen, Denmark, June 7, 2005

P. Ole Fanger: Pettenkofer Gold Medal, the highest Award of the International Academy of Indoor Air Sciences, Beijing, China, September 4, 2005

P. Ole Fanger: Honorary Professor, Harbin Institute of Technology, China, October 24, 2005

P. Ole Fanger: Honorary Medal awarded by the Technical University of Sofia at its 60 year jubilee, Sofia, Bulgaria, November 17, 2005

P. Ole Fanger (left)

Jørgen Fredsøe: Coastal Dynamics Award 2005

David R. Fuhrman: Myhrwold Foundation Ph.D. Special Achievement Award (10.000 DKK), One of two awards given for the best Ph.D. thesis completed at DTU during the 2004-5 academic year, Lyngby, Denmark, October 28, 2005.

David R. Fuhrman (left)

Steen Krenk: EASDs (European Association of Structural Dynamics) medal for excellent research, Paris, France, September 7, 2005

Arsen K. Melikov: Awarded Membership of the International Academy of Indoor Air Sciences, Beijing, China, September 4, 2005

Arsen K. Melikov (right)

Bjarne W. Olesen elected Member of Danish Academy of Technical Sciences, Copenhagen, 4 April 2005

Bjarne W. Olesen: International Honorary Member of the Japanese Engineering Society SHASE, Tokyo, Japan, May 17, 2005

Bjarne W. Olesen (right)

Peter Strøm-Tejsen: The Fanger Research Grant (25.000 DKK) from the Danish Engineering Society DANVAK, Copenhagen, Denmark, April 14, 2005

Peter Strøm-Tejsen (centre)

Pawel Wargocki: Rockwool Grant for Young Researchers (50.000 DKK), Copenhagen, Denmark, January 17, 2005

Pawel Wargocki (left)

Bo Cerup Simonsen: 2005 RINA - Lloyds Register Ship Safety Award, academia category, London, United Kingdom, 26 April 2006.

Bo Cerup Simonsen (right)

Jørn Toftum: Awarded Membership of the International Academy of Indoor Air Sciences, Beijing, China, September 4, 2005

Jørn Toftum (right)

B. Mutlu Sumer and Jørgen Fredsøe have received the 2005 Karl Emil Hilgard Hydraulic Prize, 2005.

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Thomas Mentus Petersen
Hans Jørn Poulsen
Hans-Jürgen Schürmann
Andreas Szekacs
Ralf Tønder

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