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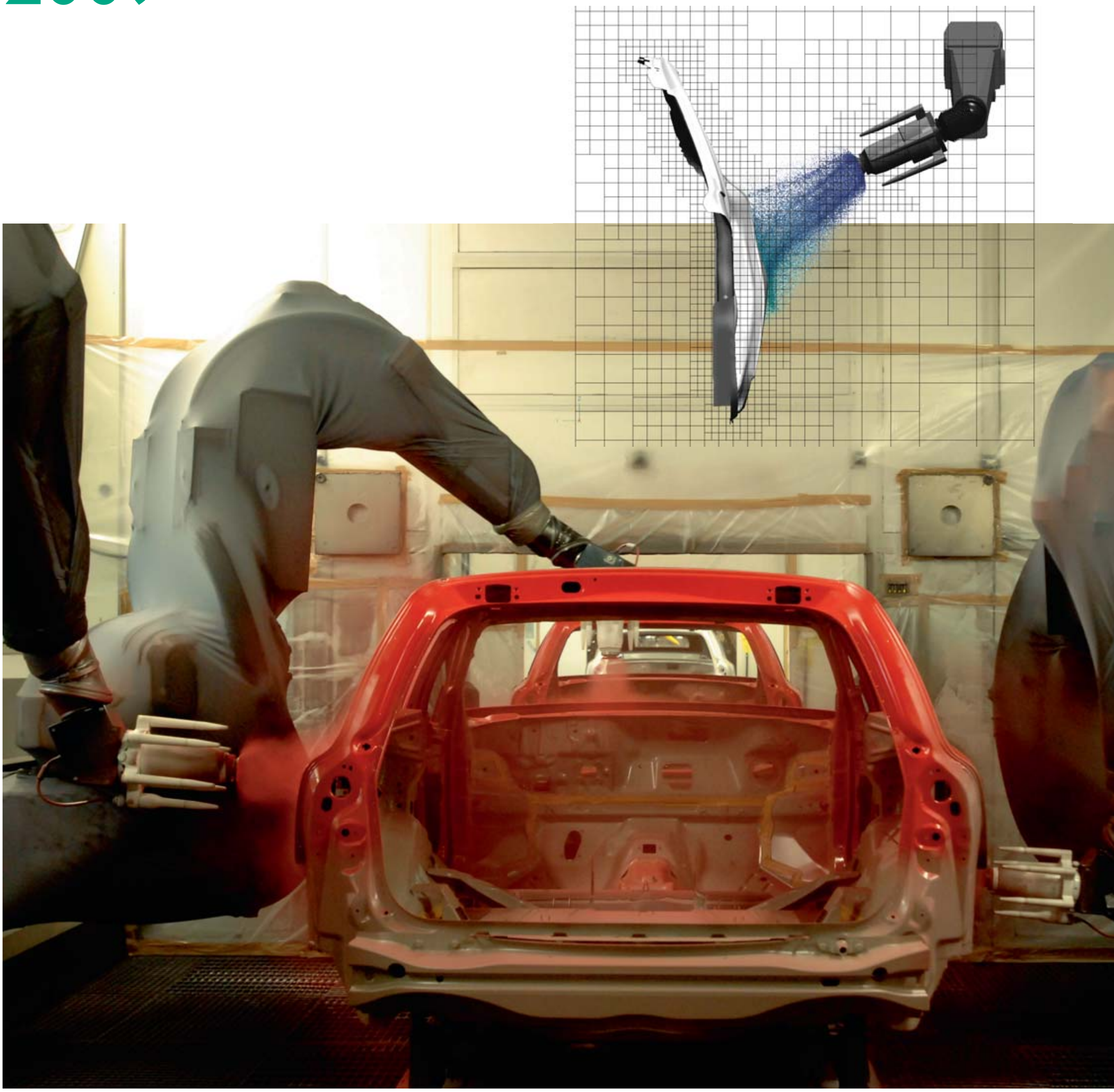
Research Centre

Industrial Mathematics

Annual Report 2009



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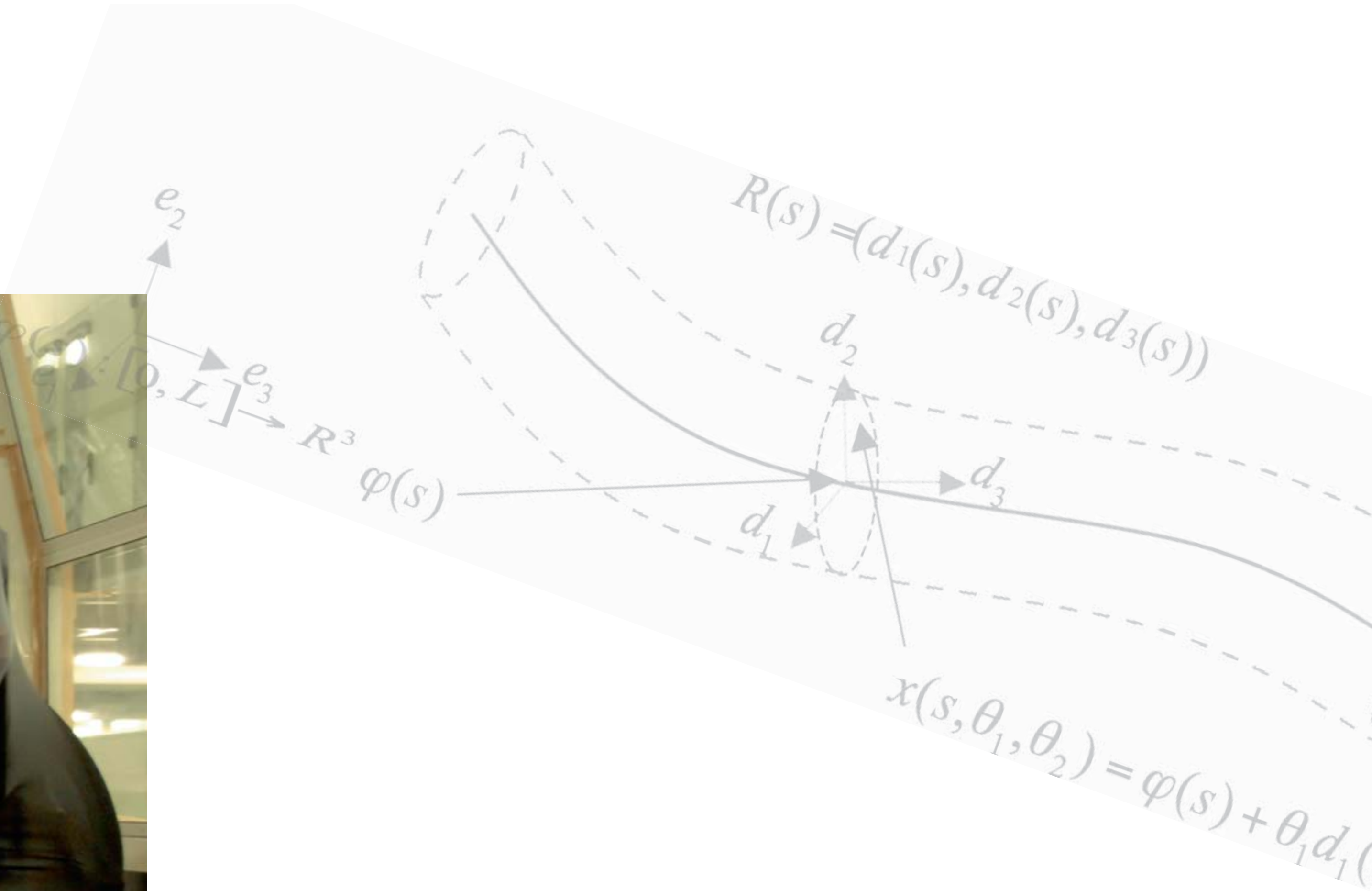

Cover
Paint simulation in IPS Virtual Paint, cf page 14-17 (courtesy of Volvo Car Corporation).

Annual Report 2009
Fraunhofer-Chalmers Research Centre for Industrial Mathematics, FCC
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Contents

Preface and profile

FCC has since start 2001 completed more than two hundred industrial and public projects. We have successfully cooperated with more than seventy companies from different branches. We have seen the power of our vision "Mathematics as Technology" and we are impressed and proud of the trust we enjoy from our founders Fraunhofer-Gesellschaft and Chalmers, from industrial partners, and from public research agencies.

Our mission is to undertake and promote scientific research in the field of applied mathematics to the benefits of Swedish and European industry, commerce, and public institutions. We do this as a business-making, non-profit, Swedish institution. From this perspective the year 2009 is by far our most successful year so far, with the turn-over increased by almost thirty percent.

We note a strong increase of public projects in absolute and relative numbers. At the same time the industrial income has dropped, while industry is to a large extent present as contract partners in the public projects. We expect it will take two to three years to reestablish the normal level of an industrial income around forty percent through a campaign aiming at a broader base of industrial clients including small and medium-sized companies.

Together with our partners Chalmers and the Fraunhofer industrial mathematics institute ITWM we cover a wide range of applications. In 2009 we have intensified our cooperation further, including joint actions with all ITWM departments and with Chalmers Wingquist Laboratory, Chalmers Systems Biology, Chalmers Fluid Dynamics, and within the Gothenburg Mathematical Modelling Centre GMMC.

Two years ago we started the industrial partner group IPG as a successor of the former Swedish Association of Industrial Mathematics STM. The group meets two to four times a year in Kaiserslautern and in Gothenburg to define a research programme from research scenarios, industrial scenarios, and making a synthesis. The first year was on parameter identification and optimization resulting in a proposal on multi-scale, multi-objective simulation and optimization. In 2009 we addressed uncertainty, risk, reliability, and quality with research scenarios presented by GMMC. The research proposal focused on variation mode and effect analysis VMEA.

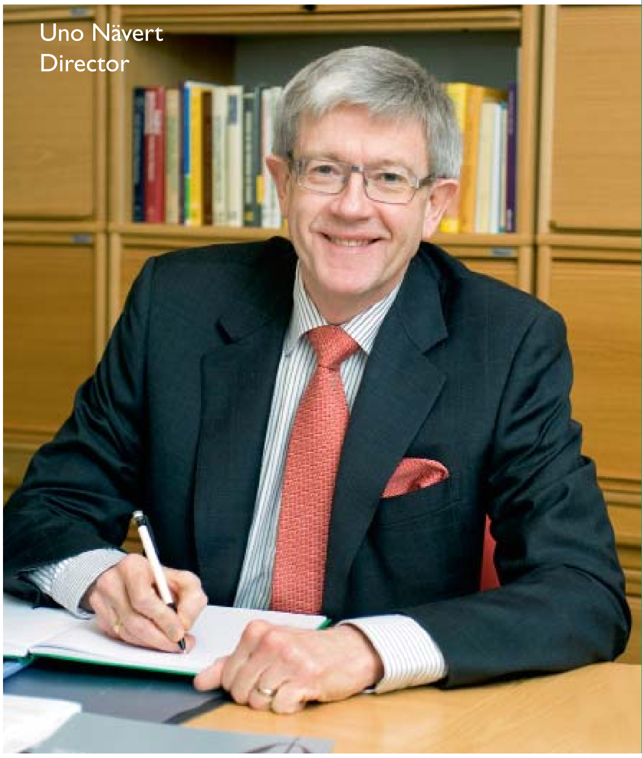
In 2009 we were fortunate to recruit four new co-workers. Our staff of applied researchers is a mix of PhDs and Masters of Science, where about half have a doctor's degree. We believe in a model where an MSc first works in industrial and public projects for two to five years. In this period we encourage participating in conferences and submitting papers to get a research flavour. If a proper project then appears, which would naturally include a PhD student, we are well positioned to offer the project a candidate who would contribute significantly from start, and the interested staff member a possibility for bringing her or his education one step further. Seven of our employed MScs, five of them in 2009, have started PhD studies in this way: five at Chalmers and two on leave abroad.

Two years ago we initiated a campaign to offer an interesting option to Chalmers students while boosting our base for future recruitments. We invite master students from a handful of Chalmers and Gothenburg University international programs with a mathematical profile to information meetings "Earn Money on Mathematics". We describe FCC and our activities, including the possibilities for talented students to be contracted on ten percent of full time, or half a day per week, for work in the Centre, and to do master thesis projects at the Centre with joint supervision from Chalmers and FCC. In 2009 the volume of students doing contracted work and master thesis projects reached ten full-time equivalents.

I thank my co-workers at FCC for your excellent work and my colleagues at Chalmers and Fraunhofer ITWM for our fruitful collaboration. Since start the Centre has earned more than twenty million euros including forty percent industrial and thirty percent public income. Together we are well positioned for the challenges to come!

Below we give a flavour of our activities through describing three profile projects and presenting our competences organized in four departments. Enjoy your reading!

Gothenburg in March 2010



Uno Nävert
Director

The department Geometry and Motion Planning, working in close cooperation with the Chalmers Wingquist Laboratory, has entered the second phase of the ten-year Wingquist Laboratory VINN Excellence Centre for Virtual Product Realization 2007 – 2016. In 2009 the department started four three-year or longer public projects, including a project on virtual paint and a project on intelligently moving manikins. The software platform IPS for rigid body motion planning, robotics path planning, and flexible cable simulation is recognized through licensing by industrial clients in Europe, United States, and Japan. The department has substantial joint development with the ITWM department Mathematical Methods in Dynamics and Durability.

The department Computational Engineering and Design has expanded its work on multi-physics applications involving fluid-structure and fluid-electromagnetics interaction, in particular through projects with Swedish industrial partners together with the ITWM departments Optimization, Flow and Material Simulation, and Transport Processes. In 2009, the department started a project on innovative simulation of paper with Swedish paper and packaging industry and a companion project on dynamic fiber network modelling in a finite element setting through the Gothenburg Mathematical Modelling Centre GMMC. The department is a key partner in the project on virtual paint mentioned above.

The department Reliability and Risk Management has its focus on fatigue life and load analysis of mechanical structures in, e.g., automation and automotive industry. In 2009 we successfully finished a four-year joint project "Guide to load analysis for automotive applications" with the Chalmers Stochastic Centre, Fraunhofer ITWM Dynamics and Durability, SP Technical Research Institute of Sweden, and six industrial partners from Germany, Italy, the Netherlands, and Sweden.

The department Systems Biology and Bioimaging, has continued to grow by adding substantial industrial (pharmaceuticals) and public (EU and GMMC) income to our long-term grant from the Swedish Foundation for Strategic Research SSF. In 2009 we submitted our final report to SSF, summarizing our research and describing the department built up as the result of this grant. Our cooperation with the ITWM department System Analysis, Prognosis and Control has intensified through a strategic project on integration of systems biology, biotechnology, mathematics, and image processing in fundamental animal cell protein production. An exciting project on simulation of atrial electrical activity is presented below.

Facts and figures

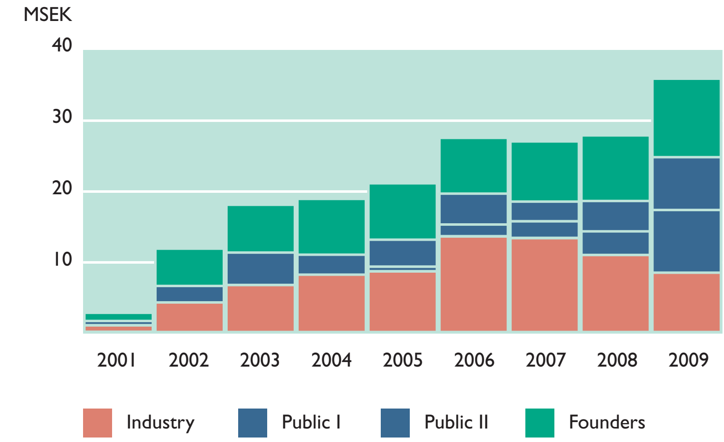
Total income

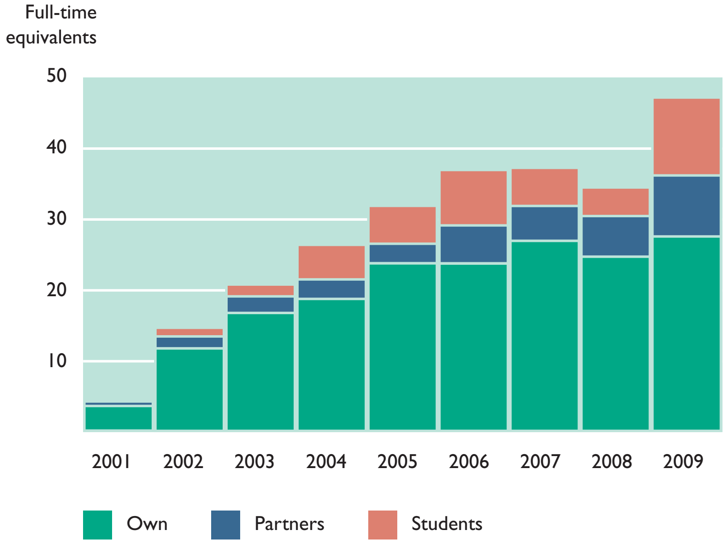
In 2009 the total income increased by 28% to thirty-six million Swedish crowns or three point six million euros after three years of stagnation. The result was again a small positive net, as has been the case every year since our start in 2001.

The profile of the Centre is controlled by its income structure. Here we note a strong increase of public projects, part of which (I) are under industrial command. At the same time the industrial income has dropped. We expect it will take two to three years to reestablish the normal level of an industrial income around forty percent.

Staff – full-time equivalents

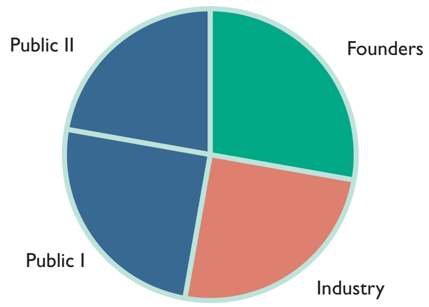
In 2009 the number of staff exceeded forty full-time equivalents. We were happy to recruit four new co-workers and the volume of students doing contracted work and master thesis projects reached ten full-time equivalents.





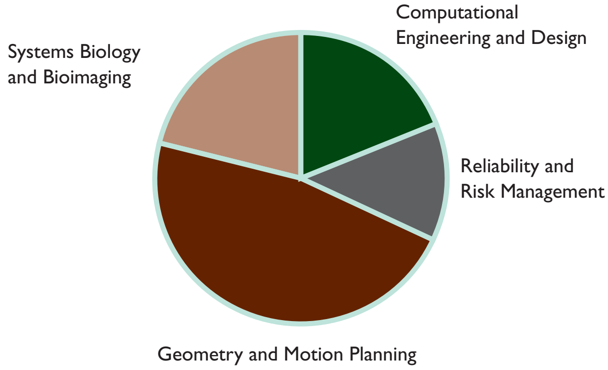
Project mix by income 2009

The profile of the Centre is controlled by its income structure. Here 2009 deviates drastically from previous years, since the project volumes from industry (25%), public financiers (47%), and Fraunhofer and Chalmers (28%) show a strong shift from industrial to public income; the basic funding was approximately unchanged.



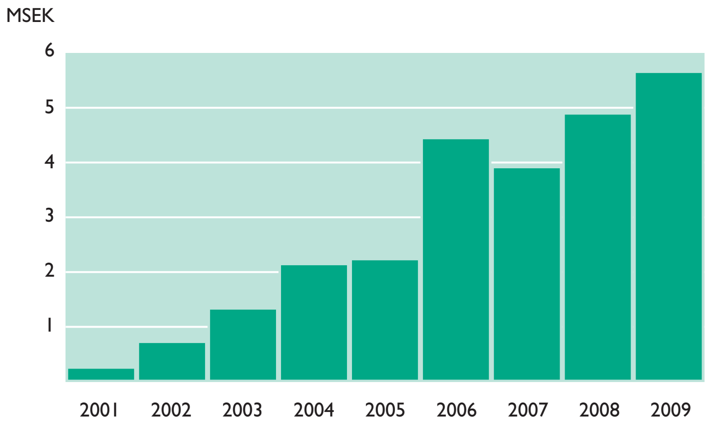
Departments by income 2009

The Centre has four departments, cf page 18, 20, 22, and 24. The relative income of each department varies between 13% (Risk) and 47% (Geo) of the grand total.



ITWM project income from FCC

For FCC the basic funding is equally shared between Fraunhofer and Chalmers, in 2009 being 475 thousand euros from each founder or approximately 4.75 million Swedish crowns. The project flow to ITWM is in line with the development of the total FCC income and showed a substantial increase in 2009.



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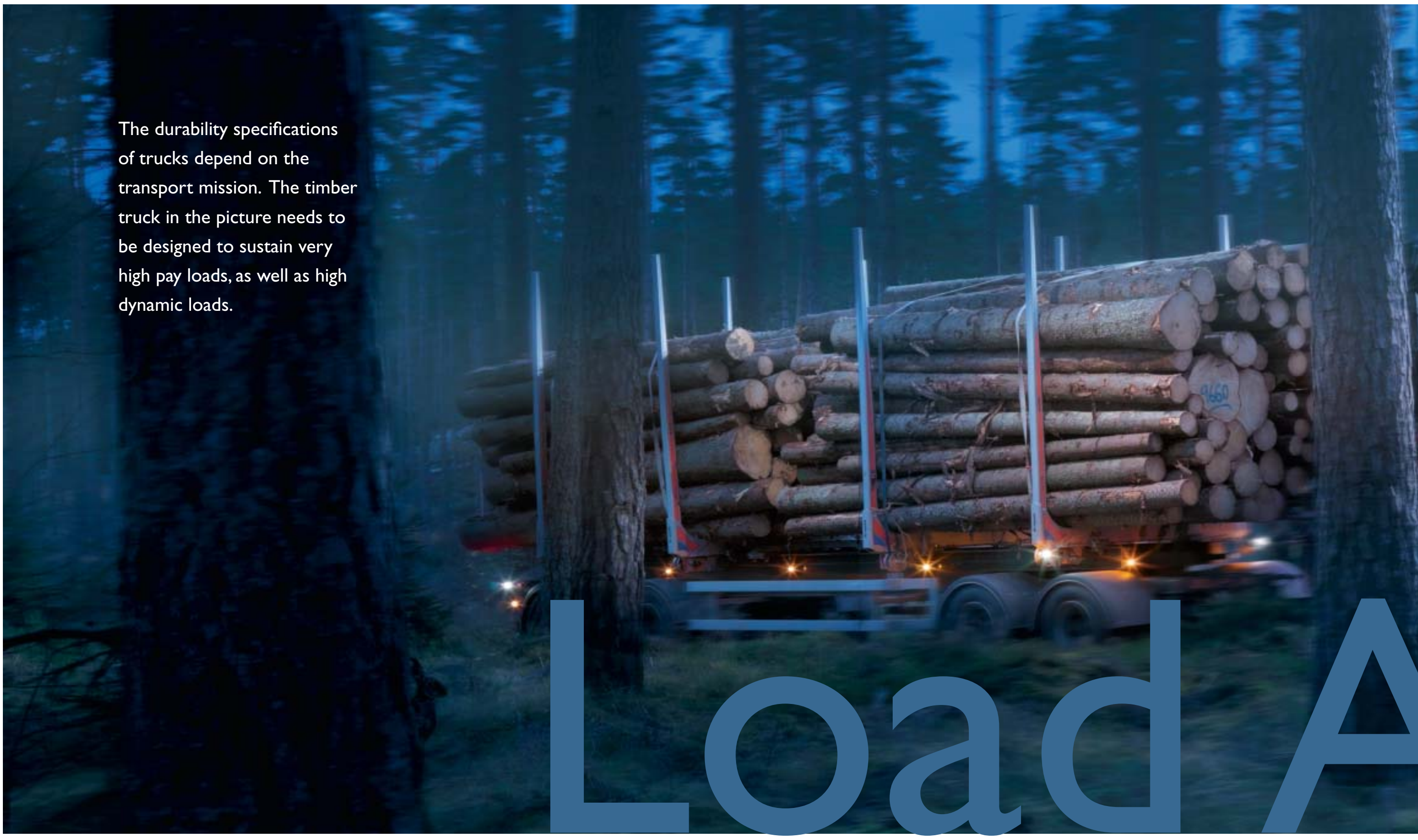


The durability specifications of trucks depend on the transport mission. The timber truck in the picture needs to be designed to sustain very high pay loads, as well as high dynamic loads.

Load A

for Automotive Applications

Transport vehicles are exposed to dramatically different operating conditions in different parts of the world and in different transport missions. Six leading European truck manufacturers: DAF, Daimler, Iveco, MAN, Scania, and Volvo, commissioned a research project starting in 2006 to produce a guide to load analysis oriented towards fatigue design of trucks.

The project was run by FCC, with Dr P Johannesson as the project leader, in collaboration with SP Technical Research Institute of Sweden, Chalmers Mathematical Sciences, Fraunhofer ITWM, and the industrial partners. The complete guide was available in 2009 after a joint effort of ten staff-years.

Outline

In 2006 an initial investigation was carried out of current practice and future needs within load analysis, together with a survey of the state-of-the-art in load analysis for automotive applications, see figure 1. After this pre-study the parties agreed on the main project.

In 2007-2009, the Guide was developed in close collaboration between all parties, including regular meetings and annual seminars at each company. After the Introduction in Part 1, the second part of the Guide presents Methods for load analysis, describing useful methods and how and when they should be used. The year 2009 was spent on the third part: Load analysis in view of the vehicle design process. Below we describe this part in somewhat more detail, starting with the philosophy of the load-strength model for reliability and robust design.

Analysis

Figure 1
The design specifications within the automotive industry are to a large extent based on testing and measuring loads on test tracks (courtesy of Volvo).

The Load – Strength Model

The ultimate goal for the manufacturer is to make a design that exactly meets the needs of the customers, neither too strong nor too weak. The requirements need to be converted into for example a certain small risk of failure, a proper safety factor, or an economical expected life. In order to make a robust design it is as important to have good knowledge of the properties of the customer loads, as it is to have good knowledge of the mechanical behaviour of the material and structure in question.

Load Analysis in the Vehicle Design Process

To present load analysis in view of the truck design process, and describe what methods are appropriate in the different design stages, it is important to consider loads on different levels: system, sub-system, and component.

In figure 2 the upper arrow summarizes the overall design steps: concept phase, computer aided design and digital mock-up, computer aided engineering including physics modelling, and computer aided engineering and manufacturing.

Functional specifications and design goals are set on the different load levels as indicated in the lower left part of figure 2. Here we are concerned with the durability demands in terms of reliability target for the truck, for sub-systems, and for components. It is important to follow these demands throughout the design process. Chapter 7 of The Guide is concerned with the customer load evaluation, in particular characterization of customer populations, Chapter 8 treats the derivation of design loads specifications to bridge the lower left and right parts of figure 2, and Chapter 9 is dedicated to the verification stage, from components to the full vehicle.

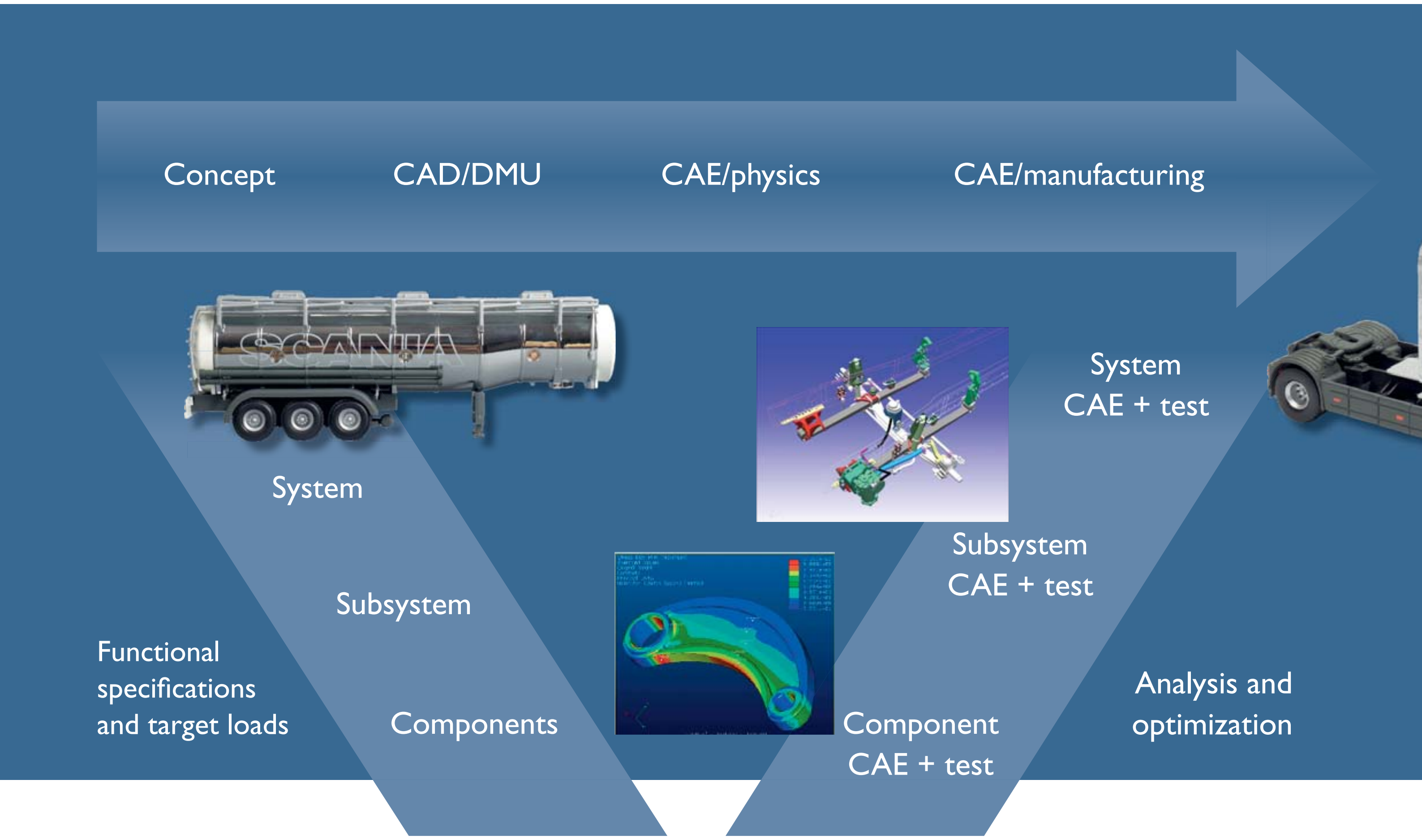


Figure 2
The vehicle engineering design process.

Evaluation of Customer Loads

The task is to assess the customer load distribution. Apart from defining the load of interest (e.g. the load on the steering arm), it is important to define which population it represents, e.g. all potential customers, a specific application (e.g. timber trucks), or a specific market (e.g. the European market). Three strategies for estimating the customer load distribution are discussed:

- Random sampling: Choose customers randomly, however, not necessarily with equal probabilities, and measure their loads.
- Customer usage and load environment: Estimate the proportion driven on different road types, and combine this with measurements from the different road types.
- Vehicle independent load description: Define models for customer usage, road types, driver influence, and legislation, which can then be combined with a model for the vehicle dynamics.

Derivation of Design Loads

The topic is to derive loads for design and verification purposes. The basic specification is the severity of the load, which needs to be related to the design approach taken. Load time signals can be derived using simple synthetic loads, random load models, modification of measured signals, standardized load sequences, test track measurements, or can be defined through an optimized mixture of test track events.

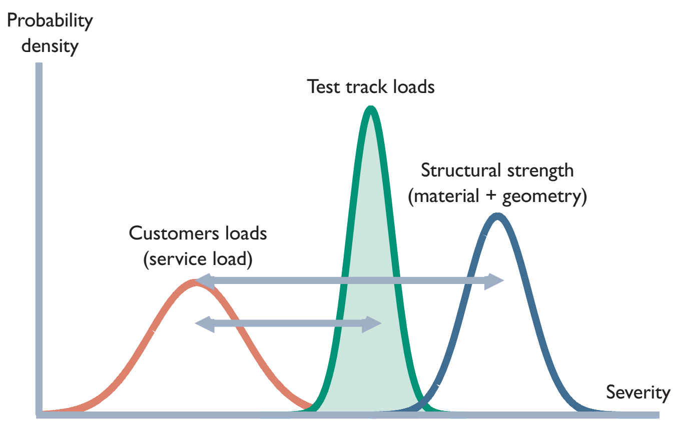


Figure 3

The Guide

The main result of the project is the 424-page-document Guide to Load Analysis for Automotive Applications:

Part I. Introduction
Chapter 1: Loads for Durability

Part II. Methods for Load Analysis
Chapter 2: Basics on Load Analysis
Chapter 3: Load Editing and Generation of Time Signals
Chapter 4: Response of Mechanical Systems
Chapter 5: Models for Random Loads
Chapter 6: Load Variation and Reliability

Part III. Load Analysis in view of the Vehicle Design Process
Chapter 7: Evaluation of Customer Loads
Chapter 8: Derivation of Design Loads
Chapter 9: Verification of Systems and Components

Verification of Systems and Components

The verification process is discussed; principles of verification, generation and acceleration of loads, and planning and evaluation of verification tests. Three verification approaches are presented:

- Highly Accelerated Life Testing, HALT, based on the idea that failures give more information than non-failures and give rise to improvements regardless severities that exceed what is expected.
- Load-Strength analysis based on characterizing tests. Strength and load properties are investigated by characterizing experiments. Scatter and uncertainties are analysed within a statistical framework to verify the design against reliability targets by means of established safety factors, see figure 3.
- Probability based formal procedures, with test plans based on formal consistent rules that, by experience, give safe designs. Typically, a low quantile in the strength distribution is verified by testing.

The Truck Guide team in Kaiserslautern in September 2009.

Summary of results

The quality manager at one of the industrial partners kindly stated that the Guide “should be the “bible” for all our new design and test engineers for the 15 coming years”.

Mathematical modeling of biological systems that are of interest in the pharmaceutical industry is a rapidly growing area. The use of mathematical models brings the promise of reducing the high costs and long times associated with the development of new drugs and models are gradually finding their way into the drug development routine.

# of Atrial Electrical Activity

AstraZeneca, a world leader in cardiovascular medicines, has worked together with FCC in a series of collaboration projects aiming at a better understanding of atrial arrhythmias and of the properties of drugs that successfully can treat them. Atrial fibrillation is the most common form of heart arrhythmia and is associated with a significantly increased risk of stroke.

High age being a risk factor for atrial fibrillation, the growing proportion of older people in the populations of developed countries is expected to increase the incidence of this arrhythmia. Also considering the modest efficacy or potentially serious side effects of existing drugs, the future market of anti-fibrillatory medicines is forecast to show substantial growth.

AstraZeneca believed that a mathematical approach would give insight in the interplay by which different ionic currents shape the action potential, knowledge that could assist in the screening of novel anti-arrhythmic drugs. Starting with implementation and computational analysis of mathematical models describing single canine heart muscle cells, the scope has successively widened to also include simulations of the electrical activity in realistic atrial geometries and models of interactions between drugs and specific ion-channels. These projects have increased the understanding of atrial arrhythmias and have enabled quantitative evaluation of treatment strategies *in silico*.

The Model

Computer models make it possible to relate the dynamics of the action potential propagation in realistic atrial geometries to drug effects at the single cell level. This in turn permits *in silico* reconstruction and investigation of phenomena like atrial flutter and fibrillation.

FCC has developed a framework for modeling and simulation of electro-chemical activity in large scale cell networks. A geometric model of the canine atria has been constructed utilizing ultra sound imaging data and a realistic fiber structure and cell type distribution has also been incorporated, see figure 1.

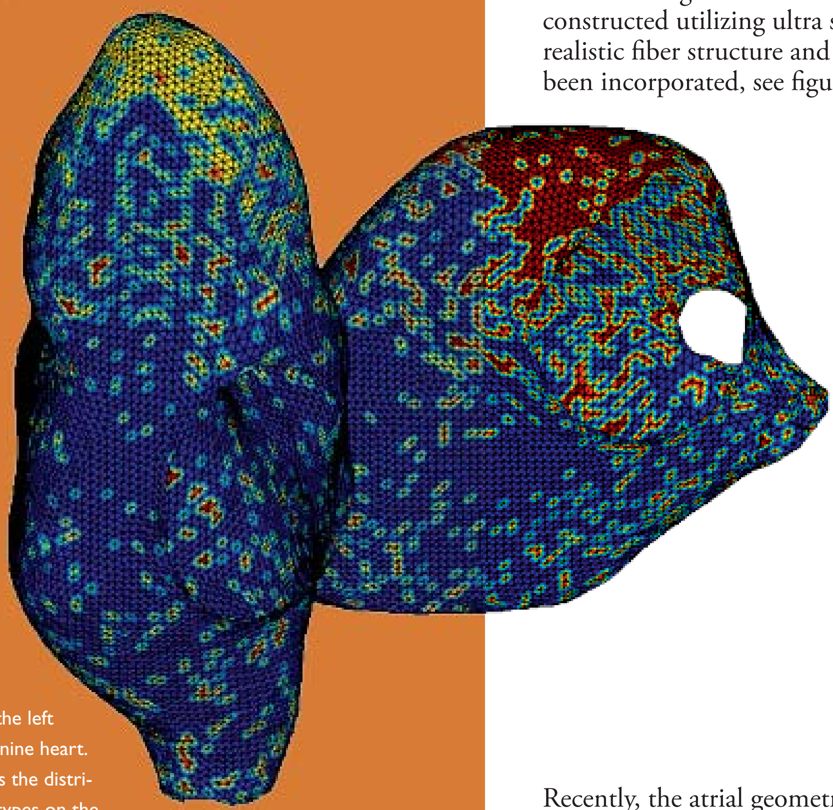


Figure 1
Geometrical model of the left and right atrium of a canine heart. The color coding shows the distribution of different cell types on the atrial surfaces in a computational heart model used for studying the effects on fibrillation by inhibition of single or multiple ion-channel types.

Recently, the atrial geometry model has been improved by refining the spatial discretization. In its present state it consists of a network of 70 000 nodes representing the quantitative behavior of a cluster of real cells, each node being an instance of a single cell model. An illustration of a single cell model is shown in figure 2.

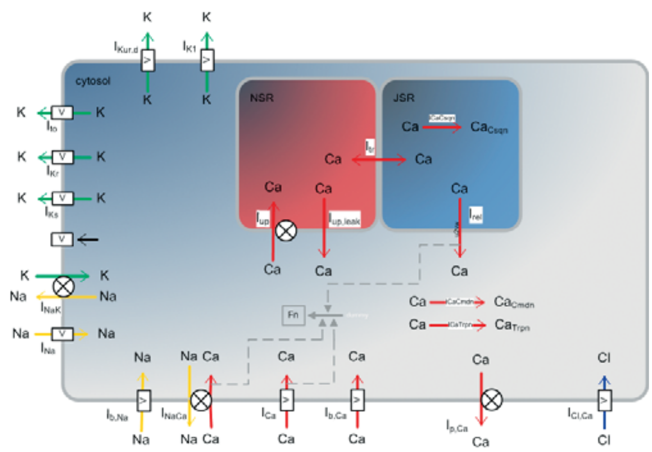


Figure 2
Model diagram of the single cell model structure used as building block in the cell network modeling the atrial tissue. The single cell model is represented by a system of non-linear differential equations including mass and charge transfer over the cellular membrane via a number of different ion-channel types.

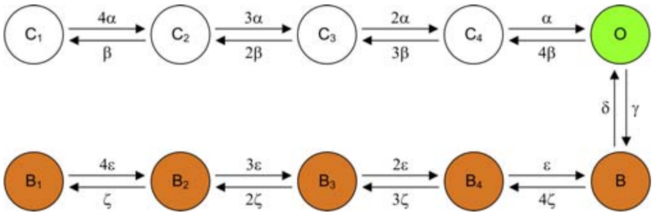


Figure 3
A graphical representation of a potassium ion channel model, which may be in one of ten discrete states representing different conformations. The channel can be either closed (C), open (O), or blocked (B) and the transitions between the different states are characterized by rate constants denoted by the Greek letters.

The cell models used implement ion-channel mechanisms using the Hodgkin-Huxley paradigm. To gain insight of the quantitative effects of a drug inhibiting a particular ion-channel so called Markov models are believed to provide the necessary level of detail. We have implemented more detailed models of a potassium ion-channel of particular interest using this formalism, see figure 3.

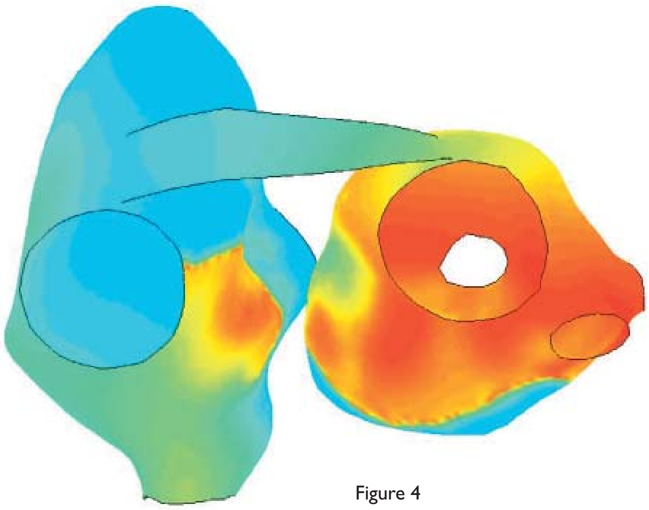


Figure 4
Simulated fibrillation in a canine atrial model, where blue color show cells with low membrane potential and red color show cells with high membrane potential. The electrically conducting structure between the left and right atria is known as Bachmann's bundle.

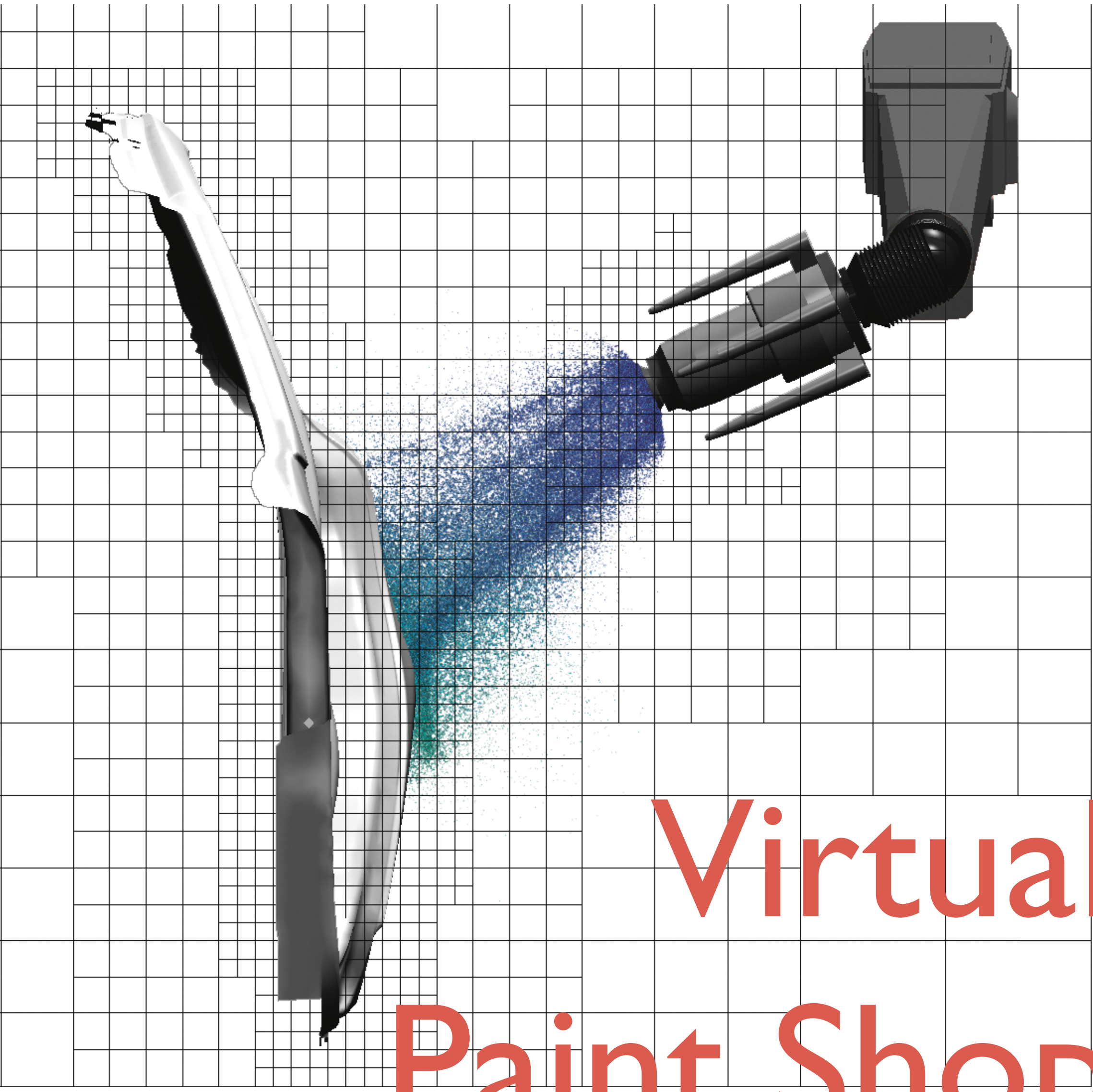
Results and achievements

The complete atrial tissue model consists of about 2.000.000 coupled nonlinear ordinary differential equations. To meet the computational demands of this model the developed modeling and simulation framework has been translated into a high performance computing setting first tested and executed on FCC's internal computational servers and recently deployed onto Chalmers Centre for Computational Science and Engineering (C3SE) facilities.

The simulation framework has been used to induce fibrillation and flutter like electro-dynamic activity in cell networks from simple sheets up to realistic atrial geometries as shown in figure 4. In addition, the effect of ion-channel modulation on this behavior has been investigated. The simulations are in good accordance with in vivo observations, have great potential to provide insights into the underlying mechanisms of atrial fibrillation and flutter, and can serve as a tool for prediction of drug effects.

Future

Finding suitable targets and drugs that modulate their activity appropriately is difficult. Some new anti-arrhythmic drugs are targeting multiple ion-channels simultaneously. As the possible combinations of targets, modulation type, and relative strength of the effect on the different targets are overwhelmingly complex, such treatment strategies present an even more difficult problem. Predictive mathematical models may be particularly suited to identify useful multi-target drug profiles. The importance of foresight in choosing drug candidates is pivotal as very few compounds will eventually reach the market. Hence, an interesting area for future development of our atrial modeling efforts would be *in silico* investigations of different multi-target strategies.



Paint simulation in IPS Virtual Paint. Paint droplets are visualised and colored by mass, where blue is small and red is large.

Virtual Paint Shop

The goal of this ongoing project is to develop new simulation algorithms and tools for paint and surface treatment processes in automotive paint shops. The project is part of Vinnova's MERA and FFI programs that support the Swedish automotive industry and our research partners are Volvo Cars, Saab Automobile, Scania, Volvo AB and Swerea IVF.

Paint and surface treatment processes in the car paint shop are to a large extent automated and performed by robots. Having access to tools that incorporate the flexibility of robotic path planning with fast and efficient simulation of the processes is important, since such tools will reduce the time required for introduction of new car models, reduce the environmental impact and increase quality. The key process in the paint shop, which is also the most demanding from a modelling point of view, is the spray painting of the car body.

In spray painting paint primer, color layers and clear coating are applied through the Electrostatic Rotary Bell Sprayer (ERBS) technique. Paint is injected at the centre of a rotating bell; the paint forms a film on the bottom side of the bell and is atomized at the edge. The droplets are charged electrostatically and driven towards the target car body both by shaping air surrounding the rotating bell and by a potential difference in the order of 50-100 kV between paint applicator and target.

The combination of high physical complexity, large moving geometries, and demands on near real time results constitutes a big challenge. The current situation in the automotive industry is therefore to rely on individual experience and physical validation for improving their processes.

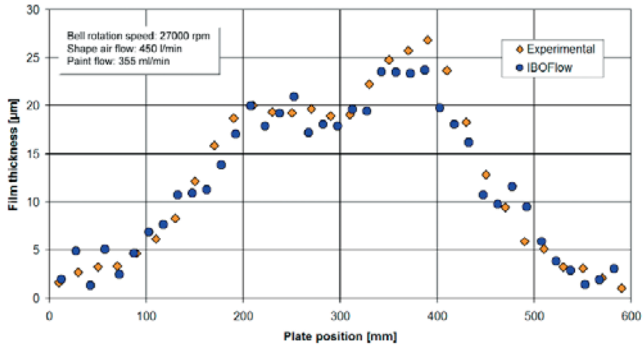
▸▸

Spray Painting

Copyright: Volvo Car Corporation

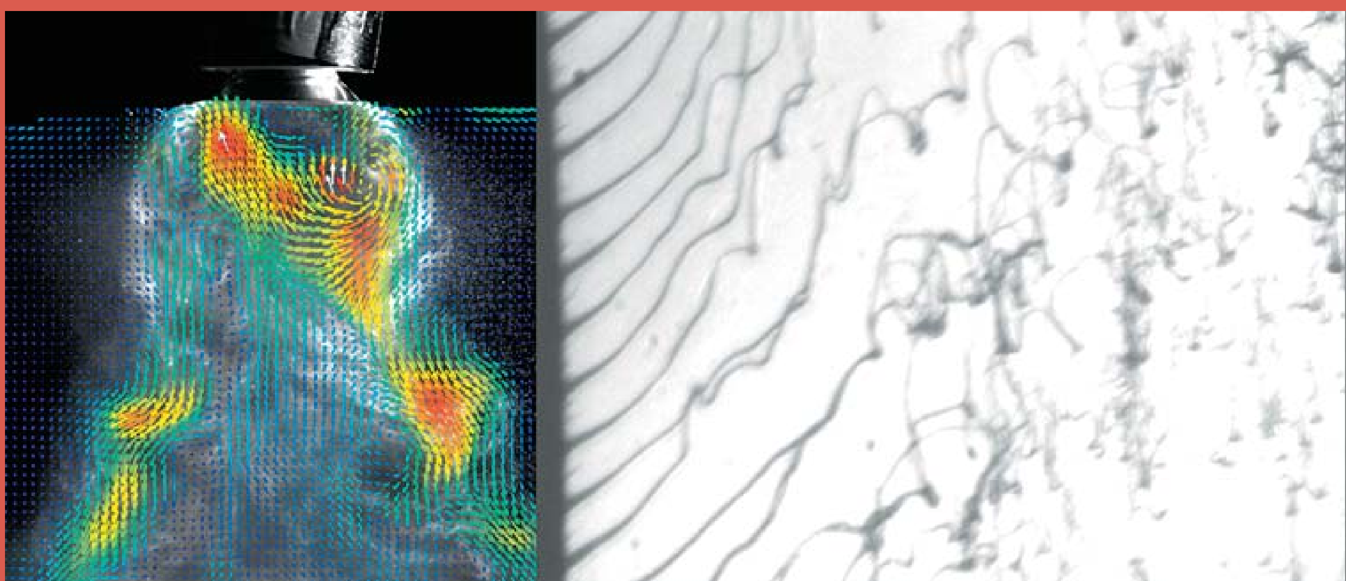
This multi-physics application requires tracing of paint droplets that are two-way coupled to the fluid flow and electrostatic field, from bell to target. The major part of the computational work is done within the flow solver – where the transient Navier-Stokes equations are solved to obtain the air flow velocity field. An accurate solution is necessary in order to predict where paint hits the target surface.

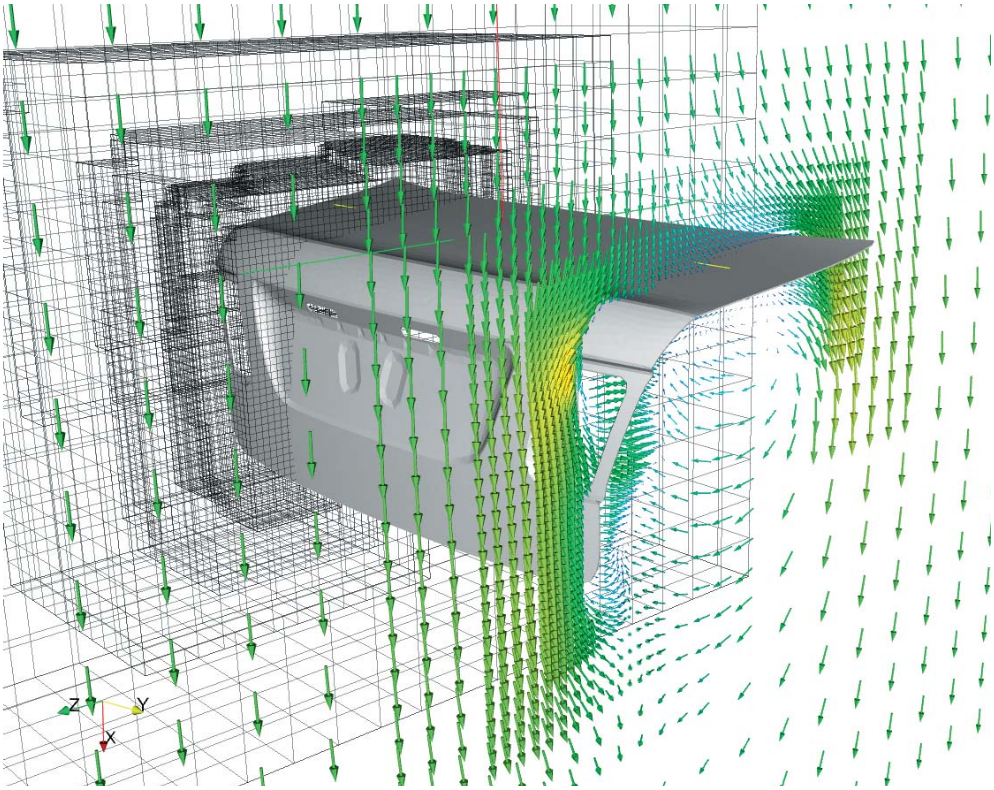
A major improvement in computational speed compared to other approaches has been realized through the development of the incompressible flow solver IBOFlow. IBOFlow is based on a finite volume discretization of the Navier-Stokes equations on a Cartesian octree grid that can be dynamically refined and coarsened. Unique immersed boundary methods are used to model the presence of objects in the fluid. This enables modeling of moving objects (robots or cars) at virtually no additional computational cost.



Comparison of paint thickness profile across the paint stroke between simulation and experiments. Note that both width of paint brush and the asymmetric shape is well captured by the simulation.

Images from experiments performed at Volvo Car Corporation in Torslanda. The left image shows an instantaneous image of the paint velocity field below the paint applicator, the right image shows a close-up of liquid paint being broken up into droplets at the rim of a bell cup. (courtesy of Volvo Car Corporation)



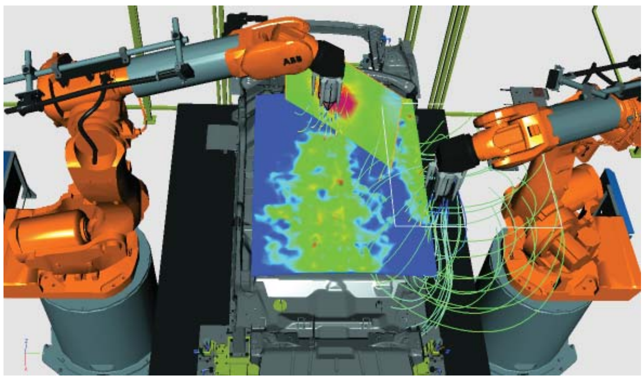


Geometry treatment in IPS Virtual Paint. The solver utilizes a Cartesian grid that can be arbitrarily refined around stationary as well as moving objects. The no-slip condition is enforced using novel second-order accurate immersed boundary conditions without the need of a body fitted volume grid (courtesy of Saab Automobile AB).

The IBOFlow solver has been integrated in the in-house package for automatic path planning, IPS. The first version of the software IPS Virtual Paint was released in 2009 and our industrial partners predict that positive effects will include a reduced time required for introduction of new car models, a reduced environmental impact and an increased product quality. In the software, an arbitrary geometry can be painted using a moving, pre-defined electrostatic rotary bell, where the user can set process conditions like paint flow, air flow, electrostatic droplet charge and atomizer bell rotation speed. The process conditions are used to compute physical inlet conditions such as paint droplet size and velocity distributions and applicator inlet air flow. Validations of the film thickness for test plates are in excellent agreement with experimental data.

Currently we are working on further improvements of IPS Virtual Paint as well as additional modules to enable simulation of the other processes relevant to the automotive paint shop such as electro dipping, sealing and cavity wax, and oven curing. Another challenge is the automatic generation of collision free robot paths through 3D scanning of complex components. This technology will mainly target low volume series which have until today been painted manually due to the lead time of programming a paint robot to perform the same operation.

Two robots are painting a car roof in IPS Virtual Paint. The colours on the roof show the paint film thickness. Electric field lines and electric field strength on a cutting plane are also illustrated.



The Geometry

Many products such as car and truck bodies, engines, medical prosthesis, mobile phones, and lumbering equipment depend visually and functionally on its geometry. Since variation is inherent in all production, consistent efforts in styling, design, verification and production aiming at less geometrical variation in assembled products is necessary to achieve easy-to-build high-quality products. Also, the demand on short ramp up time, throughput, and equipment utilization in the manufacturing industry increases the need of effectively generate and visualize collision-free and optimized motions in the assembly plant. During 2009 the department of Geometry and Motion Planning have successfully developed methods, algorithms and tools supporting these activities within four main subjects:

- Packing and Assembly Path Planning
- Robotics and Discrete Optimization
- Computer Graphics
- Geometry Assurance

Acknowledgement

In 2009, the Geometry and Motion Planning group has received substantial funding from the FFI and Vinnex program within Vinnova and the ProViking program within the Swedish Foundation for Strategic Research (SSF).

Johan Carlson
PhD, Vice Director FCC,
Head of Department

In particular, the FCC software tool Industrial Path Solutions for automatic path planning of collision-free motions has been successfully used by our partners in the automotive industry to solve geometrically complex manufacturing problems in mere minutes instead of hours or days. The strength of the mathematical algorithms in combination with the easy user interface has allowed the path planning technology to be spread outside the expert teams of simulation engineers. The IPS path planning technology is now also part of the master education in virtual production at Chalmers.

An industrial and scientific challenge of car body manufacturing is to guarantee geometrical quality and factory throughput during spot welding. To solve this problem FCC has started to develop algorithms integrating line balancing, sequencing and coordination of operations with our path planning technology.

Today, many assembly problems are detected too late in product and production processes, involving cables, hoses and wiring harness. The reason for this is the lack of virtual manufacturing tools supporting real time simulation of flexible parts and motions. The FCC technology developed together with ITWM has been successfully implemented as a module in the IPS software. IPS is now used in Sweden, Germany, US, and Japan.

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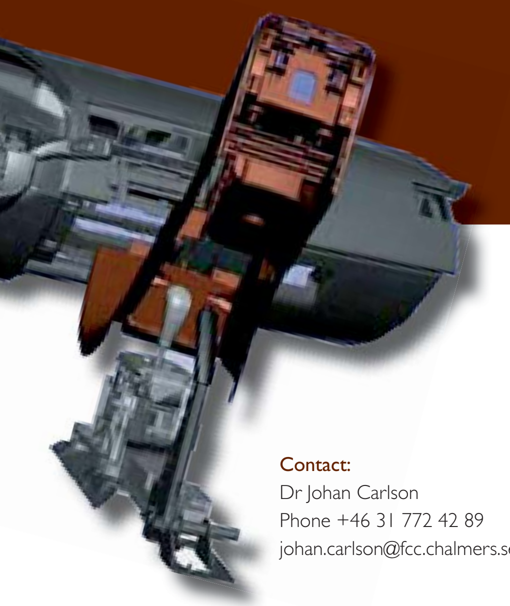
Sebastian Tafuri
MSc

Johan Torstensson
MSc

Geometry and Motion Planning



Cooperation

During 2009, the successful collaboration with Wingquist Laboratory Vinn Excellence Centre has continued with Geometry and Motion Planning as one of its major research groups. Also the collaboration with the Industrial Research and Development Corporation (IVF), the Virtual Ergonomics Centre (VEC) and the ITWM departments Dynamics and Durability has grown by working together on common projects.

Rikard Söderberg
Professor Product and Production Development Chalmers,
Director Wingquist Laboratory,
Scientific Adviser FCC

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and Motion Planning Research Group

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Fredrik Andersson
MSc student

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Christer Eriksson
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Kristoffer Hahn
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Patrik Magnusson
MSc student

Babak Saboori
MSc student

Behzad Saboori
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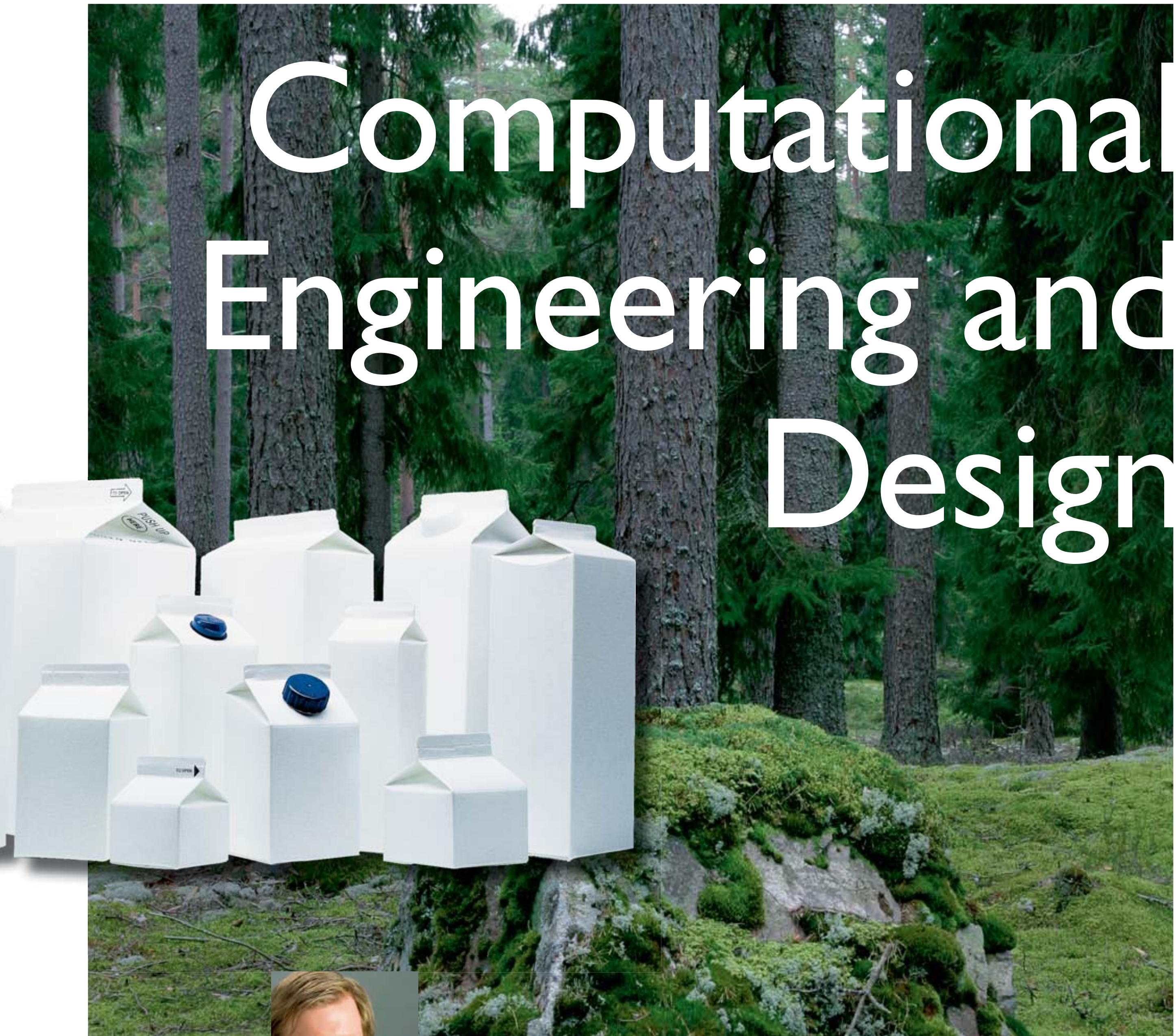
Johan Segeborn
MSc Engineering,
Volvo Cars, PhD student



Computational Engineering and Design

The Computational Engineering Research Group

Fredrik Edelvik
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Head of Department
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Björn Andersson
MSc

Stefan Jakobsson
PhD

Andreas Mark
PhD

Robert Rundqvist
PhD

Anders Ålund
Lic

Modern product design and process operations are heavily based on computational mathematics through work in the virtual world. Traditional hands-on engineering is replaced by systematic approaches based on computer simulations, which provide additional insight in the design phase and reduce the need for expensive measurements. The department of Computational Engineering and Design has key competence in applications that can be mathematically modeled by partial differential equations (PDEs). Novel numerical methods, fast algorithms and engineering tools are developed to enable efficient simulation and optimization of industrial applications, and thereby support virtual product and process development in various industrial sectors.

The work is organized in three areas:

- Fluid dynamics
- Electromagnetics
- Optimization

The research in fluid dynamics is focused on the development of methods and algorithms for multi-phase flows, free surface flows, and fluid-structure interaction. The department strives to provide an innovative software that integrates state-of-the-art research on grid-free techniques and offers unique possibilities for efficient simulation of complex industrial flow applications. The IBOFlow (Immersed Boundary Octree Flow Solver) software is tailored for applications involving moving objects interacting with the flow and sets a new standard for CFD software by avoiding the cumbersome generation of 3D volume meshes. Major activities during 2009 were continued efforts on simulation of paint and surface treatment processes in automotive paint shops (see pages 14-17), and the start of a three-year project on simulation of papermaking and paperboard package quality with industrial partners Albany International, Eka Chemicals, Stora Enso and Tetra Pak.

In electromagnetics research is performed on the platform that was developed in the national research and code development project GEMS and the department collaborates with the company Efield that commercializes the GEMS software. Activities during 2009 included a new joint project with Efield and Lund University, within the framework of the Swedish National Aerospace Research Programme (NFFP), on improved simulation software for analysis of sensors and antennas integrated on platforms.

In optimization the research is focused on simulation-based optimal design and multiple criteria optimization. This includes development of novel optimization algorithms, coupling of simulation and optimization software and development of decision support systems that integrate multiple criteria optimization and simulation. The main applications in 2009 were optimization of MIMO antenna systems and EEG-based localization of epileptic foci in the human brain.

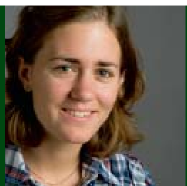
Acknowledgement

In 2009 the department received substantial funding from Vinnova and the Swedish Foundation for Strategic Research (SSF) through the Gothenburg Mathematical Modelling Centre (GMMC).

Cooperation

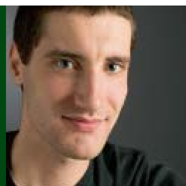
During 2009, the successful collaboration with the department of Geometry and Motion Planning at FCC has been strengthened through joint projects on virtual paint-shop. Also the collaboration with the departments of Optimization and Flow and Material Simulation at Fraunhofer ITWM has grown by working on joint projects. New collaborations with the Chalmers divisions of Fluid Dynamics and Biomedical Engineering were initiated.

g and Design



Emma Bengtsson
Contracted student

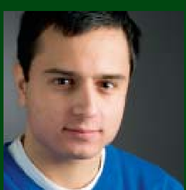
Martina Blom
Contracted student



Olivier Goury
Contracted student

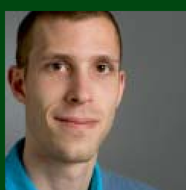
Linda Noreheim
Contracted student

Elke Schaper
Contracted student



Ruben Sharma
Contracted student

Christoffer Strömberg
Contracted student



Erik Svenning
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Samuel Lorin
MSc student

David Sjögren
MSc student

Peter Lindroth
Lic, Volvo 3P, PhD student

Cooperation

We collaborate closely with Chalmers Mathematical Sciences, Fraunhofer ITWM and SP Technical Research Institute of Sweden.

Acknowledgement

In 2009 the department has received funding from the Swedish Foundation for Strategic Research, SSF, through the Gothenburg Mathematical Modelling Centre, GMMC.

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Reliability and Risk Management

Understanding the impact of uncertainty and quantifying and managing risk to secure and optimize reliable operations, products, and systems are important issues for most industrial and societal sectors. The department develops mathematical models of products and processes, emphasizing a sound balance between model complexity, uncertainty, and optimality, providing key competences in mathematical statistics and stochastic processes.

Our focus is on fatigue life and load analysis of mechanical systems. We have addressed automotive and related applications, as illustrated by one profile project on pages 6-9. Within the Gothenburg Mathematical Modelling Centre (GMMC) we emphasize an enhanced perspective on reliability through Variation Mode and Effect Analysis, VMEA. Wiley has in 2009 published a volume on robust design methodology for reliability including a description of VMEA techniques.

Jacques de Maré
Professor Mathematical Statistics Chalmers, Scientific Adviser FCC

Igor Rychlik
Professor Mathematical Statistics Chalmers, Affiliated expert FCC

The Reliability and Risk Mar
Research Group

Fatigue Life and Load Analysis

Many failures of engineering structures are caused by the fatigue of metals. Numerical solvers of partial differential equations can calculate mechanical stresses and strains into great detail. However, the knowledge of the actual loads on the structure in service is usually very vague. In addition, fatigue damage must be predicted for the whole specified service life of the structure. Lacking detailed information about material imperfections and geometry, the engineer is forced to use simple empirical models for the fatigue damage evaluation, and compensate by large safety factors, which unfortunately often are based on experience and not rationalized in a robust way. Statistical methods are needed for a rational development of sound safety factors based on both measurements and on historical experience.


Copyright: SKF


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PhD


Sara Lorén
PhD


Roland Jakobsson
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Yun Niu
MSc student

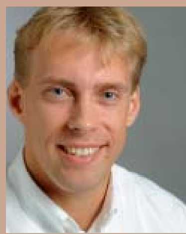

Mattias Ohlsson
MSc student


José Sanchez
MSc student

Variation Mode and Effect Analysis, VMEA

The Failure Mode and Effect Analysis, FMEA, is often used in industry for reliability assessments. Studies of FMEA have indicated that the failure modes are trigged by unwanted variation. As a complement, or possibly, as a replacement of FMEA we suggest an enhancement of that technique what we call Variation Mode and Effect Analysis, VMEA. The VMEA takes the quantitative measures of failure causes into account. The VMEA method is presented at three levels of complexity, basic, enhanced and probabilistic. The basic VMEA can be used when we only have vague knowledge of the variation. The sensitivity and variation size assessments are made by engineering judgement and are usually made on a 1-10 scale. When we can better judge the sources of variation the enhanced VMEA can be used. The probabilistic VMEA can be used in the later design stages where we have more detailed information in terms of for example material data, finite element models, and physical experiments.

Systems Biology and Bioimaging



Mats Jirstrand
PhD, Associate Professor,
Head of Department

Mats Kvarnström
PhD

Joachim Almquist
MSc

The Systems

Re

Kristoffer Andersson
MSc

Jonas Hagmar
MSc

Johan Karlsson
PhD

Mikael Sunnåker
MSc (on leave)

Mikael Wallman
MSc (on leave)

David Wrangborg
MSc

…Biology and Bioimaging …search Group

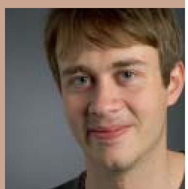
Cooperation

We have very close collaboration with the Swedish company InNetics. Other collaborations include joint work with General Zoology at Kaiserslautern University; Bionanophotonics, Systems Biology, and Mathematical Sciences at Chalmers; Cell- and Molecular Biology at Gothenburg University; the Department of System Analysis, Prognosis and Control at ITWM; and partners in the BIOSIM, YSBN, UNICELLSYS, CANCERSYS, and SYSINBIO EU-projects.

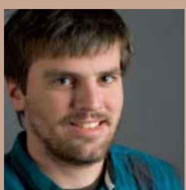
Acknowledgement

In 2009, the Systems Biology and Bioimaging department has received funding from the Swedish Foundation for Strategic Research via Gothenburg Mathematical Modelling Centre, GMMC. Furthermore, the group has received funding for the BIOSIM, YSBN, UNICELLSYS, CANCERSYS, and SYSINBIO projects from the European Commission.

Mats Rudemo
Professor Mathematical Statistics Chalmers, Scientific Adviser FCC

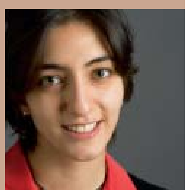


Armin Böller
Contracted student

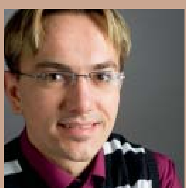


Heidar Eyjólfsson
Contracted student

Erik Holmgren
Contracted student



Atefeh Kazeroonian
Contracted student



Dimitri Koch
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Emilia Lundberg
Contracted student

Nico Reissmann
Contracted student

The application of tools and techniques, borrowed from engineering disciplines such as systems and control theory, signal processing, and computer science, for studying biological and biochemical systems has received an increasing attention over the last couple of years. This is due to a number of factors such as recent advancements in measurement technology, a need for pharmaceutical companies to find alternative strategies to beat current shortcomings in early drug development and increase competitiveness, and the improved understanding of living systems due to the sequencing of genomes and characterization of the function and role of corresponding proteins. FCC provides an integrated approach to the study of biochemical and physiological processes, from the characterization of single parts to the analysis of dynamic phenomena on a systems level. The work at the department includes both biological/biomedical modeling applications as well as development of computational tools and algorithms. The department is organized in two areas:

- Systems Biology
- Bioimaging

We are currently involved in modeling projects where yeast *(Saccharomyces cerevisiae)* and frog oocytes *(Xenopus laevis)* are used as model organisms. Modeling of ion-channels and action potential propagation related to atrial fibrillation as well as signaling pathways involved in liver cancer are other areas of interest. The computational tools and algorithms developed at the department can be divided in four main areas: system identification, model reduction, image analysis, and software tools.

This year was the fifth and final year of operation for the EU funded network of excellence – BIOSIM, which aims at increasing the use of biosimulation in drug development. The department is also partner in four other EU funded projects: YSBN – the Yeast Systems Biology Network, UNICELLSYS – Eukaryotic unicellular organism biology – systems biology of the control of cell growth and proliferation, CANCERSYS – Mathematical modeling of β-catenin and ras signaling in liver and its impact on proliferation, tissue organization and formation of hepatocellular carcinomas, and SYSINBIO – Systems Biology as a Driver for Industrial Biotechnology.

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Årsredovisning

Styrelse och ledning den 3 november 2009

Från vänster:
Uno Nävert, föreståndare FCC
Dieter Prätzel-Wolters, Fraunhofer ITWM
Helmut Neunzert, vice ordförande, Fraunhofer ITWM
Peter Jagers, ordförande, Chalmers
Bo Johansson, Chalmers
Johan Carlson, biträdande föreståndare, FCC

Styrelsen för Stiftelsen Fraunhofer-Chalmers centrum för industrimatematik, FCC, får härmed avge följande redovisning över verksamheten under tiden 1 januari 2009 – 31 december 2009, stiftelsens åttonde verksamhetsår.

Stiftelsen bildades av Chalmers och Fraunhofer-sällskapet i juni 2001 och registrerades av Länsstyrelsen i Västra Götalands län i oktober 2001 som en svensk näringsdrivande stiftelse. Stiftelsen skall utveckla och anpassa matematiska metoder för industrin. Stiftelsen bedriver konkurrensneutral forskning och marknadsföring med finansiering från stiftarna och offentliga finansiärer. Stiftelsen genomför projekt med företag på kommersiell grund.

Stiftelsen skall enligt strategiplan från oktober 2005 bygga upp en verksamhet som år 2010 omsätter tre och en halv miljon EUR och omfattar 35 anställda. Chalmers och Fraunhofer-sällskapet kommer under denna period att stegvis öka sin finansiering från 400 000 EUR 2006 till 500 000 EUR 2010.

Resultaträkning
090101 – 091231, (kSEK)

Intäkter	
Nettoomsättning	36 064
Summa intäkter	**36 064**
Kostnader	
Externa kostnader	-14 914
Personalkostnader	-20 522
Avskrivningar av materiella anläggningstillgångar	-346
Summa kostnader	**-35 782**
Rörelseresultat	**282**
Resultat från finansiella investeringar	
Ränteintäkter och liknande resultatposter	243
Räntekostnader och liknande resultatposter	-176
Resultat efter finansiella poster	**349**
Bokslutsdispositioner	-143
Årets skatt	-119
Årets resultat	**87**

Balansräkning
091231, (kSEK)

Anläggningstillgångar	
Maskiner och inventarier	530
Summa anläggningstillgångar	**530**
Omsättningstillgångar	
Kundfordringar	4 930
Förutbetalda kostnader och upplupna intäkter	3 245
Övriga kortfristiga fordringar	300
Skattefordringar	176
Kassa och bank	9 085
Summa omsättningstillgångar	**17 736**
Summa tillgångar	**18 266**
Eget kapital	
Eget kapital vid årets ingång	2 993
Årets resultat	87
Summa eget kapital	**3 080**
Obeskattade reserver	1 189
Kortfristiga skulder	
Leverantörsskulder	4 437
Övriga kortfristiga skulder	370
Upplupna kostnader och förutbetalda intäkter	9 190
Summa kortfristiga skulder	**13 997**
Summa skulder och eget kapital	**18 266**

Årets omsättning har varit drygt trettiosex miljoner kronor. Antalet anställda och studenter har motsvarat 39 heltidsekvivalenter varav fyra kvinnor, inklusive studenter i mastersprogram (åtta heltidsekvivalenter) och industridoktorander (drygt två heltidsekvivalenter). Under året har 22 studenter anställts till ca 10% för arbete inom projekt. Stiftelsen har ett femårigt hyresavtal till och med 31 mars 2011 omfattande 1 096 kvm i Chalmers Teknikpark med Fastighets KB Forskarbyn. Hyresvärd fr o m oktober 2008 är Chalmersfastigheter AB.

Rörelsens intäkter har uppgått till 36 064 kSEK (28 091 kSEK föregående år). Av detta utgör 25% (40%) industriprojekt, 47% (30%) offentliga projekt och 28% (30%) finansiering från stiftarna. Årets resultat efter skatt är 87 kSEK (366 kSEK). Eget kapital uppgick den 31 december 2009 till 3 957 kSEK (3 747 kSEK) inkluderat kapitalandelen i obeskattade reserver.

Stiftelsens styrelse har under verksamhetsåret sammanträtt två gånger. Ersättning har utgått till ordföranden med 33 075 kronor och till övriga ledamöter med 16 538 kronor per person.

Stiftelsens ställning och resultatet av dess verksamhet framgår av efterföljande resultat- och balansräkningar, vilka utgör en integrerad del av årsredovisningen.

Göteborg den 9 mars 2010

Peter Jagers, ordförande
Helmut Neunzert, vice ordförande
Bo Johansson
Dieter Prätzel-Wolters

Räkenskaperna har granskats av Deloitte

Appendix

Publications

K Wärmefjord, J Carlson, R Söderberg:
A Measure of the Information Loss for Inspection Point Reduction, Journal of Manufacturing Science and Engineering, Volume 131, No. 5, 2009.

F Edelvik, B Andersson, S Jakobsson, S Larsson, M Persson, Y Shirvany:
An Improved Method for Dipole Modeling in EEG-Based Source Localization, World Congress 2009 - Medical Physics and Biomedical Engineering, Vol 25/IX, pp 146-149, München, Germany, September 2009.

A Stjernman, A Derneryd, S Jakobsson, B Andersson, F Edelvik:
Multi-objective Optimization of MIMO Antenna System, Proceedings from 3rd European Conference on Antennas and Propagation, Berlin, Germany, March 2009.

S Jakobsson, M Patriksson, J Rudholm, A Wojciechowski:
A Method for Simulation Based Optimization Using Radial Basis Functions, Optimization and Engineering, available online: June 2009.

S Jakobsson, M Saif-Ul-Hasnain, R Rundqvist, F Edelvik, B Andersson, M Patriksson, M Ljungqvist, D Lortet and J Wallesten:
Combustion engine optimization: A multiobjective approach, Optimization and Engineering, available online: August 2009.

S Jakobsson, B Andersson, F Edelvik:
Approximation of Antenna Data with Rational Radial Basis Function Interpolation, International Conference of Numerical Analysis and Applied Mathematics 2009, Vol 1, pp 473-477, Crete, Greece, September 2009.

S Jakobsson, B Andersson, F Edelvik:
Rational radial basis function interpolation with applications to antenna design, Journal of Computational and Applied Mathematics, Vol 233(4), pp 889-904, December 2009.

A Jansson, M Jirstrand:
Biochemical modeling with Systems Biology Graphical Notation, submitted to Drug Discovery Today, September 2009.

P Johannesson, T Svensson, L Samuelsson, B Bergman, J de Maré:
Variation mode and effect analysis: an application to fatigue life prediction, Quality and Reliability Engineering International, Volume 25, issue 2, pp 167-179, March 2009.

M Kvarnström, A Westergård, N Lorén, M Nydén:
Brownian dynamics simulations in hydrogels using an adaptive time-stepping algorithm, Physical Review E (79), 016102, 2009.

B Bergman, J de Maré, S Lorén, T Svensson (eds.):
Robust design methodology for reliability exploring the effects of variation and uncertainty, Wiley, August 2009.

R Rundqvist, A Mark, B Andersson, A Ålund, F Edelvik, S Tafuri, J S Carlson:
Simulation of Spray Painting in Automotive Industry, submitted.

R Rundqvist:, Microstructure simulations of early paperforming:
Proceedings from Papermaking Research Symposium, Kuopio, Finland, June 2009.

B Saboori, B Saboori, J Carlson, R Söderberg:
Introducing fast robot roller hemming process in automotive industry, World Academy of Science, Engineering and Technology, Volume 58, October 2009.

J Segeborn, J Carlson, A Carlsson, R Söderberg:
Parameters Influencing Geometrical Quality and Station Cycle Time in Sheet Metal Assemblies, Proceedings of The 2nd Nordic Conference on Product Lifecycle Management, January 28-29, 2009.

J Segeborn, A Carlsson, J Carlson, R Söderberg:
A Chronological Framework for Virtual Sheet Metal Assembly Design, accepted at the 11th CIRP International Conference on Computer Aided Tolerancing, Annecy, France, March 26-27, 2009.

D Spensieri, J Carlson, L Lindkvist, R Bohlin, R Söderberg:
A Method to Optimize Geometrical Quality and Motion Feasibility of Assembly Sequences, accepted at the 11th CIRP International Conference on Computer Aided Tolerancing, Annecy, France, March 26-27, 2009.

M Sunnåker, H Schmidt, M Jirstrand, G Cedersund:
Zooming of states and parameters using a lumping approach including back-translation, accepted for publication BMC Systems Biology.

Theses

F Andersson (Chalmers); examiner B Johansson
Surface interpolation for detail restoration, Master Thesis, June 2009.

G Eek, C Eriksson (University of Gothenburg); examiner M Wahde
Effective methods for solving the balanced and synchronized multiple TSP using genetic algorithms, Master Thesis, June 2009.

R Jakobsson and M Ohlsson (Volvo Buses and Chalmers); examiner J de Maré
Real World Fuel Consumption of Buses - Prediction for Auxiliary Units Using Multivariate Regression Methods, Master Thesis, June 2009.

P Magnusson (Chalmers); examiner M Fabian
Implementation of an interconnection between softPLC and simulation software, Master Thesis, October 2009.

S Lorin (Chalmers); supervisors J Carlson and F Edelvik, examiner I Rychlik
Geometric Variation in Injection Molding, Master Thesis, June 2009.

B Saboori, B Saboori (Chalmers); examiner R Söderberg
Development of roller hemming process in automotive industry - Saab Automobile AB, Master Thesis, June 2009.

J Sanchez, (Volvo Trucks and Chalmers); examiner J de Maré,
Vehicle Damage Prediction from Advanced and Simple Systems Measurements, Master Thesis, May 2009.

D Sjögren (Chalmers); supervisor S Jakobsson, examiner T Norberg
Statistical methods for improving surrogate models in antenna optimization, Master Thesis, April 2009.

Y Niu (Det Norske Veritas and Chalmers); examiner I Rychlik
How much are Whippings Contributing to Fatigue and Extreme Responses in ship Structure Details, Master Thesis, June 2009.

N Delfs, S Gustafsson, P Mårdberg (Chalmers, University of Gothenburg); examiner C-H Fant
Robotik och invers kinematik, BSc Thesis, June 2009.

Presentations/Posters/Conferences

J Almquist, M Wallman, I Jacobson, M Jirstrand:
In Silico Simulation of Fibrillation in Canine Atrial Tissue Using Detailed Ion-Channel Models Including Drug Interaction Effects, 5th BioSim conference, Copenhagen, August 2009.

B Andersson:
Tekniska beräkningar på FCC, Matematik i yrkeslivet, Chalmers, October 2009.

R Bohlin:
Path Planning Software and Advanced Simulation, Guest lecture, Robotics and Robot Systems, Department of Product and Production Development, April 2009.

R Bohlin
Mathematics and Robotics, Guest lecture, Portalens Gymnasium, Gothenburg, June 2009.

J Carlson, E Shellshear, D Spensieri, S Tafuri:
Wingquist Laboratory Annual Seminar on Virtual Product Realization, Chalmers, Gothenburg, November 2009.

F Edelvik:
EEG-based Source Localization in the Human Brain, 8th European Conference on Numerical Mathematics and Advanced Applications (EnuMath), Uppsala, June 2009.

F Edelvik:
Multi-objective Optimization of MIMO Antenna Systems, 8th European Conference on Numerical Mathematics and Advanced Applications (EnuMath), Uppsala, June 2009.

F Edelvik:
Simulation of Coating Processes in Automotive Industry, 8th European Conference on Numerical Mathematics and Advanced Applications (EnuMath), Uppsala, June 2009.

F Edelvik:
An Improved Method for Dipole Modeling in EEG-Based Source Localization, World Congress 2009 - Medical Physics and Biomedical Engineering, München, Germany, September 2009.

F Edelvik:
Multi-objective Optimization of MIMO Antenna Systems, Invited Seminar Department of Signals and Systems, Chalmers, Gothenburg, September 2009.

F Edelvik:
EEG-baserad lokalisering av elektrisk aktivitet i hjärnan, Guest Lecture for Engineering Physics Program, Chalmers, Gothenburg, October 2009.

S Jakobsson:
Rational radial basis function interpolation with applications to antenna design, CAM Seminar at Department of Mathematics, Chalmers, Gothenburg, April 2009.

S Jakobsson:
Approximation of Antenna Data with Rational Radial Basis Function Interpolation, International Conference of Numerical Analysis and Applied Mathematics 2010, Crete, Greece, September 2009.

S Jakobsson:
Rational radial basis function interpolation with applications to antenna design, Seminar at Institut für Numerische und Angewandte Mathematik, Göttingen, Germany, November 2009.

T Svensson, M Karlsson, B Johannesson, P Johannesson, J de Maré:
Predictive Safety Index for Variable Amplitude Fatigue Life, Presented at the conference Material and Component Performance under Variable Amplitude Loading, Darmstadt, Germany, March 2009.

T Svensson, P Johannesson, J de Maré:
Poster: Engineering reliability assessment, Fatigue design for safety, Nya Varvet, Gothenburg, May 25-27, 2009.

P Johannesson, T Svensson:
A Load-strength Model for Fatigue Applications, ENBIS9, Gothenburg, September 20-24, 2009.

T Svensson, P Johannesson, J de Maré:
Poster: Engineering reliability assessment, ENBIS9, Gothenburg, September 20-24, 2009.

S Lorén, T Svensson:
Monte Carlo versus second moment evaluation in reliability, a fatigue life example, ENBIS9, Gothenburg, September, 20-24,2009.

S Lorén, T Svensson, J de Maré, B Bergman:
Poster: Robust Design Methodology for Reliability Exploring the Effect of Variation and Uncertainty, ENBIS9, Gothenburg, September 20-24, 2009.

S Lorén, T Svensson, J de Maré, B Bergman:
Poster: Robust Design Methodology for Reliability Exploring the Effect of Variation and Uncertainty, Fatigue design for safety, Nya Varvet, Gothenburg, May 25-27, 2009.

J de Maré:
Maintenance for reliability, Optimization of Maintenance Activities - Models, Methods and Applications, Gothenburg, December 10-11, 2009.

R Rundqvist:
Microstructure simulations of early paperforming, Papermaking Research Symposium, Kuopio, Finland, June 2009.

Other assignments

R Bohlin:
Reviewer for IEEE International Conference on Robotics and Automation

R Bohlin:
Reviewer for IEEE Conference on Automation Science and Engineering

F Edelvik:
Reviewer for IEEE Antennas and Wireless Propagation Letters

F Edelvik:
Reviewer for ICOSAHOM'09 proceedings

F Edelvik:
Reviewer for IEEE Transactions on Advanced Packaging

F Edelvik:
Chairman for the session on "Interface dynamics" at 8th European Conference on Numerical Mathematics and Advanced Applications (EnuMath), Uppsala, June 2009.

S Jakobsson:
Reviewer for Zentralblatt

M Jirstrand:
Reviewer for Journal of Dynamic Systems, Measurement and Control

M Jirstrand:
Reviewer for BMC Systems Biology

M Jirstrand:
Reviewer for The European Control Conference 2009

M Jirstrand:
Reviewer for FEBS Journal

Courses

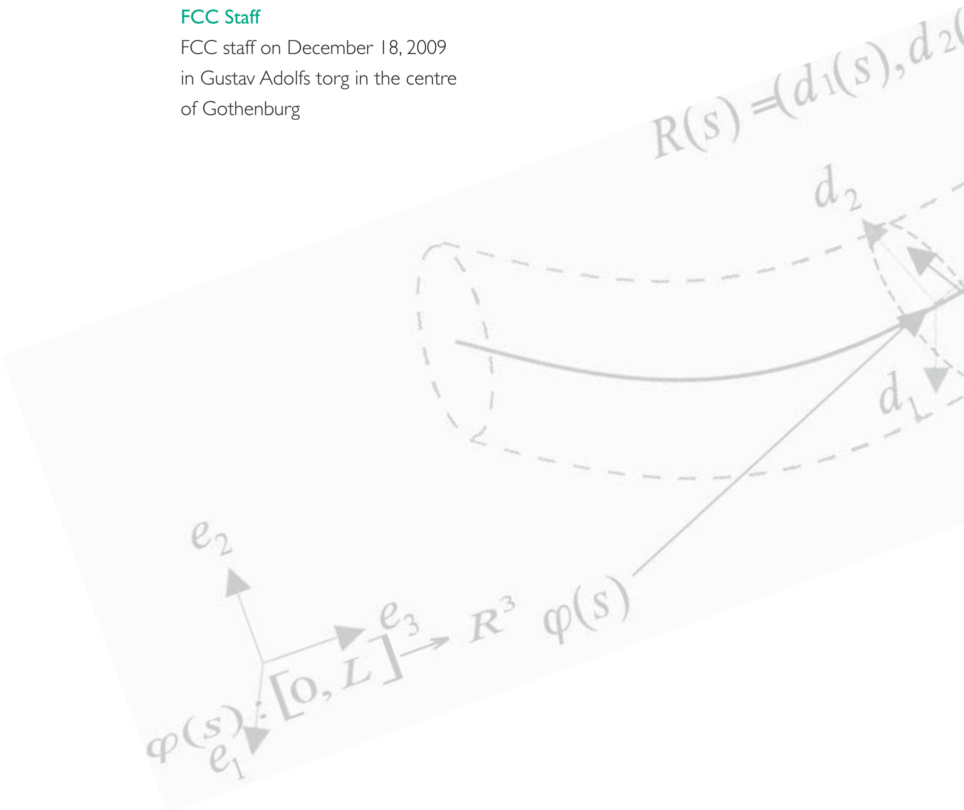
M Jirstrand:
Introduction to Computational Systems Biology and Tutorial on PathwayLab. Invited lecturer for The 4th International Course in Yeast Systems Biology, Gothenburg, June 2009.

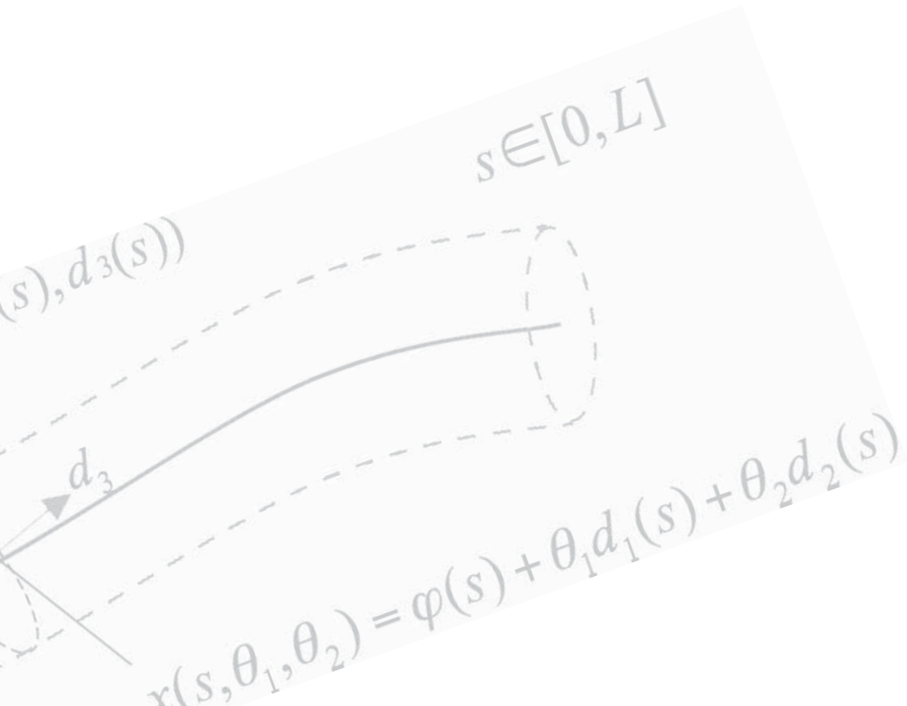
M Jirstrand:
Systems Theory in the Toolbox for Systems Biology and Modeling Tools: PathwayLab, Systems Biology Toolbox, and Mathematica, co-lecturer in the course Mathematical Modelling and Computational Tools, Int. Master's Program for Bioinformatics and Systems Biology, Chalmers University of Technology, Gothenburg, November 2009.

J de Maré, S Lorén:
Underhållsplanering för ökad tillförlitlighet, Chalmers Teknikpark, Gothenburg, September 16-17, 2009.

FCC Staff

FCC staff on December 18, 2009 in Gustav Adolfs torg in the centre of Gothenburg




$s \in [0, L]$
d_3
$x(s, \theta_1, \theta_2) = \varphi(s) + \theta_1 d_1(s) + \theta_2 d_2(s)$

The Fraunhofer-Chalmers Research Centre for Industrial Mathematics, FCC, has been founded by Chalmers and the Fraunhofer-Gesellschaft as a business making, non-profit Swedish foundation.

The purpose of FCC is to promote the application of mathematical methods in industry. To do so the Centre will undertake pre-competitive scientific research in the field of applied mathematics and work on projects defined by companies or public institutes.

The Centre, in close cooperation with Chalmers in Gothenburg and Fraunhofer ITWM in Kaiserslautern, shall be a leading partner for international industry and academia to mathematically model, analyse, simulate, optimize, and visualize phenomena and complex systems in industry and science, to make development of products and processes more efficient and secure their technological and financial quality.

ITWM

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