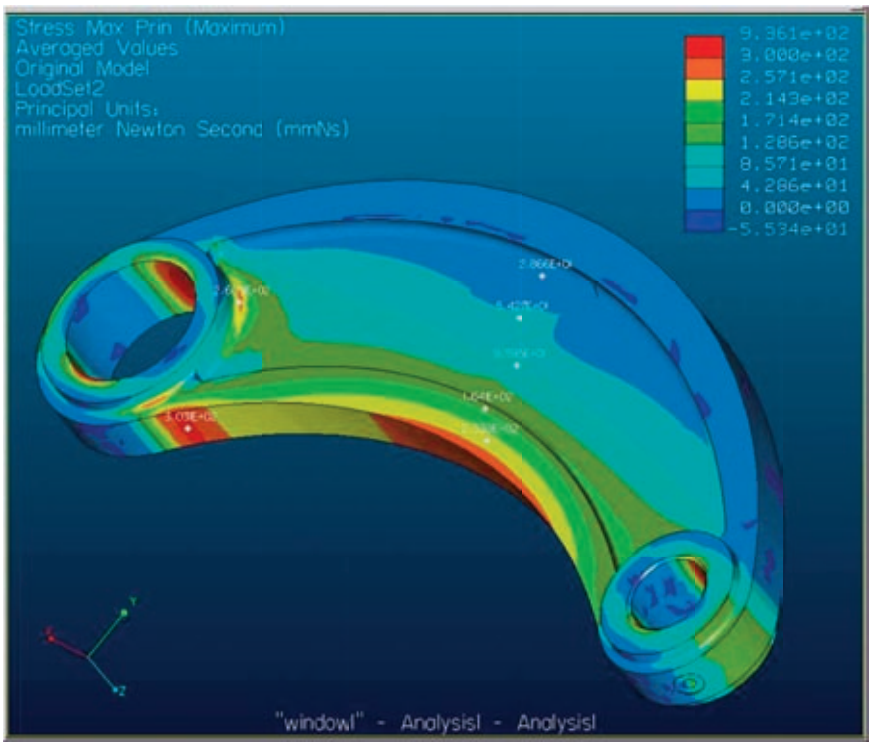
Fraunhofer CHALMERS
Research Centre
Industrial Mathematics

Annual Report 2005



FCC

Fraunhofer-Chalmers Research Centre for Industrial Mathematics

This and other FCC reports are distributed by

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Cover

The front cover shows stresses in a linkage arm exposed to traction forces, cf pages 19 and 25 (courtesy of Atlas Copco Rock Drills).

Illustrations

To illustrate our research on pages 12 - 45 we use the fourteen Swedish sites on UNESCO´s World Heritage List, cf the inner back cover.

Annual Report 2005

Fraunhofer-Chalmers Research Centre
for Industrial Mathematics, FCC

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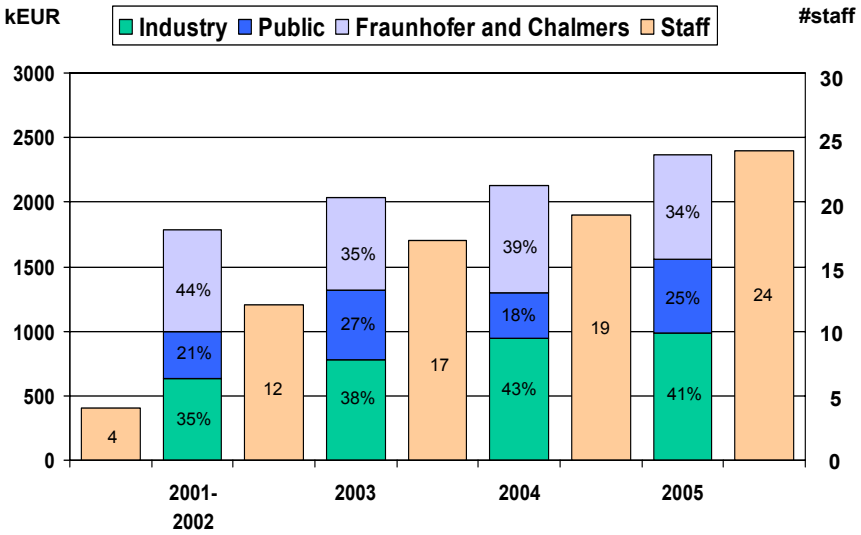
Contents

Preface

FCC operates in Chalmers Science Park.

The concept of mathematics as a technology is nowadays gaining general acceptance, not only by the big companies, but also gradually by small and medium size enterprises. Mathematical and statistical analysis including modelling, simulation, and visualization are used to quantify performance and properties of processes and products for optimal design and quality control. This framework is being recognized as a powerful tool for industrial innovation and competitiveness.

FCC has successfully been operating according to this vision since the start in 2001. Together with our partners Chalmers and the Fraunhofer industrial mathematics institute ITWM we cover a wide range of applications. From 2001 we have started more than 160 projects, 130 of which have been completed, with companies and organizations of different size and from different branches. The diagram below shows the build-up of the Centre in terms of income and staff.



The profile of the Centre is controlled by its income structure. The result of 2005 is well in line with the Fraunhofer financial model, i e, the project volumes from industry (41%), public financieers (25%), and Fraunhofer and Chalmers (34%) are well in balance.

www.fcc.chalmers.se

The department Geometry and Motion Planning, working in close co-operation with the Chalmers Wingquist Laboratory, has continued its success story. Our research together with industrial partners has also attracted substantial public funding, e g, through a three year grant within the MERA programme starting 2005. A new challenging aspect in the robotics application is the handling of flexible cables being addressed together with our partner Fraunhofer ITWM.

In December 2005 the Swedish Foundation for Strategic Research decided to start the Gothenburg Mathematical Modelling Centre (GMMC) as one of seventeen strategic centres, to be financed by SSF in five years 2006 – 2010. The Centre is run by Chalmers Mathematical Sciences and has FCC as a key component.

In 2005 both Fraunhofer and Chalmers decided to continue (and increase) their commitments for the next five years 2006 - 2010. This is a wonderful quality certificate which gives FCC a strong basis for future operations.

Later in this annual report we present our departments and research areas. For illustration purposes we use the fourteen Swedish sites on UNESCO's World Heritage List of sites having outstanding universal value; I wish to acknowledge the kind help of the Swedish National Heritage Board and the National Land Survey of Finland to realize this idea.

Before ending this preface I take the opportunity to thank my co-workers at FCC for their enthusiastic commitment to form our new Centre, and express my appreciation of the fruitful collaboration with our friends at Chalmers and Fraunhofer ITWM on a local as well as European scale.

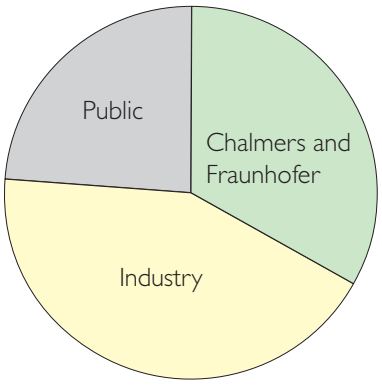
Göteborg in May 2006

Uno Nävert
Director

Uno Nävert, Director of FCC.

Profile

Mathematics has become a key technology for industrial innovation since mathematics is behind all work in the virtual world.



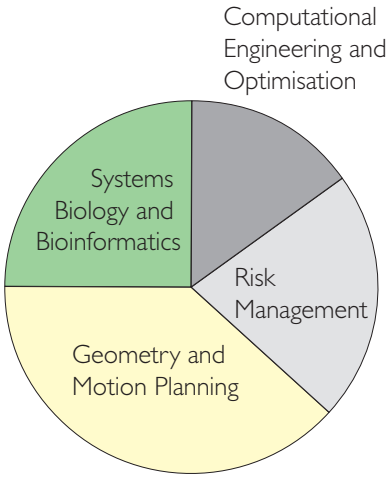
Project mix by income.

The Fraunhofer Society and Chalmers have founded FCC to undertake and promote scientific research in the field of applied mathematics to the benefits of Swedish and European industry, commerce, and public institutions. To do so the Centre undertakes scientific research and marketing financed by the founders and works on projects defined by companies and public institutes on a commercial basis.

FCC is an example of a bottom-up strategy to build the European research space. First we define a small network of closely (daily) cooperating research institutes. To solve concrete problems from companies from all over Europe, we then create optimal teams built out of this network. We do this in the field of mathematics, which is a key technology for industrial innovation, lying behind all work in the virtual world, e g, simulation for prediction, control, optimisation, and risk assessment.

By the end of 2005 the staff was twentyfour full-time equivalents, including four scientific advisers from Chalmers, each one working 10% - 20% of full time at FCC.

FCC undertakes scientific research financed by its founders and by public institutes.



Departments by income.

Scientific competence

The Centre undertakes scientific research projects and marketing of scientific results financed by its founders and by public institutes. Respecting the confidentiality of data from customers, the Centre encourages the publication of results. FCC supports efforts to use its research for educational purposes at all levels at Chalmers as well as at other educational institutions in Sweden and Europe. FCC sponsors PhD work, if the subjects are of basic interest for the research in the Centre. FCC keeps contact with the worldwide community of applied mathematicians by active participation in conferences and by inviting guest scientists.

In 2005 the Centre has received public grants from SSF (Swedish Foundation for Strategic Research), Vinnova (Swedish Agency for Innovation Systems), and EU (Network of Excellence Biosim).

Entrepreneurial competence

FCC works on projects defined by companies and public institutes on a commercial basis.

The Swedish Society for Applied Mathematics, STM, is a consortium of companies with business in Sweden, cf page 7. This consortium is the largest individual industrial client of FCC and represents almost fifteen percent of the total industrial income.

Experiences from Fraunhofer show that small and medium size companies constitute an important market for an industrial mathematics institute. The number of SME projects at FCC is however still less than ten percent of the total industrial income.

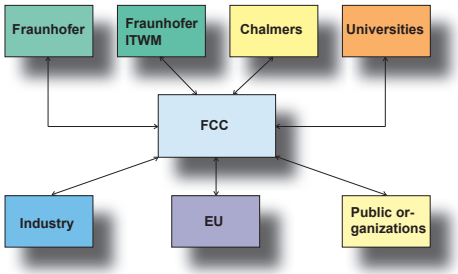
In 2005 the Centre has served international industrial clients from France, Germany, Italy, and the Netherlands.

Professional networking

FCC in close co-operation with Chalmers and Fraunhofer shall be a leading international partner in industrial mathematics.

The Centre has a very close relation to its founders Chalmers and Fraunhofer ITWM, cf pages 8 - 11, exchanging staff members, co-operating in projects, by joint participation in European projects, by connecting Swedish clients with ITWM and vice versa, and by stimulating the co-operation between Swedish industry and other Fraunhofer institutes.

In order to fulfil its tasks optimally, the Centre co-operates with competent scientific groups at universities and elsewhere, cf pages 14 - 15, 22, 28, 40, and 42. It also promotes research and education in industrial mathematics at institutions outside the Centre, cf pages 10 - 11, 13, 19, 21, 25, 29, 39, and 42.



Financial mix

FCC earns approximately 35% from its founders, 40% industrial income, and 25% public income.

The financial model distinguishes between three income sources: project financing from the founders, industrial project income, and public project income. These three should be in reasonable balance.

Over the five year period, the industrial and public project volume has increased more than expected in the original business plan. As a result of this, the relative project financing from the founders has decreased from 45 percent in 2001 to 35 percent in 2005, cf page 2.

Acknowledgements

The Centre is a Swedish foundation established by Chalmers and Fraunhofer-Gesellschaft. The decision has been based on a business plan prepared by the Swedish Institute for Applied Mathematics (ITM) and Fraunhofer-Institut für Techno- und Wirtschaftsmathematik (ITWM).

The Swedish Society for Applied Mathematics (STM) and the former Swedish National Board for Technical and Industrial Development (NUTEK) have supported FCC taking over ITM operations.

The Swedish Foundation for Strategic Research (SSF) has played an essential role by giving support of one million euros for a public project where two future scientific leaders have been recruited to establish a research team in Bioinformatics and Systems Biology at the Centre.

In 2005 Fraunhofer and Chalmers decided to continue their commitments for the next five years 2006 - 2010.

Clients and Partners

Since its start in 2001, FCC has successfully co-operated with enterprises of different sizes and from many branches. In the following, those clients and project partners are listed who have accepted to be cited.

- ABB
- ABB Robotics
- ABB Power Technologies
- Adam Opel GmbH (D)
- Aerotech Telub
- Albany International
- AP2 Second Swedish National Pension Fund
- AstraZeneca R&D Mölndal
- AstraZeneca R&D Södertälje
- Atlas Copco Rock Drills
- Bergaskolan
- Bombardier Transportation
- BTG Pulp and Paper Sensors
- Consorzio Politechnico Innovazione (I)
- Elforsk
- Elmo Leather
- Ericsson
- Ericsson Microwave Systems
- Faurecia Exhaust Systems
- FOI
- Fortum Power and Heat OY
- Front Capital Systems
- InNetics
- Innovativ Vision
- IVF Industriforskning
- Jernkontoret
- KP Pension and Insurance
- NMCT
- Novo Nordisk (DK)
- Optimization Partner Stockholm
- PLANit Sweden
- Poseidon Diving Systems
- PSA Peugeot Citroën (F)
- Saab
- Saab Automobile
- Saab Ericsson Space
- Safe Technology
- Saint-Gobain Sekurit Scandinavia
- Sandvik Steel
- SCA
- Scania
- Simula Research Laboratory AS (N)
- SKF (Sweden and NL)
- STM Forskningsservice
- SP Sveriges Provnings- och Forskningsinstitut
- StoraEnso Corporate Research
- Sveriges Försäkringsförbund
- Sydkraft
- Uddcomb
- Universitetssjukhuset MAS
- Volvo Aero Corporation
- Volvo Car Corporation
- Volvo Trucks
- Volvo 3P

- Chalmers tekniska högskola
- Chalmers Industriteknik
- Chalmers Matematik
- Chalmers Matematisk statistik
- Chalmers Wingquist Laboratory
- EU Biosim / DTU (DK)
- EU Visicade / Fraunhofer IGD (D)
- Fraunhofer ITWM (D)
- Göteborgs Universitet/ Mikrobiologi
- Göteborgs Universitet/ Molekylärbiologi
- ITM
- Kungliga Tekniska Högskolan /PSCI
- Linköpings Universitet / Beräkningsbiologi
- Linköpings Universitet / Reglerteknik
- Lunds Universitet / Matematisk statistik
- Univ of California, Berkeley/ Mathematics

STM

The Swedish Society for Applied Mathematics (STM) has financed projects at FCC with 165 kEUR in 2005.

Members and shares 2005:

Engineering and transport	
Volvo	5
SKF	5
ABB	3
Saab	3
SP Swedish National Testing and Research Institute	1
Pharmaceuticals	
AstraZeneca R&D Mölndal	5
Telecommunications	
Ericsson Microwave Systems	1
TeliaSonera Sverige	1
Energy	
Vattenfall	5
Insurance and finance	
Swedish Insurance Federation	5
Wood, pulp, paper	
StoraEnso Corporate Research	1
	35

www.itm.se

Fraunhofer-Gesellschaft

Professor Helmut Neunzert, ITWM, Vice Chairman of FCC.

The Fraunhofer-Gesellschaft is the largest organization for applied research in Europe.

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration. The Fraunhofer-Gesellschaft maintains roughly 80 research units, including 58 Fraunhofer Institutes, at over 40 different locations throughout Germany. A staff of some 12500, predominantly qualified scientists and engineers, works with an annual research budget of over one billion euros. Of this sum, more than 900 million euros is generated through contract research. Roughly two thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. The remaining one third is contributed by the German federal and Länder governments, partly as a means of enabling the institutes to pursue more fundamental research in areas that are likely to become relevant to industry and society in five or ten years' time.

The Fraunhofer-Gesellschaft is also active on an international level: Affiliated research centers and representative offices in Europe, the USA and Asia provide contact with the regions of greatest importance to present and future scientific progress and economic development.

The Institut für Techno- und Wirtschaftsmathematik (ITWM) in Kaiserslautern became a Fraunhofer institute on January 1, 2001. ITWM has continued its exceptional development and has now (2005) a budget of ten million euros and a staff of 150 persons including 90 scientists, 40 PhD students, and 20 employees of the central services. The Institute further engages some 150 students and diploma workers. Its Director is Professor Dieter Prätzel-Wolters.

The ITWM is organized into eight units, which reflect key competence fields: Departments in Transport Processes, Flow in Complex Structures, Models and Algorithms in Image Processing, Adaptive Systems, Optimisation, Financial Mathematics, Dynamics and Durability, and the Competence Centre High Performance Computing and Visualization.

Professor Helmut Neunzert is responsible for international affairs at ITWM. FCC originates from his vision of a European institution operating in the Fraunhofer spirit.

www.fraunhofer.de
www.itwm.fraunhofer.de

Co-operation

A key element in the operation of FCC is its close co-operation with Fraunhofer ITWM. In 2005 the project volume was 250 kEUR.

Computational Engineering and Optimisation

FCC and ITWM run joint projects on fibre flow modelling, fibre flow measurements, and optimisation of products and configuration, cf pages 17 and 19. We have also started joint strategic projects in optimisation and visualisation, cf page 19.

Geometry and Motion Planning

ITWM has developed improved methods for the simulation and vizualisation of robot cable motion based on compliant objects. The new method includes (1) realistic visual appearance of cable motion, for robot arm contacts and approximately constant cable length, (2) accurate prediction of the position of the cable segments during robot arm motion, for realistic collision checks, (3) fast algorithm, for interactive computation of cable motion, cf page 28.

Image Processing

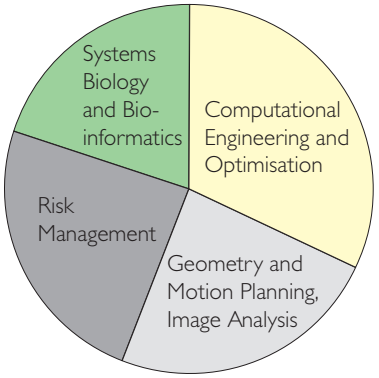
FCC and ITWM run a joint industrial project on surface inspection, where we develop an automatic grading system for leather manufacturing, cf page 37.

Risk Management

FCC and ITWM run several joint projects in finance and insurance mathematics, where we develop asset liability management tools and risk measures for solvency assessment with Swedish industrial partners, cf page 27.

Systems Biology and Bioinformatics

FCC and its Swedish partner InNetics develop methods and software (Pathway Lab) in systems biology for the identification and analysis of biochemical reaction networks. ITWM has developed software (Analog Insydes) for the reduction of complex signal networks, based on advanced symbolic computation and approximation techniques. In a joint project we study the coupling of these two software packages for pharmaceutical and biotech applications, cf page 41.



ITWM income from FCC projects in 2005, in total 250 kEUR.

Chalmers

Professor Peter Jagers, Chalmers, Chairman of FCC.

The Chalmers University of Technology (Chalmers tekniska högskola) was founded in 1829. It is a non-profit, non-governmental university. With its more than 8600 students for engineering and architecture degrees, and more than 1000 PhD students it is one of Sweden's two leading technology universities.

Most of Chalmers' resources come from contracts with the state of Sweden (69%), but Chalmers also has strong support from non-governmental research organizations (19%) and industry (12%). The annual (2005) turnover is 230 million euros. Two thirds of the budget are alotted to research and to graduate studies. With its staff of 2245 full time equivalents, including 158 full professors, the University has strong and well-known departments in most fields of science and engineering.

Chalmers has made special efforts to integrate mathematics into a broader scientific and technological perspective. Strong activities in stochastics and numerical and modelling mathematics have emerged. Thus, besides activities in the various mathematical fields, Chalmers Applied Mathematics comprises three more specialized centres.

Professor Peter Jagers was the President of the Chalmers Faculty Senate 1993 - 2002. He brought up the idea of engaging Chalmers in a joint venture, when the Fraunhofer Society started to look for Swedish partners. He also represented Chalmers in the subsequent negotiations.

Co-operation

A key element in the operation of FCC is its close co-operation with Chalmers.

This co-operation is mainly organized through scientific advisers. Each adviser typically spends between 10 and 20 percent of full time at the Centre. In 2005 there were four advisers representing optimisation, stochastics (fatigue life), bio, and mechanical engineering (product and production).

Below we describe three particularly successful areas within the co-operation.

www.chalmers.se
www.math.chalmers.se

Geometry and Motion Planning

Chalmers started the Wingquist Laboratory in October 2001 as part of Mechanical and Vehicular Engineering to increase the collaboration with Swedish industry and to concentrate research in strategic areas. The laboratory conducts interdisciplinary research within the field of virtual verification of product and production concepts.

FCC and Wingquist have a very close co-operation in geometry and motion planning focusing on product- and production system modelling, robust design and variation simulation, and flexible production and automation systems, cf pages 28 - 35.

"Together, FCC and Wingquist Laboratory possess a unique set of competence that enables industrial projects with extraordinary requirements in the field of simulation and analysis to be carried out successfully."

Professor Rikard Söderberg,
Director Wingquist Laboratory,
Scientific adviser FCC

Statistical Fatigue of Materials

Chalmers and FCC have together built up a strong operation in fatigue life and load analysis, with industrial income 2001 - 2005 from Swedish (585 kEUR), French (150 kEUR), and Italian (15 kEUR) companies. The industrial income 2005 was 210 kEUR.

The strategy has been to consider the fatigue group as one unit jointly supported by Chalmers and FCC. In that way, problems from industry are imported into the academic work and research results are exported to industry. This two-way communication has proved fruitful for the students at Chalmers, including students from industry hosted at Chalmers and FCC, as well as for the industrial partners, cf pages 22 -25.

"The establishment of FCC has made it possible for the fatigue group to host competence for solving particular industrial problems as well as for doing purely academic work."

Professor Jacques de Maré
Chalmers Mathematical Sciences,
Scientific adviser FCC

Gothenburg Mathematical Modelling Centre GMMC

In December 2005 the Swedish Foundation for Strategic Research (SSF) decided to finance seventeen strategic centres including the Gothenburg Mathematical Modelling Centre (GMMC).

The vision of GMMC is to be a role model for co-operation between mathematics and industry-society-science. The basis of GMMC is the Chalmers and Gothenburg University department of Mathematical Sciences, the Chalmers Stochastic Centre, the Chalmers department of Quality Sciences, and FCC. The research programme includes (1) Risk, reliability, and quality, (2) Biomathematics, (3) Computational technology and optimisation, and (4) Spatial models, environmental statistics, and algorithms.

SSF has decided on a five year grant to Chalmers of 500 kEUR per year 2006 - 2010 for the Gothenburg Mathematical Modelling Centre GMMC. The director of GMMC is Professor Holger Rootzén.

Computational Engineering and Design

Industrial process and product design often rely on the fundamental understanding of the development of field variables such as temperature, pressure, forces, and velocities. Traditionally this understanding is achieved by trial-and-error approaches and hands-on engineering, but the increased competition on the market requires a more systematic approach to guarantee success.

The department of computational engineering and optimisation does mathematical modelling of physical phenomena, such as fluid mechanics and electromagnetics, and computer simulation based on these models, which typically are in the form of partial differential equations (PDE). The development of scientific computing enables solution of complex systems of PDEs, making real industrial problems tractable to scientific analysis and optimisation based on simulations.

Many problems exhibit multiscale behavior. For instance, a composite material may be described by fibres in a matrix on the microscale and linear elasticity on the macroscale. Multiscale computational methods are techniques to handle such problems. Typically, these techniques involve solutions on the microscale to compute the transfer of microscale effects to the macroscopic properties.

The work is organized in three areas:

- Electromagnetics
- Fluid Dynamics
- Optimisation

The research in fluid dynamics is focused on fibre flow and fluid-structure interaction. In electromagnetics we develop efficient methods to numerically solve the Maxwell equations within the framework of a general electromagnetic solver resulting from the national Swedish project PSCI project 24082-62591. The focus in optimisation is on simulation-based optimal design, multi criteria optimisation, and decision support for maintenance planning.

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The High Coast, Höga Kusten, Ångermanland *was inscribed on the World Heritage List in 2000:*
"The site is one of the places in the world that is experiencing isostatic uplift as a result of deglaciation. Isostatic rebound is well-illustrated and the distinctiveness of the site is the extent of the total isostatic uplift which, at 285 m, exceeds others. The site is the "type area" for research on isostasy, the phenomenon having been first recognised and studied there."

The Computational Engineering and Design Research Group

- Fredrik Edelvik, PhD, Computational Electromagnetics
- Erik Höök, MSc Engineering
- Robert Rundqvist, PhD, Computational Fluid Dynamics
- Ann-Brith Strömberg, PhD, Optimisation
- Anders Ålund, Lic, Numerical Analysis and High Performance Computing
- Leonid Gershuni, PhD student
- Peter Lindroth, PhD student
- Michael Patriksson, Professor in Applied Mathematics at Chalmers, Scientific Adviser at FCC


Fredrik Edelvik


Erik Höök


Robert Rundqvist


Ann-Brith Strömberg


Anders Ålund


Leonid Gershuni


Peter Lindroth


Michael Patriksson

Electromagnetics

Simulation of electromagnetic propagation and interaction is an emerging technology in application areas such as wireless technology, antenna analysis, electromagnetic compatibility, micro electronics and radar signature.

The main challenge in computational electromagnetics is that the frequencies of interest are often large and accurate modeling of small geometrical details has a crucial impact on the results. This implies very large systems with possibly several million or even billion degrees of freedom. This puts high demands on the numerical methods and the available computer resources.

The project GEMS (General Electromagnetic Solver) has been a national Swedish co-operation between academia and industry run by the Stockholm-Uppsala Parallel and Scientific Computing Institute PSCI. FCC has been subcontracted by PSCI, project 24082-6259, and has later been contracted by the participating telecommunications and aircraft companies to perform further development and software maintenance. The GEMS project has brought Sweden (and FCC) to the forefront in electromagnetic simulations.

In 2005 our competence in computational electromagnetics has been strengthened with a specialist in the areas of finite element methods, multiscale methods and electromagnetic compatibility.

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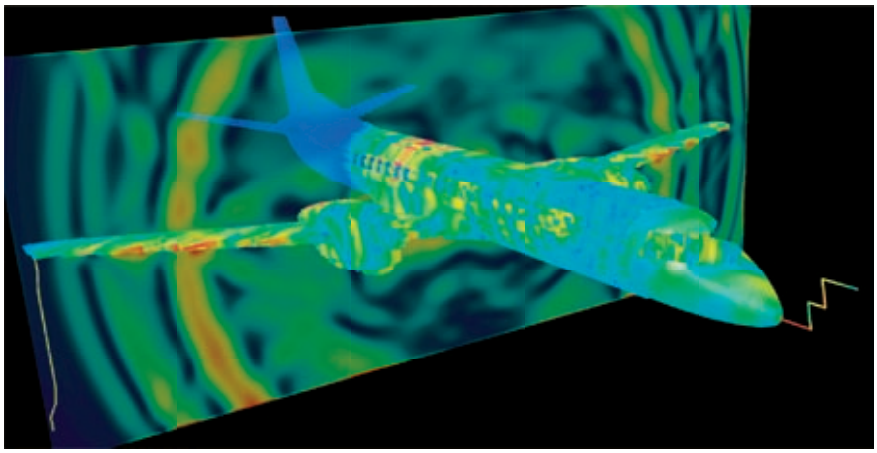
Grimeton *was added to the World Heritage List in 2004:*
"The Varberg radio station at Grimeton is an outstanding monument representing the process of development of communication technology in the period following the First World War. The Varberg radio station is an exceptionally well preserved example of a type of telecommunication centre, representing the technological achievements by the early 1920s, as well as documenting the further development over some three decades."

The GEMS software

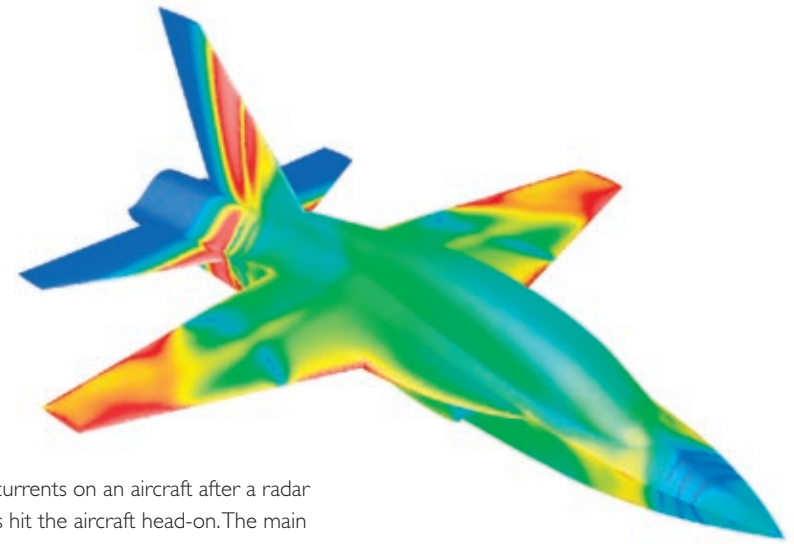
The GEMS software is a result from a successful collaboration between Swedish academia and industry. FCC has played an important part in the development of the software and has been contrated for further development as well as software maintenance by AerotechTelub, Ericsson Microwave Systems, and the industrial consortium STM. The software is used for antenna design, electromagnetic compatibility, radar signature and microwave applications. The solvers are based on formulations in both time domain and frequency domain. A key feature is the use of hybrid methods. In frequency domain a Method of Moments, MoM, boundary integral solver is coupled to a physical optics solver. In time domain an unstructured finite element method is coupled to a finite difference method. The underlying idea of the hybrid methods is to take advantage of the strengths of the individual methods without suffering from their weaknesses and thereby substantially increase the spectrum of solvable problems.

Modeling electrically thin sheets

The ability to model fine system detail is increasingly important not only because including these features improves the overall fidelity of the model, but more importantly, because small features can often significantly affect the overall system response. This is particularly true in the case of thin-material sheets and coatings. Important applications include among others: complex antennas etched on thin dielectric substrates, structures coated with thin layers of radar absorbing material (RAM) and radomes used to enclose antennas. In principle, a tetrahedral grid could be used to resolve fine system details. However, in practice, the number of unknowns can become prohibitively large. Thus, the development of accurate models that characterise the physics of small features without the need for a highly resolved grid is essential.

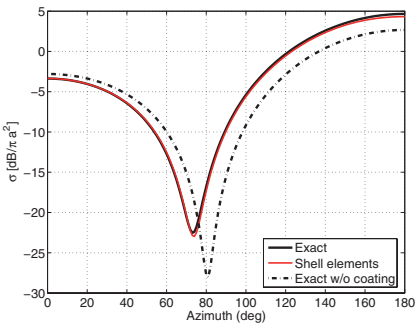


A thin wire is attached to the nose of the SAAB 2000 aircraft and a current injection is used to simulate a lightning strike. The induced surface currents are shown on the fuselage and the magnetic fields are shown on a cutting plane through the wings. A hybrid finite element - finite difference method is used.



Surface currents on an aircraft after a radar pulse has hit the aircraft head-on. The main pulse has reached the tail of the aircraft. A hybrid finite element - finite difference method is used.

The industrial consortium STM has funded a project where researchers at FCC and Uppsala University have developed a novel method based on so-called shell elements which is able to model thin material sheets without resolving their thickness by the grid. The method has been incorporated in the GEMS time-domain finite element solver. Scattering from a sphere coated with a thin dielectric layer is presented below.



Comparison of bistatic radar cross section for a coated dielectric sphere between a finite element solver that uses shell elements to model the thin coating and the exact solution.

Fluid Dynamics

Computational fluid dynamics has applications ranging from straightforward solution of standard systems of equations using commercial flow packages to advanced modelling of multiphase flow systems involving chemical reactions and compressible flows. In industrial systems, like paper making, energy production, or other manufacturing facilitites, understanding the physics of fluid dynamics holds one key to drastically improve the process with respect to production speed, environmental impact, or production cost.

Different problems require different solver capabilities. At one end of the scale, in meteorology, large-scale structures are modelled, the geometry of the system is simple, and the fields are generally computed on a two-dimensional grid. The complexity lies solely in the large amount of data to be handled and the strong non-linearity of the system. At the other end lies combustion engineering, where the flow is fundamentally three dimensional and the geometry is complex and involves moving boundaries. The picture is further complicated by the presence of fuel sprays, flame fronts and compressibility effects. FCC solves problems within the field of fluid dynamics using the best tool at hand rather than advocating a specific method. In some cases, this tool is a commercial flow solver, e g, a general PDE-solving package like COMSOL, or a specialized solver like FLUENT. In other cases the solution can only be obtained by programming everything from scratch. The most common strategy is however a mixture of the above approaches.

In 2005, FCC has focused on two areas within fluid dynamics: Fibre flows and Fluid-Structure Interaction.

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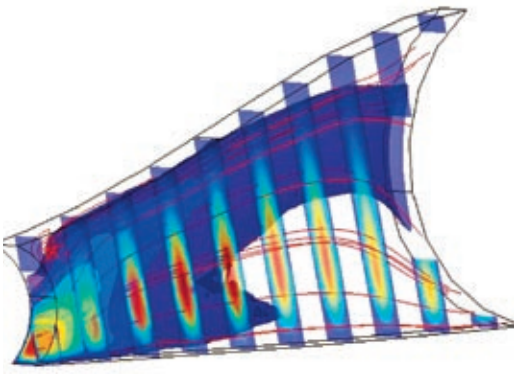
The Naval Port of Karlskrona *was inscribed on the World Heritage List in 1998:*
"Karlskrona is an exceptionally well preserved example of a European planned naval town which incorporates elements from earlier establishments in other countries and which was in its turn to serve as a model for subsequent towns with similar functions."

Fibre flows

In March 2005 FCC held a workshop on fibres in industrial flow. Selected lecturers from FCC and Fraunhofer ITWM presented views, ideas and simulation software on different aspects of fibres in industrial flows. Interest from industry was good, with participants in the audience from filter manufacturers as well as pulp and non-vowen industry. The workshop lead to several industrial projects at ITWM and FCC. Further projects with SCA Personal Care and BTG Pulp and Sensors have been completed during 2005.

The project with BTG was concerned with modelling fibre orientation in pulp flows. A statistical model for fibre orientation was coupled to the flow equations and solved in a simple test case relevant to pulp flow. The purpose was to see what could be accomplished in pulp modelling using this approach, and the results were promising. Incorporating models for denser suspensions and accounting for turbulence are future projects in this field.

The project with SCA was related to flocculation of dry-formed cellulose fibres in production of absorption cores for personal hygiene products. A system for automatic floc detection and classification based on high-speed photography of air/cellulose suspensions was developed. Results from measurements with this set-up were also used for simulations of the forming process.



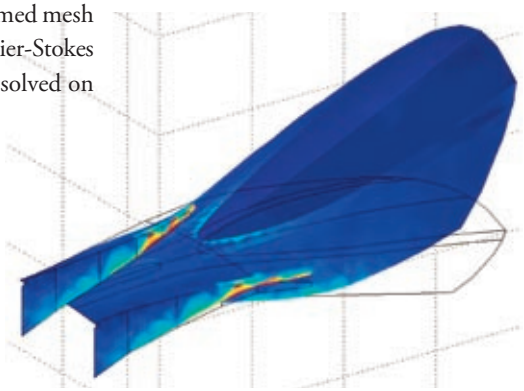
3D simulation of a statistical model for floc development in a dry forming process. The flow in the image goes mainly from left to right, following the red streamlines. Slices indicate mean size of flocs with blue being small and red being large, and isosurfaces indicate number density of flocs.

Fluid-Structure Interaction

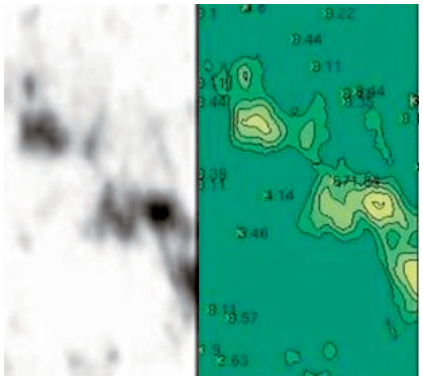
In a project with Poseidon Diving Systems, manufacturer of scuba diving equipment, we have simulated loads, deformation and swimming properties of a diving fin being developed by Poseidon.

A model of a fin-kick cycle was studied, coupling the Navier-Stokes equations of the water flowing round the fin to the structural equations describing the deformation of the fin. The fluid pressure on the fin was taken as the deforming load. The fin structure was modelled using shell elements, and the deformation was propagated into the Navier-Stokes domain using a deformed mesh approach. This means that the Navier-Stokes equations were transformed and solved on a deformed geometry.

The fin was made up of four different zones, allowing different material properties to be used. In the core region (dark blue colour in the image), a soft material was used to enhance the spoon shape of the fin when deformed. The spoon forces fluid to be redirected in the longside direction to some extent, and this is useful as this is the desired direction of the force on the swimmer/diver. This simulation was compared to simulation with a stiffer core as well as predictions for a completely stiff fin in order to quantify the effectiveness of the design.



Simulations showing the maximum deformation of the fin in a forward kick. The fin is strongly deformed, which can be both beneficial and harmful to the propulsion properties of the fin. The colours indicate von Mises stresses in the fin material. The dark blue region is the core region, which has a softer material than the rest of the fin, meaning that less stresses are absorbed here. Surrounding this region is a fork-shaped region of thicker material to increase the structural integrity of the fin. The red regions have higher stresses, indication regions that may be of concern with regard to crack formation in the material during wear.



Floc detection system. To the left is a back-lit photography of an air/fiber suspension, the dark areas containing fibres whereas the brighter areas are mostly air. To the right is a Matlab representation of the image, with contours of intensity and a crude pattern of markers for individual flocs. The numbers are a measure of the size and intensity of the floc.

Optimisation

Optimisation arises as stand-alone models and is applied in many fields in natural, medical, economical, and technical sciences to model, solve, and analyse systems.

- **Product and process optimisation with multiple criteria**

In the last decades the engineering sciences have seen a massive break-through of computer assisted methods. This enables the use of simulations for virtual testing of products and processes prior to expensive physical testing and validation. Traditionally, developers use experience from the development of similar products in a trial–and–error loop, in which parameters are set to reasonable values. Then the system is simulated, the simulation responses are evaluated, the parameters are adjusted by a rule of thumb and a new simulation is made. Mathematical optimisation methods can improve this process by efficient search strategies tailored for specific application areas and customer demands on precision and robustness.

The optimisation group runs a three-year project on multiple criteria optimisation in product and process design based on simulation.

- **Product configuration**

Many technical products are characterised by specialisation and customisation. To fulfil market demands a large number of variants is produced inducing high costs for product development, production, and sales. Hence, the number of variants offered to the customers must be limited but must also fulfil most of the customers' demands. The optimisation group studies truck configurations in a PhD project.

- **Maintenance planning**

For all technical systems large savings can be made by optimising plans for maintenance and replacement. Maintenance planning usually combines statistics and optimisation techniques. The optimisation and fatigue groups study efficient methods for the maintenance of aircraft engines in a paired PhD project.

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The Church Town of Gammelstad, Luleå *was inscribed on the World Heritage List in 1996:*
"Gammelstad Church Town is a unique example of the traditional church town found in northern Scandinavia. It illustrates in an outstanding way the adaptation of traditional town planning to the distinctive geographical and climatological conditions prevailing in a difficult natural environment."

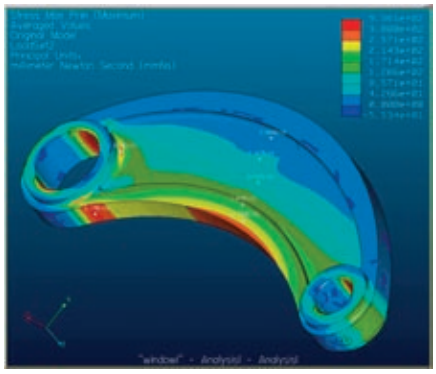
Decision support based on simulation and multi-criteria optimisation

This is a three year project which is part of a base programme with the industrial constortium STM, cf page 7. The goal is to develop and market a prototype optimisation tool that integrates multi-criteria optimisation and simulation and visualizes solutions in an interactive decision support tool. In 2005 two case studies have been investigated, cf below.

In two strategic companion projects with ITWM we focus on multi-criteria aspects and visualization.

Case study: linkage arm

If, when exposed to external forces, the stress anywhere in the linkage arm is larger than a certain threshold value a fracture will occur, causing a break. If the stress is more evenly distributed, a larger proportion of the linkage arm will be exposed to a fairly high stress which increases the probability of a fatigue break. The goal is to design a good compromise between low maximum and low average stress. Two main modelling principles are applied - topology and form optimisation - of which the former has a larger degree of freedom in the search for a good design but also demands a larger computational effort.

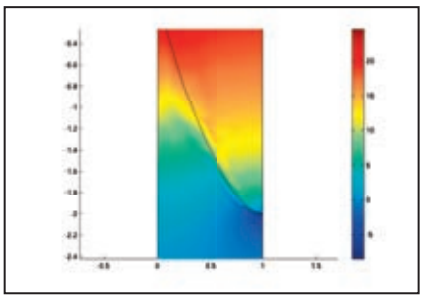


Stresses in a linkage arm exposed to traction forces (courtesy of Atlas Copco Rock Drills).

Case study: air filters

A number of filter bags are placed in a box through which polluted air passes. The filter is successively clogged by particles and the goal is to maximise its life time. This is achieved by minimising the average pressure drop over the filter over time. Optimisation parameters are the height and shape (in 2D) of the bags and material properties.

In the first phase, the instantaneous pressure drop over the filter was simulated using a 2D formulation of the Navier-Stokes and Darcy equations for flows in porous media. The optimisation algorithm used is based on quadratic models of the real objective function. Each quadratic model interpolates the objective function in a number of points and is minimised, then one interpolation point is exchanged and a new quadratic model is created. The simulation is performed in the interpolation points only. This procedure is repeated until the method converges or a sufficiently good solution is reached.



The distribution of the pressure in half a filter bag where the air flows from the top to the bottom.

Product configuration in a heterogeneous and dynamic environment

The truck industry is increasingly characterised by specialisation and customisation. This means that a truck's specification and equipment must be tailored to suit its transport tasks. Trucks are available in an enormous number of variants in order to fulfil different demands on features, transport missions, operating environments, and vehicle utilisations. The provision of a large number of truck configurations may induce high costs related to product development, production, and the sales process. It is desirable to control the number of configurations that are offered to the customers to secure that these fulfil the customers' demands and are technically feasible.

The problem of finding a good configuration of a truck is a multi-criteria optimisation problem, where the valuation of different quality measures may differ between customers and depend on the environment in which the vehicle will be used, and on the specific transport assignment. The purpose of the project is to design a framework for the truck configuration problem, aiming at finding Pareto-optimal sets of configurations such that no other configuration is better with respect to all the criteria considered. The Pareto-optimal configurations will then be clustered into a much smaller set of representative configurations to offer to the customers.

At a final stage, the aim is to incorporate the framework into the development process - to identify the variants of technical solutions needed - as well as in the sales system - to guide each customer to the right configuration.

The PhD student MSc Peter Lindroth at Chalmers Mathematics studies the product configuration problem in a project with Volvo 3P and receives co-advisement from FCC and ITWM.

Decision support for maintenance planning

The computation of optimal time points for maintenance of aircraft engines is complicated and time consuming. For each maintenance occasion it must be concluded which articles should be exchanged and which article individuals should replace these.

Tekn Lic Niclas Andréasson at Chalmers Mathematics works on the project "Optimisation of logistics for cost-efficient maintenance" with Volvo Aero Corporation and receives co-advisement from FCC.

Risk Management

This department covers uncertainty and risk in a broad sense. The basic tool is mathematical statistics including stochastic process theory. Our focus is on two application areas:

- Fatigue Life and Load Analysis
- Finance and Insurance

Many failures of engineering structures in the real life are caused by fatigue of metals and it is therefore important to be able to predict the time until fatigue failures. The fatigue phenomenon is extremely complex, and hence reliable predictions demand detailed knowledge to an extent that is rarely possible to achieve. There are two main approaches to fatigue design in practise: The first one is about components that are subjected to at most a few millions of damaging stress fluctuations, then one design for fatigue life, using empirical relationships between stress and life. The second approach is about components that need to withstand more stress fluctuations, then one design for infinite life, using the estimated fatigue limit.

Finance and insurance mathematics is one of the most growing fields in applied mathematics. The underlying mathematical tools were developed in the last decades. So the time until the application was very short although the theory contains some sophisticated results. By now we concentrate on developing methods to assess asset and liability risk for insurance companies and portfolio optimisation under risk control.

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Stora Kopparberget and Falun *were inscribed on the World Heritage List in 2001:*
"The historical landscape around the Great Copper Mountain and Falun is one of the world´s most important areas for mining and metal production. Mining came to an end in the closing years of the 20th century, but it exercised a profound influence on the technical, economic, social and political development of Sweden and Europe for many centuries."

The Risk Management Research Group

- Pär Johannesson, PhD, Fatigue Life and Load Analysis
- Joachim Johansson, PhD, Finance and Insurance
- Sara Lorén, PhD, Fatigue Life and Load Analysis
- Thomas Svensson, PhD, Fatigue Life and Load Analysis
- Magnus Karlsson, PhD student
- Jacques de Maré, Professor in Mathematical Statistics at Chalmers, Scientific Adviser at FCC


Pär Johannesson


Joachim Johansson


Sara Lorén


Thomas Svensson


Magnus Karlsson


Jacques de Maré

Fatigue Life

Since start our strategy has been to develop new methods for fatigue assessment in industrial practise together with the Chalmers Stochastic Centre. Our methods are based on two main fundaments, namely
- the scientific knowledge and skills within the group and its closely connected academic partners, and
- the knowledge about actual industrial practice and skills.

These efforts have been fruitful and during 2005 several industrial projects have been evaluated with good results. The group has also increased in size by the employment of Sara Lorén, whose specific competence gives opportunities to extend the field of statistical applications in fatigue.
In addition we have made some new scientific developments and been active in direct cooperation with academy for joint future projects in line with our overall strategy.

- **Scientific developments**

During 2005 the fatigue group has concentrated its scientific efforts on new methods for reliability in industry.
- We have formulated a new reliability concept, that has been applied to safety component design problems for trucks.
- The method for spectrum fatigue assessment earlier developed by FCC has been completed with new findings giving possibilities to combine old and new experimental results in a common strength measure.
- Several years experience within measurement uncertainty evaluation was collected in a handbook for practising engineers. The handbook was written from a pronounced statistical viewpoint with the aid of experiences from both the Swedish National Testing and Research Institute and industry.

- **Industrial projects**

Projects for two large customers have dominated our work during 2005, namely two reliability projects for Volvo Aero and two projects for SKF. These projects are partly results of our efforts during 2004 in reliability, arranging a seminar for industry and discussing with several industrial contacts that are experienced in the field. One of the projects for SKF is primarily a result of our continuous work in the ESIS committee TC20 "Inclusions".

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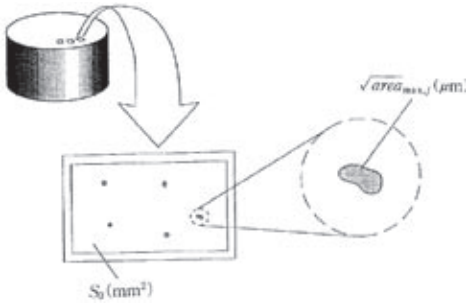
Engelsberg Ironworks, Fagersta *was inscribed on the World Heritage List in 1993:*
"Engelsberg is an outstanding example of an important European industry from the seventeenth to the nineteenth centuries, with important technical remains and with both offices and homes preserved."

Connections between the fatigue limit properties in bearings and defect distribution in the material

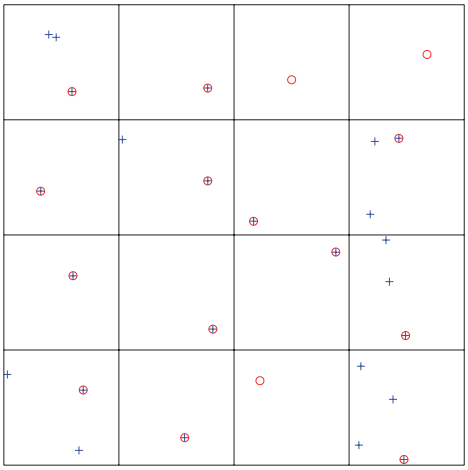
During the last years the fatigue group has been involved in the scientific problem of extreme value analysis of inclusions in steel. We have worked both with new developments resulting in several scientific publications and worked with standardization within the international engineering organization ESIS. Typically, such scientific results are not immediately useful in industry since the scientific efforts of generalization may limit the economic gains that are possible to achieve. However, for a specific application, the results may be taken further by limiting the presuppotions and be useful for industrial purposes. In a project for SKF, inclusion rating in combination with threshold theory (Murakami $\sqrt{\text{area}}_{\text{max}}$ -model) and an extrapolation formula was investigated.



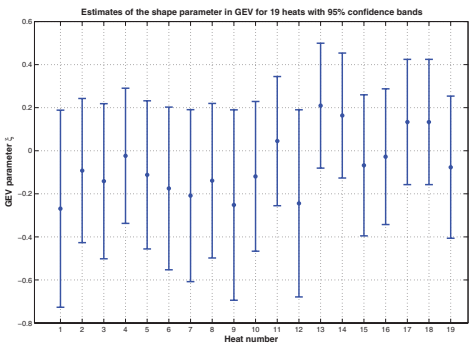
Detection of the maximum inclusion in a control area S_0.

There are two different extreme value approaches for extrapolation, namely the "*control area maxima*" (CAM) method and the "*peak over threshold*" (POT) method, which where compared in the SKF project. For the particular case in bearing steel inspections, we investigated the advantages and disadvantages with the two approaches and found rules of thumb for the choice between them. For the CAM method the total inspection area is divided into equally sized control areas, and the maximum in each control area is registered. These observations of maximum inclusion size in each control area are fitted to a Gumbel distribution, which is used for extrapolation to the reference area. The idea of the POT method is to look at all "large" inclusions in the total inspection area, instead of looking at only the largest inclusion in each control area. All inclusions with sizes above a threshold size are considered to be "large". The overshoot of the inclusion sizes above the threshold are fitted to an exponential distribution, which is used for the extrapolation to the reference area. The two approaches of sampling inclusion sizes are illustrated in the figure below.

Total inspection area, which is divided into 16 equally sized inspection areas of size 150 mm^2. The largest inclusion in each control area is marked by 'o', and the inclusions which are larger than the threshold size of 15 μm are marked by '+'.



Extreme value analysis of non-metallic inclusions has recently been standardized by ASTM, where the Gumbel distribution is assumed. This ASTM standard practice was found useful for characterization of materials, similar to the ones investigated. There is an ongoing discussion whether to use the generalized extreme value distribution. The SKF data, representative for the specific bearing application, showed no arguments for use of a non-Gumbel distribution type when modelling maximum inclusion lengths (see figure).



There is no evidence of a non-Gumbel distribution. All confidence intervals of the shape parameter in the Generalized Extreme Value distribution cover zero, the value corresponding to the Gumbel distribution.

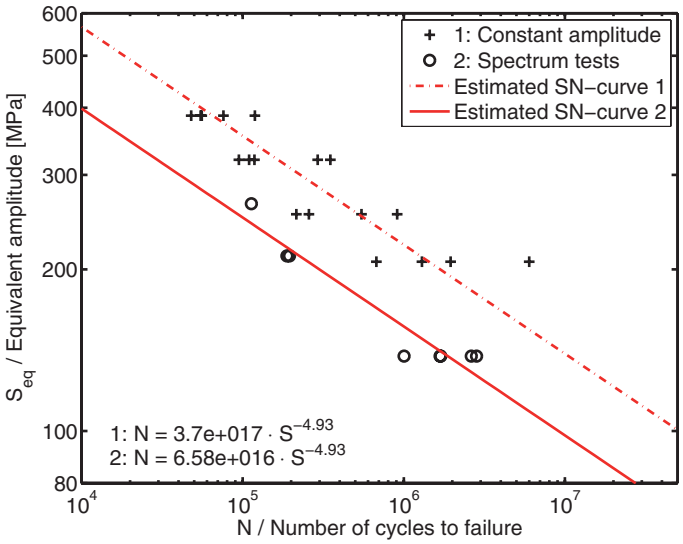
Life Prediction for Service Loads

Design against fatigue should be performed based on loads that are representative for the use in service. In most applications the amplitude of the loads varies with time, and the component is exposed to a spectrum of different amplitudes. The topic is often referred to as spectrum fatigue. During 2002 and 2003 the fatigue group at FCC conducted, in co-operation with a number of industries and institutes, projects with the goal to develop a new methodology that take care of the spectrum effects by directly making fatigue tests with spectrum loads, and was successfully applied to a number of case studies. It has now been published as two papers in *International Journal of Fatigue*, the first describing the methodology, and the second three applications. The methodology of the Wöhler curve for spectrum loads has also been extended to incorporate mean value effects, presented at the ECF15 conference in 2004.

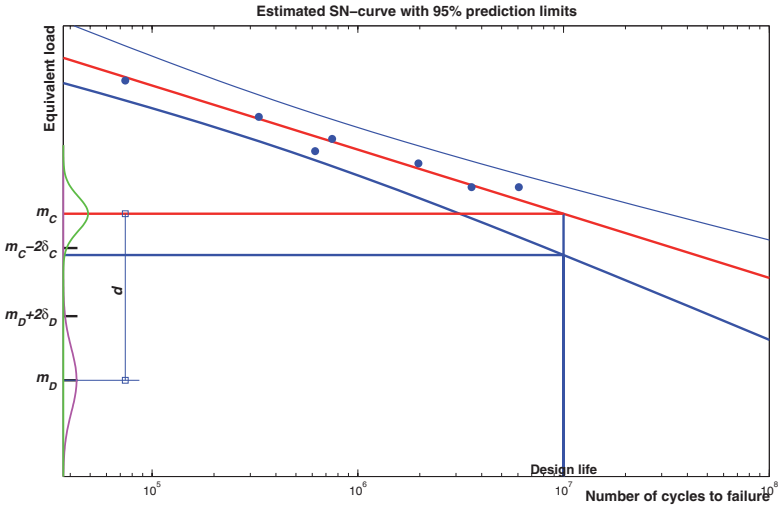
At the ICOSSAR conference in June 2005 we presented another extension of the methodology which is also a direct extension of the relative Miner rule. Our assumption is the same as in the relative Miner rule that the damage exponent is the same for both the constant and variable amplitude cases. An example is presented in the figure below.

In fatigue design of mechanical components and systems there are two main variables, namely the load the component is exposed to, and the strength of the component. We have developed a probabilistic design approach based on the Wöhler curve for spectrum loads, here called the Uncertainty Weighted Safety method (see figure below). This work was carried out and published jointly by Volvo Trucks, FCC and Chalmers. An application to design of safety critical components for trucks was presented at a VDI conference in Germany 2005.

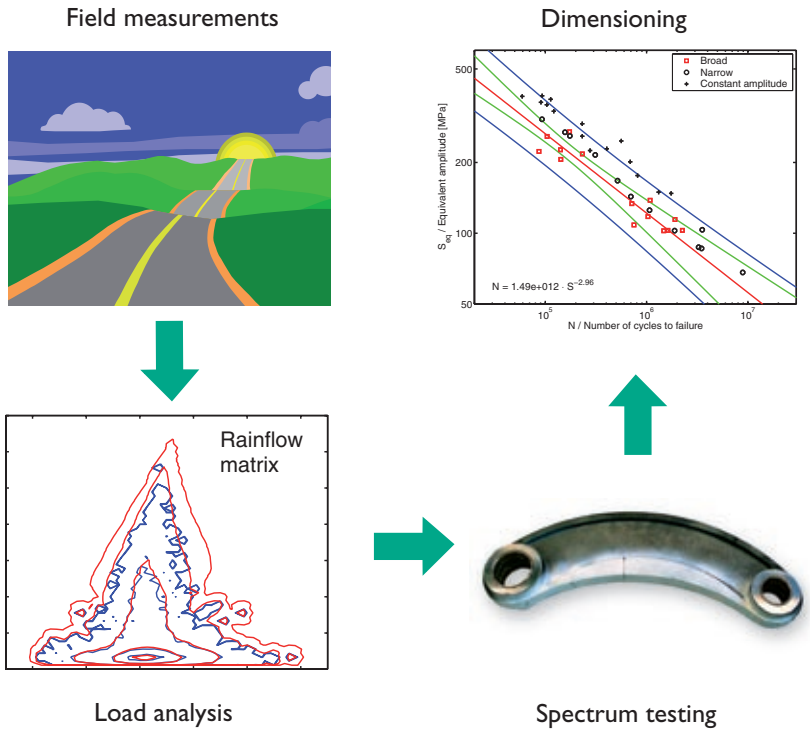
During 2004 we developed a course on spectrum fatigue together with SP Swedish National Testing and Research Institute, and it was held for the second time in September 2005. The course is based on the idea that fatigue design against spectrum loads must be based on fatigue tests and that these tests must be performed close to the service situations, both with respect to load spectrum and with respect to the multi-axial states of stress and strain at critical locations. This is because the theories behind fatigue mechanisms are too complicated to be useful for accurate life predictions.



The two Wöhler curves for constant amplitude and spectrum loads are estimated simultaneously assuming a common slope.



The Uncertainty Weighted Safety method. The "Capacity" distribution is obtained from the Wöhler curve, and is compared to the "Duty" distribution.



The FCC-SP spectrum fatigue approach may be divided into four tasks, where FCC provides the competence within load analysis and life prediction.

Courses for practising engineers

An important part of the fatigue group activities is to give courses for industry. Four different courses have been developed during the last years and three of them were given 2005 at different occasions.

- Measurement uncertainty. This newly developed three days course was given for fifteen engineers at Volvo Trucks.
- Variable amplitude fatigue. This three days course was given in Borås for the second time in co-operation with the Swedish National Testing and Research Institute. Twelve engineers from various Swedish industries participated.
- Problem driven fatigue. This three days course was given for the fourth time at Scania in Södertälje.

Supervising PhD students

- As an important continuation of our co-operation with PSA in France Pär Johannesson and Jacques de Maré supervise Gwenaëlle Genet in her PhD work. Her research subject is closely connected to the automotive industry needs and is focussed on statistical approaches to multi-axial fatigue.
- The automotive industry problem of customer correlation is represented in our work by the PhD project "Parameterization of customer environment for Volvo Trucks." Magnus Karlsson is supervised by Thomas Svensson, Jacques de Maré and Pär Johannesson.
- In a joint project for Volvo Aero two PhD students work on optimization of maintenance schemes for aero engines. One part of the project is devoted to statistical aspects on optimal maintenance and the PhD student Johan Svensson is supervised by Jacques de Maré, Thomas Svensson and Pär Johannesson.
- In a more theoretically oriented work, Jenny Andersson, who defended her PhD thesis in December 2005, studies statistical properties of point processes with applications in fatigue properties of the grain structures in metallic materials.

Work in progress

- A new project for European Truck industry has been discussed resulting in a one year project aiming at a plan for creating a handbook for fatigue load analysis in truck applications.
- The new reliability concept has been discussed with different industrial representatives aiming at a joint future project for implementing the concept in industry.
- Contacts with steel manufacturers have been established for future implementation of different methods for improvement of fatigue limit estimation.

Finance and Insurance

The financial and insurance sectors today are two of the largest industries in the world. In 2005, the global options and futures markets alone saw a turnover in excess of 1400 trillion USD, according to the Bank for International Settlements.

Both finance and insurance offer a wide range of mathematical challenges. Insurance faces issues such as estimation of mortality and risk, fair pricing of insurance contracts, pension plans and so on. Finance, especially the options and futures markets, needs to model interest rates, stocks, bonds, real estate – to name but a few – in order to derive fair prices for its wide selection of products.

As the finance and insurance markets become increasingly intertwined, as can be seen for instance by the emergence of the CAT bonds market and in the interest in ALM modeling, it will be important to find a common mathematical ground for the two disciplines. This is important also for avoiding arbitrage opportunities between the two sectors – a problem acknowledged in the ongoing Basel II and Solvency II initiatives.

FCC and our associates, having a strong understanding of the underlying mathematics complemented by practical modeling experience, are valuable partners for financial and insurance institutes in Sweden and across Europe.

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Birka and Hovgården, Ekerö *were inscribed on the World Heritage List in 1993:*
"The Birka-Hovgården area is a well preserved example of the Vikings trading networks during the two centuries when they expanded economically and politically in Europe. Birka is one of the most complete and untouched Viking Age trading sites from the years 700-900."

Pricing of Structured Equity Products

A derivative is a financial contract which, at some fixed future date, pays a certain amount to its holder. The size of the payoff depends on the price evolution of some underlying asset or assets. In recent years there has been a drastic increase in the number of equity derivatives with complex payoff structures, known as structured equity products. Efficient risk management requires the ability to price these products quickly and reliably, which can be difficult since it often involves computing high-dimensional integrals. FCC has implemented this type of pricing routines in several projects together with Front Capital Systems, a successful trading systems developer for banks and other financial institutions. The methods have mainly been based on finite difference and Monte Carlo methods, but approximation formulas have also been developed.

Standard Approaches to Solvency Assessment

Since early 2002 the International Actuarial Association has been working with the development of a global framework for insurer solvency assessment. One objective has been to find mathematical methods that determine the minimum level of capital that has to be maintained by an insurance company in order to meet its future obligations. In addition, since the methods should be used in regulations they need to be simple and robust in the sense that they should include a minimum number of parameters and be analytically tractable. The Swedish Insurance Federation and FCC have been working together since 2004 on questions related to the problem of finding and evaluating simple and robust methods for solvency assessment. The work includes several aspects of mathematics such as stochastic calculus, parameter estimation, risk measures and implementations of these in computer code.

Asset and Liability Management

The aim of ALM-studies is manyfold. It is of interest to analyze the current market conditions and see how changes, so called stress-tests, will impact existing long-term strategies. Further, combining the simulations with an optimisation algorithm may lead to important insights regarding changes in investment policies and new benchmark portfolios. It is also possible to evaluate how new and proposed rules and regulations may influence one specific company or, on a macroscopic level, the economy of an entire industrial sector.

Traditionally, companies, pension-funds and other investors do not perform these simulations themselves, but rely on the results of external consultants. A consequence of this is that the simulation model, from the customers point of view, is perceived as a black box. Also, modeling the specific properties of the Swedish pension system is often not possible, because this is usually not included in the simulation models of external consultants.

FCC and our partner ITWM have performed ALM-projects with The Second Swedish National Pension Fund, AP2 and with KP Pension and Insurance. The main aim has been to develop models which include all relevant properties of the Swedish pension system and the fund´s specific portfolios.

In this kind of projects, the first step is an investigation of models for different asset classes. It is important to focus on the ability to identify parameters, seeing as the number of parameters is usually rather high. In the above-mentioned projects, several macro-economic parameters in seven different economies were simulated. Another topic is the presence of models in the ”real-world” for bank accounts as well as corresponding models in the ”risk-neutral world” for bonds, i e it is important to choose the market price of risk.

The simulation models were implemented as stand-alone applications fitted with text-oriented user interfaces, allowing the user to change, add or remove simulated processes without changing the code of the application. Hence the companies have complete access to the models and may develop them further for purposes of fine-tuning and allowing them to change in accordance with time.

For KP, an optimisation add-on was also supplied, allowing the company to use the models for finding new benchmark portfolios suitable for handling expected changes in demography and customer stock.

Macro-economic modeling and evaluation of proposed and existing legislation

FCC has recently begun a project in co-operation with the Swedish Insurance Federation. Its aim is to model the behavior of insurance companies under different types of regulation.

The project consists of two parts. The first step is to develop a simulation program suitable for implementing econometric models. When this is done the actual modeling begins - work which is estimated to begin early 2006.

All models, along with the simulation program itself, are planned to be distributed amongst the Federation members in the hope of adding fuel to the on-going debates over the Solvency II accord and other proposed legislation. Another important aim is to further the interest of actuarial mathematics and econometric modeling in general.

Geometry and Motion Planning

Many products such as cars 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 and throughput in the manufacturing industry increases the need of effectively generate and visualize collision-free and optimized motions in the assembly plant using virtual tools. During 2005 the department of Geometry and Motion Planning at FCC have successfully developed methods, algorithms and tools supporting these activities within virtual verification.

The performed projects can be divided into three main subjects

- Geometry Assurance
- Path planning and Robotics
- Surface Inspection

In particular, the FCC software tool for automatic path planning of collision-free motions has been improved further regarding memory, graphical rendering and speed performance. This allows our partners in the automotive industry to solve geometrically complex manufacturing problems in mere minutes instead of days.

An important scientific and industrial challenge is to handle geometrical quality and factory throughput during path planning. A first step was taken this year by incorporating geometrical tolerances, sequencing and coordination of operations into the path planning technology.

During 2005 the successful collaboration with Winqquist Laboratory at Chalmers, the Industrial Research and Development Corporation (IVF), and the ITWM departments Dynamics and Durability and Image Processing, has been further strengthen by working and applying for common projects.

Public funding – acknowledgement
In 2005, the Geometry and Motion Planning group has received substantial funding from the Swedish Foundation for Strategic Research and Vinnova.

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The Royal Domain of Drottningholm, Ekerö *was inscribed on the World Heritage List in 1991: "The Drottningholm site – the castle, the theatre, the Chinese Pavilion, and the park – is the best example in Sweden of a royal eighteenth-century residence, representative of all European architecture from this period. Drottningholm Castle was influenced by the French king´s Versailles, as were many other castles in Europe at this time."*

The Geometry and Motion Planning Research Group

- Johan Carlson, PhD, Vice Director FCC
- Robert Bohlin, PhD
- Fredrik Ekstedt, Lic
- Thomas Hermansson, MSc Engineering
- Daniel Segerdahl, MSc Engineering
- Domenico Spensieri, MSc Engineering
- Sebastian Tafuri, MSc Engineering
- Johan Havner, Master Student
- Ola Karlsson, Master Student
- Rikard Söderberg, Professor in Product and Production Development at Chalmers, Director Wingquist Laboratory, Scientific Adviser at FCC


Johan Carlson


Robert Bohlin


Fredrik Ekstedt


Tomas Hermansson


Daniel Segerdahl


Domenico Spensieri


Sebastian Tafuri


Johan Havner


Ola Karlsson


Rikard Söderberg

Geometry Assurance

Geometry-related quality problems are often discovered during the assembly process when parts are about to be assembled and do not fit as expected. Often the reason is geometrically sensitive product and production concepts that have not been verified enough due to lack of powerful analysis tools. A design or production change at this stage is very costly and does almost always result in delays in market introductions with lost revenue as a consequence. Therefore, FCC in corporation with the Wingquist Laboratory at Chalmers and the Swedish Institute of Production Engineering (IVF) operates to support a systematic reduction of variability in processes and products in the following key areas:

- Robust design and variation simulation
- Inspection planning preparation and optimisation
- Statistical process control and root cause analysis

The Struve Geodetic Arc *was inscribed on the World Heritage List in 2005*:
"The Struve Arc is a chain of survey triangulations stretching from Hammerfest in Norway to the Black Sea through ten countries and over 2,820 km. These are points of a survey, carried out between 1816 and 1855 by the astronomer Friedrich Georg Wilhelm Struve. The Struve Arc represents the segment of a meridian, helping in the establishment of the exact size and shape of the world exhibits an important step in the developmetn of earth sciences."

Courtesy of National Land Survey of Finland

Robust Design & Variation Simulation

The key idea behind Robust Design is to make the product as insensitive to variation or disturbance as possible, to make it withstand potential uncertainties in the manufacturing process or changes in the operating environment. We use statistical Monte Carlo simulation, sensitivity analysis and contribution analysis from our partner RD&T Technology to make the product insensitive to manufacturing and assembly tool variation. This reduces the need for costly physical prototypes and test series, see figure 1.

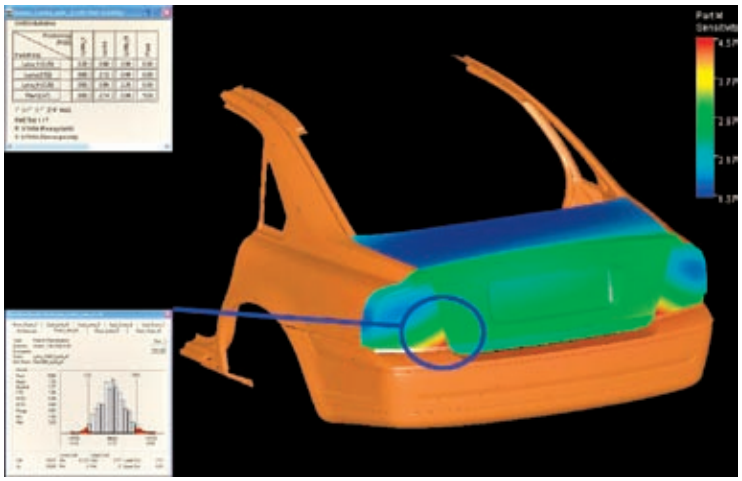


Figure 1. Colour Coding, based on sensitivity analysis, of the Volvo S80 Car Body. Areas sensitive to dimensional variation are indicated with red colour (courtesy of Volvo Car Corporation).

Inspection Planning and Analysis

Inspection planning refers to the activity to gather information about variation in individual parts, processes, assemblies and assembly equipment, in order to control the manufacturing process and to be able to give feed-back to a number of activities in the geometry assurance process. Today inspection planning is almost always solely based on experience and can be improved significantly by using mathematical and statistical analysis. We develop methods and support tools for intelligent inspection preparation. The motive is to gather as much information about the product and the process as possible with minimum number of inspection points, see figure 2.

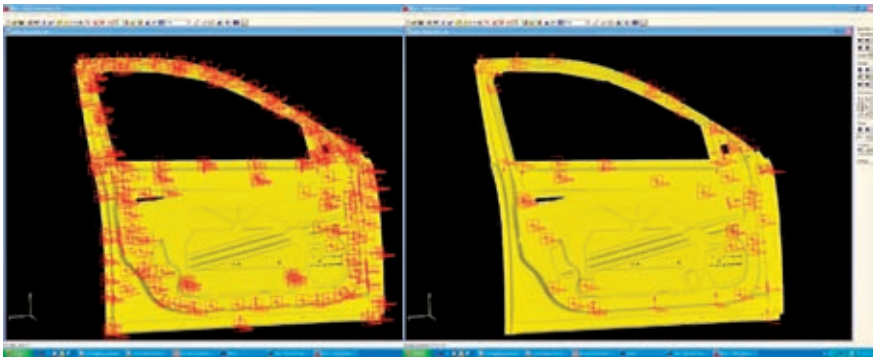


Figure 2. Inspection point reduction in action on car body door (courtesy of Saab Automobile).

Statistical Process Control and Root Cause Analysis

Today routine measurements in the industry are often made on-line during the production process. Statistical process control (SPC) is a set of quality tools aimed at reducing variability utilizing these measurements. For manufacturing processes of simple parts, patterns on a control chart may provide enough diagnostic information to an experienced operator to pin point the root cause. However, experience shows that many SPC attempts fail to produce meaningful results because the lack of diagnostic support for the effort. Therefore, we develop statistical methods to make root cause analyses on the product to find and correct problems in the manufacturing and assembly process. The motive is fast identification and correction of problems and increased knowledge about product/process correlation, see figure 3.

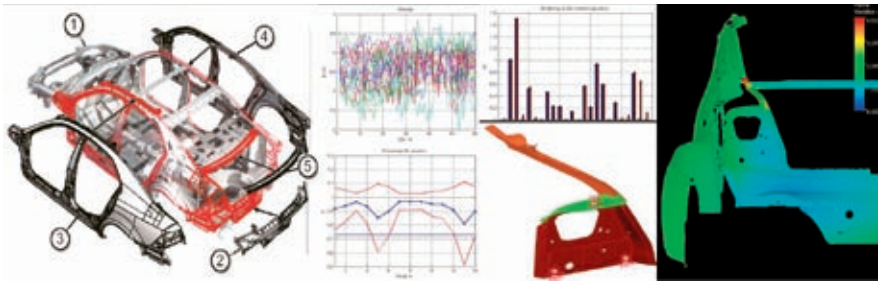


Figure 3. A multi-fixture assembly where a number of parts are assembled. From left to right: Assembly, production data, multivariate statistical process control, root cause analysis, assembly fixture fault, simulated effect of correction (courtesy of Saab Automobile).

Path Planning

Automatic Path Planning for Rigid Bodies and Industrial Robots

Despite that modern industries use virtual prototypes to replace physical prototypes, visualize assembly processes and program industrial robots off-line, the full potential of the virtual factory is not reached. Programming of motions and paths for robots and equipment is still done manually, since the existing support for automatic path planning is very limited. Another limitation is the geometrical accuracy between the virtual model and the physical reality. Therefore, geometrical tolerances need to be considered during path planning. This is a first step, going from nominal to production adapted virtual models and hence connecting the production loop including styling, design and manufacturability.

Virtual verification of that products can be assembled and later on disassembled for service purposes is an important part of geometry simulation in the manufacturing industry. Methods and software for automatically generating collision free assembly paths are therefore of great interest. Also, off-line programming of robots and coordinate measurement machines used in the factory lead to hard problems for the simulation engineer when trying to manually find collision free paths between points, with that of minimizing cycle time and joint wear. Therefore, FCC operates to support the following path planning applications:

- Assembly visualization/verification/design
- Assembling with robot
- Welding and sealing
- Coordinate measurement machine
- Load balancing, sequencing and coordination of robot operations

The Hanseatic Town of Visby *was inscribed on the World Heritage List in 1995:*
"Visby is an outstanding example of a Northern European walled Hanseatic town which has in a unique way preserved its townscape and its extremely valuable buildings, which in form and function clearly reflect this significant human settlement."

Assembly Visualization/ Verification/Design

This project with our partner Volvo Car Corporation has resulted in simulation software for automatic path planning, viewed in figure 1. The software is based on a virtual 3D model describing the kinematics and the geometry in the assembly cell, interacting with a collision tester.

For small sub-assemblies as well as final assemblies, simulations give valuable support when evaluating new concepts and comparing alternative solutions. Also different assembly sequences can be compared and verified. As a result, product functionality and manufacturability can be improved.

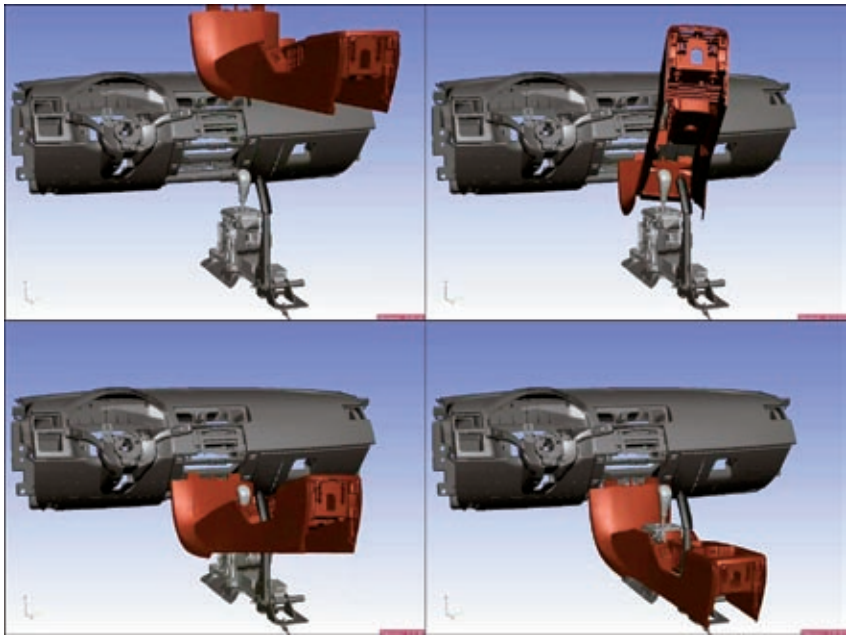


Figure 1. Is it possible to assembly the tunnel bracket? The FCC path planner finds a solution in less than 2 minutes. Even an experienced simulation engineer will struggle for days with this assembly verification (courtesy of Volvo Car Corporation).

Assembling with Robot

In addition to collision avoidance and kinematic constraints, automatic robot programming involves minimization of cycle time, robot wear and joint forces. Efficient path planning and reachability analysis is also beneficial when comparing station layouts choosing robots and designing tools, grippers, and fixtures, see figure 2.

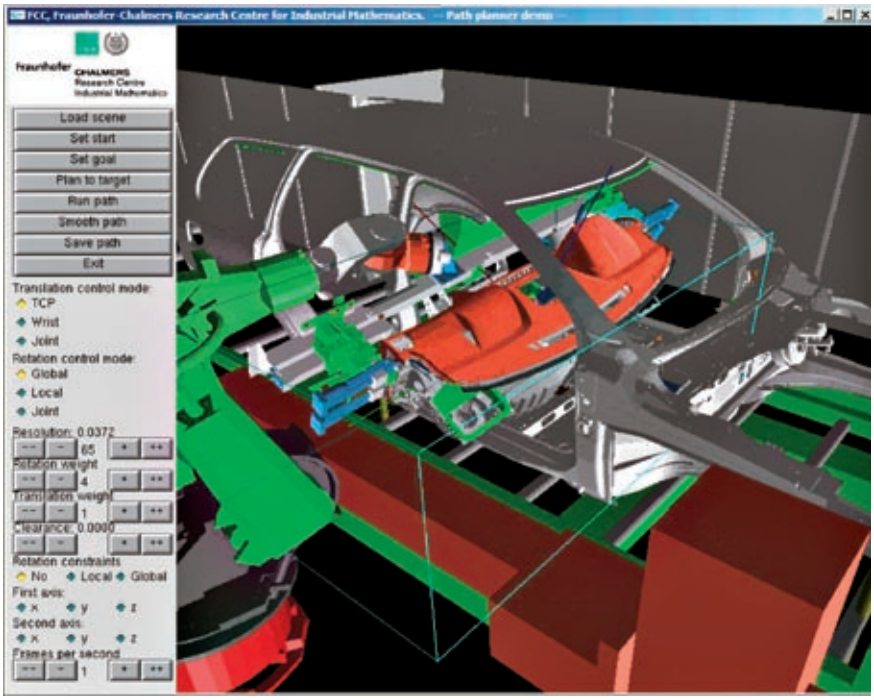


Figure 2. In this station, the driving unit is assembled into the car body. Due to the narrow door opening, the clearance is very small and programming without support from a path planner is difficult. This demo application developed by FCC finds a solution in 3 minutes (courtesy of Volvo Car Corporation).

Path Planning and Sealing of Car Body Seams

This project with our partner Volvo Car Corporation has resulted in simulation software for automatic path planning of Robotized sealing applications. In the sealing station, robots spray the sticky sealing mass along, for instance, spot welded seams. By covering the seams, dirt and water cannot come into the chinks and cause corrosion. The sealing also has a sound insulating effect. In the first step, the algorithm finds several different collision-free motions applying the sealing mass along each seam. In the second step, collision-free motions are generated in such way that an optimal sequence connecting one solution for each seam is obtained, see figure 3.

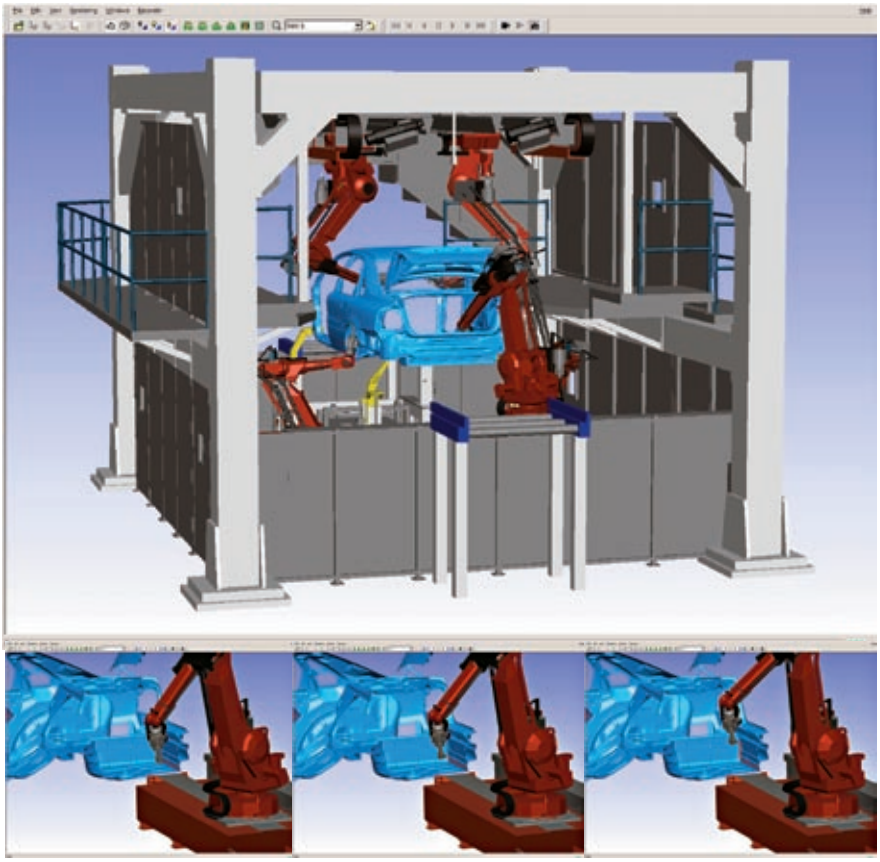


Figure 3. Automatic path planning and optimisation of a sealing station (courtesy of Volvo Car Corporation).

Coordinate Measurement Machine

FCC develops methods for automatic generation of collision free programs for coordinate measurement machines. The cycle time is minimized with respect to probe orientations and feature sequence, and the motive is to make the important activity of dimensional inspection within the geometry assurance process as efficient as possible, see figure 4.

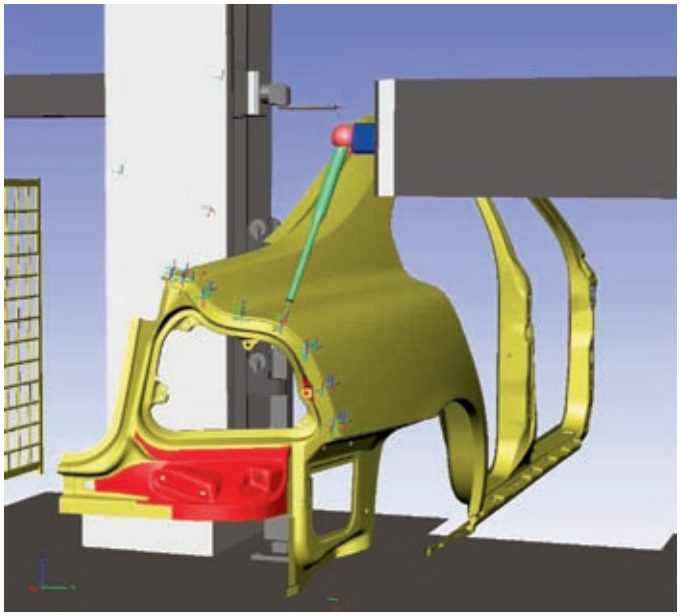


Figure 4. Automatic path planning of an inspection program used for evaluating geometry of a Volvo car (courtesy of Volvo Car Corporation).

Coordination/Interlocking of Multi-Robot Manufacturing Cells

In many manufacturing operations, e.g. spot welding of car bodies, several robots need to share the same workspace. To coordinate and avoid collisions the robots are synchronized by defining interlocking points along the robots paths. At an interlocking point it is checked whether the program can continue without risk of collision or not. If risk of collision is present the program halts until so no longer is the case. Programming of interlocking points is today done on-line, as current simulation software lacks support for automatic generation and validation. This project with our partner Volvo Car Corporation has resulted in interactive

software providing methods and algorithms for minimizing interlocking related time-loss through an efficient use of interference zones, see figure 5.

Figure 5. Where and when shall the robots wait for each other in order to avoid collisions and minimize cycle time?

Fast and Memory Efficient Sweep Volume of Moving Parts

The swept volume is the space generated when a part is moved along a path. Such volumes have many applications in virtual prototyping, e.g. booking the volumes needed for different parts during an assembly operation or to find interference zones for multi-robot coordination. The sweep volume can be very complex since both the part geometry and motion can be complex. Due to this complexity the computing time and the memory needed for generating and representing the volumes has been too large to be used in practice. In this project, FCC has developed and implemented a solution that meets the high demands of manufacturing engineering when it comes to computing time and complexity of geometry models, see figure 6.

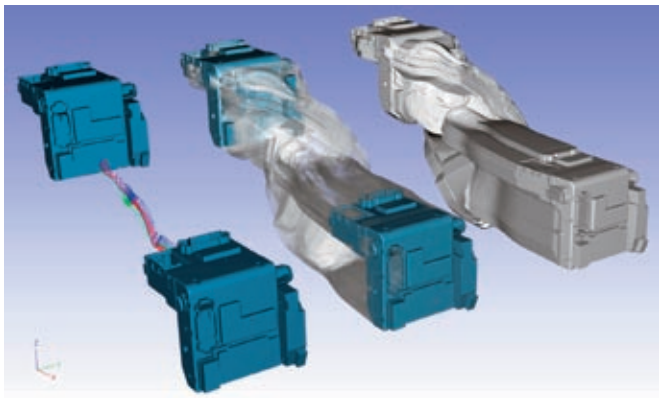


Figure 6. An assembly path and corresponding swept volume (courtesy of Volvo Car Corporation).

Non-Nominal Path Planning

One important aspect in the assembly process design is to assure that there exists a collision-free assembly path for each part. To manually verify assembly feasibility in a digital mock-up tool can be hard and time consuming. Therefore, the recent development of efficient and effective automatic path planning algorithms and tools are highly motivated. However, in real production, all equipment, parts and subassemblies are inflicted by geometrical variation, often resulting in conflicts and on-line adjustments of off-line generated assembly paths. Therefore, we have developed a new algorithm and working procedure enabling and supporting a more cost effective non-nominal path planning process for assembly operations. The basic idea is to combine state of the art technology within robust design and variation simulation with automatic path planning. By integrating variation and tolerance simulation results into the path planning algorithm we can allow the assembly path going closer to areas of low variation, while avoiding areas of high variation, see figure 7.

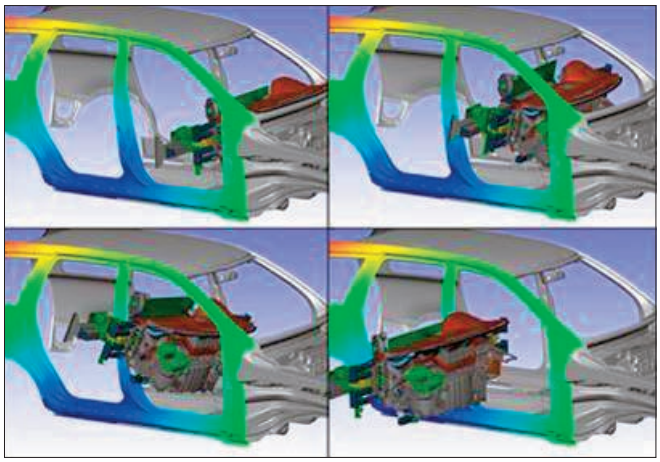


Figure 7. A driving unit assembly path taking results from variation simulation of the car body into account. Areas of high geometrical variation are avoided (courtesy of Volvo Car Corporation).

Surface Inspection

Esthetic design has become an important factor in many branches of the production industry. The interaction between the geometrical shape and the surface quality of a product has a substantial impact on the impression conveyed by a product. Despite ever improving production processes and quality enhancing measures, all industrial production is subject to errors and defects. Since the quality requirements from the customers' part are constantly increasing, improved quality control in general is of vital importance, and in particular surface quality control.

Up to recently, the quality control of produced objects´ surfaces has been done by human inspection. Even though the quality controllers usually are very experienced, variations in the inspection results occur, both between individuals, but also due to mood, fatigue etc.

An alternative is to set up an automatic surface inspection utilizing a camera system and image processing algorithms (see figure 1 and 2) to automatically detect and rate defects. A number of high-resolution cameras covering the entire object to be inspected continuously acquire images which are sent to an equal number of processing units, where modern image processing algorithms are evaluating the image data. Candidate defects are generated by some fast algorithms looking for irregularities, and these candidates are subject to a more detailed analysis verifying the existence of a defect and categorizing its type.

An automatic system has many advantages, including

- Objectivity. The inspection result for a certain object will always be the same, which is not the case for manual inspection.
- Speed. Automatic systems are usually faster than humans to find and classify defects. Furthermore, while humans have a limit, the speed of an automatic system may be improved by increasing the hardware capacity.
- On-line. An automatic system can usually be installed directly in the production line, without interrupting the production. Manual inspection must usually take place off-line, which in reality means that only a few selected samples may be inspected.
- Statistics. An automatic system supports systematic gathering of detailed statistical data over the occurrences of various defects.

The Rock Carvings in Tanum *was inscribed on the World Heritage List in 1994:*
"The rock carvings in the Tanum area are unique examples of Bronze Age art of the highest quality. The range of motifs provides rare evidence of many aspects of life in the European Bronze Age. The interaction between continuous settlement and land use, as reflected in the rock carvings, the cemeteries and the landscape make Tanum into a unique example of continuous human settlement during eight thousand years."

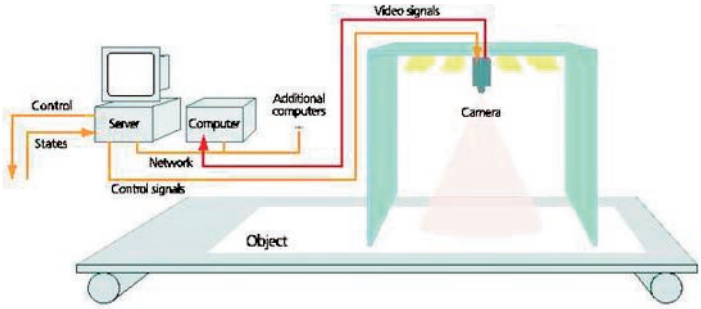
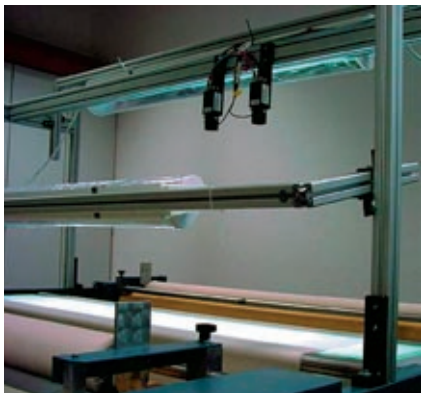


Figure 1. Schematic description of an automatic visual inspection system.

Figure 2. An automatic inspection system for fabrics.



Inspection and grading of leather hides

Currently, FFC and ITWM are jointly involved in a project for developing an automatic inspection and grading system for a major Swedish leather hide manufacturer. The system's task is to sort hides after the tanning process into a number of quality classes, depending on the number of defects and their location on the hide. The quality class controls the degree of further processing (painting) which determines the value of the hide. If the quality is overestimated, defects may be visible after finished processing, leading to further processing and additional costs. Underestimating the quality leads to excessive painting and loss of product value. An automatic system reducing the errors and variation in the early grading may thus be very cost-efficient.

The problem of automatically classifying a hide according to quality may be divided into two steps:

- Automatic detection of all relevant defects such as scratches, insect bites, warts, and shingles eczemas, while avoiding spurious detections caused by natural irregularities of the hide (e.g. veins). Examples of defects and natural structures are shown in figure 3.
- The result of the detection algorithm is a list of defects describing their type, intensity/severity, and position on the hide. All of this is taken into account by a grading algorithm to select a quality class.

During 2005, a small test system has been set up at the company to further assure the feasibility of such a system. An evaluation of this system will take place during 2006.

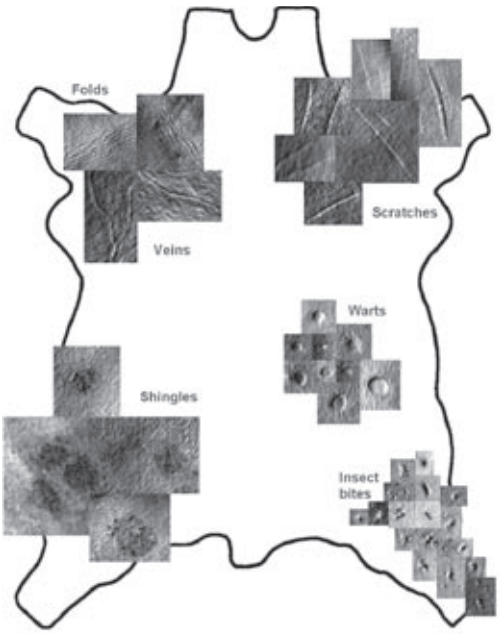


Figure 3. Schematic image of various defect types.

Systems Biology and Bioinformatics

Recent advancements in measurement technology combined with a need to introduce more efficient alternatives to the traditional empirical methods used in drug discovery have boosted the interest in bioinformatics and systems biology. FCC provides an integrated approach to the study of biochemical and physiological processes, from the analysis of sequence data to the analysis of dynamic phenomena on a systems level. The work is organised in two areas

- Systems Biology
- Bioinformatics

An important achievement during the year has been the development of a computational infra structure in terms of a systems biology toolbox for Matlab. The toolbox has been developed partly as a contribution to the BioSim project and its public release is widely spread both within and outside the BioSim network.

This year was the first year of operation for the EU funded network of excellence – BioSim. Since the network and its workpackages include both academic and industrial partners it is an ideal setting for FCC. In particular our contribution can be divided in three main areas: System identification – to build mathematical model of dynamic systems based on measured data; Model reduction – to reduce the size and scope of models to arrive at models whose parameters can be estimated and validated using available measurement data; Software tools – to support the model building process and computational analysis of the obtained models.

We are also happy to conclude that the interest from commercial clients in our applied research has resulted in challenging industrial projects during the year.

Public funding – acknowledgement
In 2005, the Systems Biology and Bioinformatics group has received substantial funding from the Swedish Foundation for Strategic Research. Furthermore, the group has received funding for the BioSim project from the European Commission.

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Skogskyrkogården, the woodland cemetary, Stockholm *was inscribed on the World Heritage List in 1994:*
"Skogskyrkogården, created by Gunnar Asplund and Sigurd Lewerentz between1914 and 1940, is an outstanding example of how architecture and landscaping from our century combine to make a cemetery. This creation has had a great influence on the design of cemeteries all over the world."

The Systems Biology and Bioinformatics Research Group

- Mats Jirstrand, PhD, Associate Professor, Systems Biology
- Marina Axelson-Fisk, PhD, Associate Professor, Bioinformatics
- Henning Schmidt, PhD, Systems Biology
- Gunnar Cedersund, PhD student
- Adil Zafar, Master Student
- Olle Nerman, Professor in Mathematical Statistics at Chalmers, Scientific Adviser at FCC


Mats Jirstrand


Marina Axelson-Fisk


Henning Schmidt


Gunnar Cedersund


Adil Zafar


Olle Nerman

Systems Biology

Combining model based signal processing, systems identification, local mechanistic models, and sensitivity analysis with novel measurement platforms provides a strong competitive edge for researchers in the pharmaceutical and biotech industry. The development of novel measurement technology can in fact be guided by biological questions in combination with adapted computational methods to enable raw-data to be compiled into a meaningful context – e g pathway diagrams. A typical example is the growing awareness of the limitations of measuring levels of biochemical entities just before and after a perturbation to a system and not during the transition. Non-dynamic data allow for at most classification of cause-effect mechanisms but are not sufficient for a true understanding of the roles of different biological entities. These are however crucial to the decision about how to intervene the process in order to accomplish a desired effect.

The activities in systems biology at FCC are focused around the application and development of computational methods and mathematical models of biological systems on sub-cellular, cellular, tissue, organ, and whole body level, utilizing systems level measurements. The research is carried out in close cooperation with both academic and industrial partners. The in-house competences are in the area of control and dynamic systems. The group has several years of experience of both software development and application of methods from systems and control theory to projects in both the engineering and pharmaceutical industry.

Our vision is to develop means to enable researchers to delineate and understand the underlying mechanisms of a disease or phenomenon at the mechanistic level, i e, in terms of biochemical reaction or interaction networks. We focus on local mechanistic models to map out and better understand a specific biological phenomenon or pathological condition.

The systems biology group at FCC also has very close collaboration with the Swedish company InNetics, who are the developers of the systems biology software PathwayLab.

The Laponian Area, Lappland *was inscribed on the World Heritage List in 1996:*
"The area is an outstanding example of how the earth has developed, especially geologically, and how ecological and biological changes happen today. There are also unique natural phenomena of exceptional natural beauty and significant natural localities for the protection of biological diversity."

Systems Biology Toolbox for Matlab

FCC has developed a Systems Biology Toolbox for the widely used general purpose mathematical software Matlab. The toolbox offers systems biologists an open and extensible environment, in which to explore ideas, prototype and share new algorithms, and build applications for the analysis and simulation of biological and biochemical systems. Additionally it is well suited for in-classroom use for educational purposes. The toolbox supports the Systems Biology Markup Language (SBML) by providing an interface for import and export of SBML models. In this way the toolbox connects nicely to other SBML enabled modeling packages, such as CellDesigner, JDesigner, or PathwayLab. Models are represented in an internal model format and can be described either by entering ordinary differential equations or, more intuitively, by entering biochemical reaction equations. The toolbox contains a large number of analysis methods, such as deterministic and stochastic simulation, parameter estimation, network identification, parameter sensitivity analysis, and bifurcation analysis. The Systems Biology Toolbox is built in a modular way, depicted in figure 1.

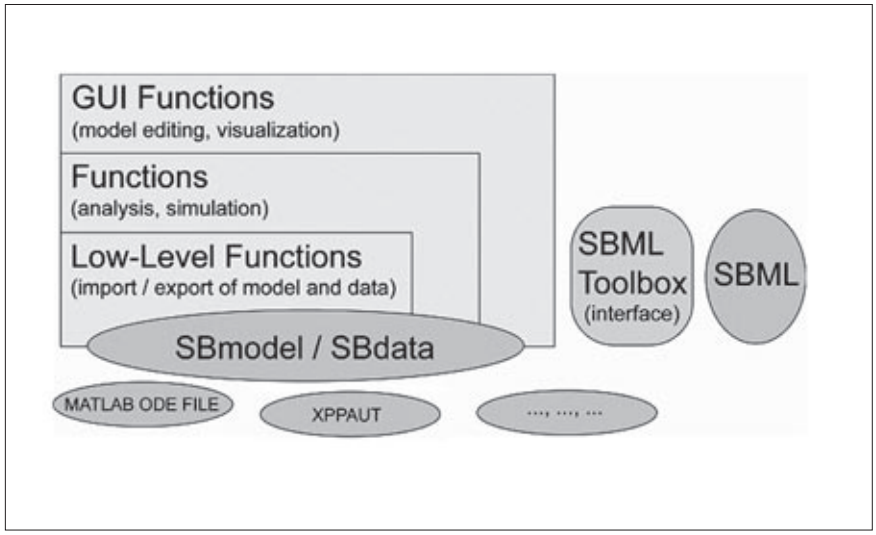
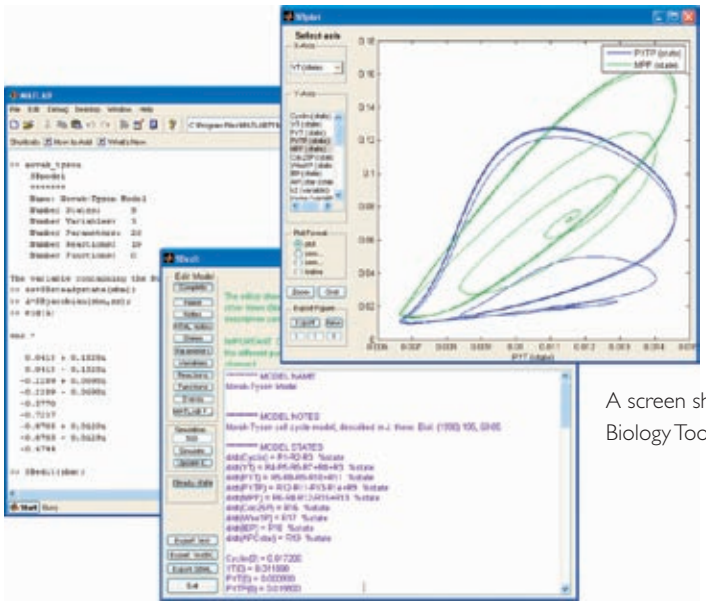


Figure 1. The modules of the Systems Biology Toolbox

The Systems Biology Toolbox for Matlab is open source and freely available from http://www.sbtoolbox.org. The website also contains a tutorial, extensive documentation, and examples. The toolbox has been developed partly as a contribution to the BioSim project, see below. During its short time of existence it has become very popular and has been widely spread both within and outside the BioSim network.



A screen shot of the Systems Biology Toolbox.

Model Reduction in Biochemical Networks

Biochemical reaction networks based on mechanistic hypotheses often exhibits behaviors that includes different time scales. To understand important features and the type of functions that such networks implement it is very useful to simplify models using different model reduction techniques. The different time scales of a complex model can be utilized by employing so called rapid equilibrium or quasi steady state approximations and to study phenomena on fast time scales more slowly varying variables can just be kept constant.

Analog Insydes is a Mathematica add-on package, originally developed for modeling, analysis, and design of analog electronic circuits. The software is based on mixed symbolic/numerical algorithms for linear and nonlinear differential-algebraic systems of equations (DAE systems), which means that it can also be used in other application fields. In a joint work with the developers of Analog Insydes at Fraunhofer ITWM an interface between the systems biology software PathwayLab and Analog Insydes has been developed, which allows the application of

numero-symbolic methods for the analysis of complex biochemical reaction networks. Hence, a set of model reduction techniques can automatically be applied to a given biochemical network model to obtain a less complex model with similar behavior.

Starting with a PathwayLab model, the interface allows for setting up the underlying model equations in terms of a symbolic differential algebraic equation system in the Analog Insydes format. All Analog Insydes functionality (e.g. the symbolic model reduction techniques) can now be applied to the model equations. Moreover, functions for the automatic detection of conservation relations and for the application of common chemical approximation techniques (rapid equilibrium approximation) have been implemented. These methods replace differential equations by algebraic ones. Applying the methods to a Wnt/Beta-catenin signal transduction pathway, eleven of the original fifteen differential equations of the model could be replaced by algebraic equations automatically, substantially reducing the size and computational burden of the original model. The approximation process generates a model with an approximation error less than 1% for the selected beta-catenin profile.

BioSim

BioSim is the acronym for a European Commission funded project with the title "Biosimulation – A New Tool in Drug Development". FCC has made significant efforts within the BioSim network of excellence during its first year of operation. The efforts naturally divide in two parts: theoretical developments and modeling of systems related to glucose homeostasis.

Theoretical developments

One of the main theoretical contributions has been the establishment of a modeling methodology denoted core-box modeling and of methods occurring in its different substeps. A key step in the core-box modeling methodology is to apply methods of model reduction to models formulated using mechanistic knowledge and first principles from biochemistry. This is done such that the reduced model is identifiable, i.e., the parameters in the model can unambiguously be determined from available in vivo data. The identifiable reduced model is then identified and validated by methods from system identification, resulting in a so called core model. We have developed new methods and adapted existing methods for system identification taking special properties of biological data into account. The well-determined features of the identified core model are then translated back to the original model, leading to a final so called core-box model. This model does not only agree well with the data, it also comes with some quality tags on the different parts of the model, saying how well they are supported by the available data.

Modeling of systems related to glucose homeostasis

FCC has contributed to modeling of several systems related to glucose homeostasis, which malfunction in Diabetes type II – a disease that is rapidly growing into one of the major diseases in the western world. One of these systems is fat cells and especially their response to insulin. We have presented a first model describing a connected pathway from insulin signaling to MAPK-kinase response. We have also done some special studies on the first steps in this cascade and especially on the role of receptor internalization. Figure 2 shows how both phosphorylated membrane bound insulin receptor and internalized phosphorylated insulin receptor may phosphorylate the insulin receptor substrate, IRS. IRS may subsequently form a complex with PI3K, which constitute the first steps in an important signaling pathway in adipocytes. One objective with the present study has been to investigate to what extent the internalized insulin receptor contributes to this signal transmission.

Another extensively studied system is glycolysis, i.e., the basic chemical reaction pathway converting glucose to pyruvate and high energy molecules necessary for other biochemical processes. Most effort has been put on glycolysis in yeast, but some efforts

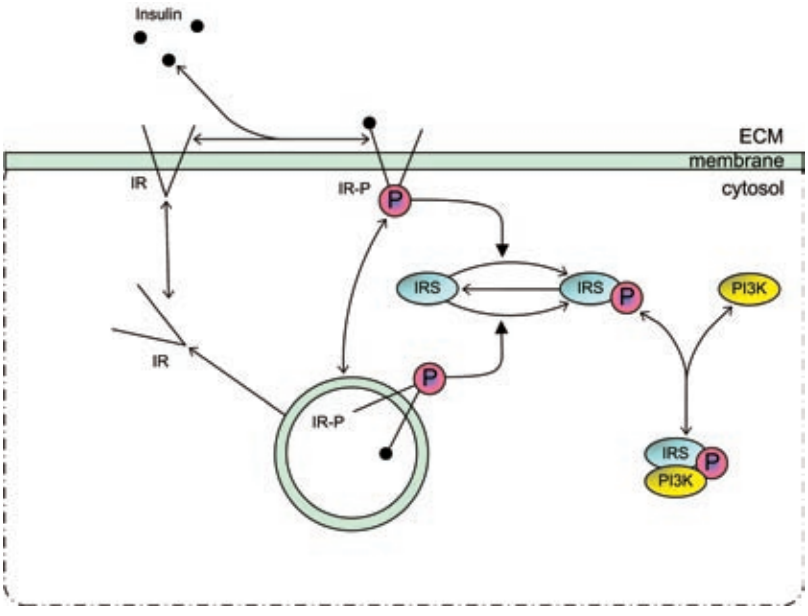


Figure 2. An insulin signaling pathway in adipocytes (cells present in adipose tissue).

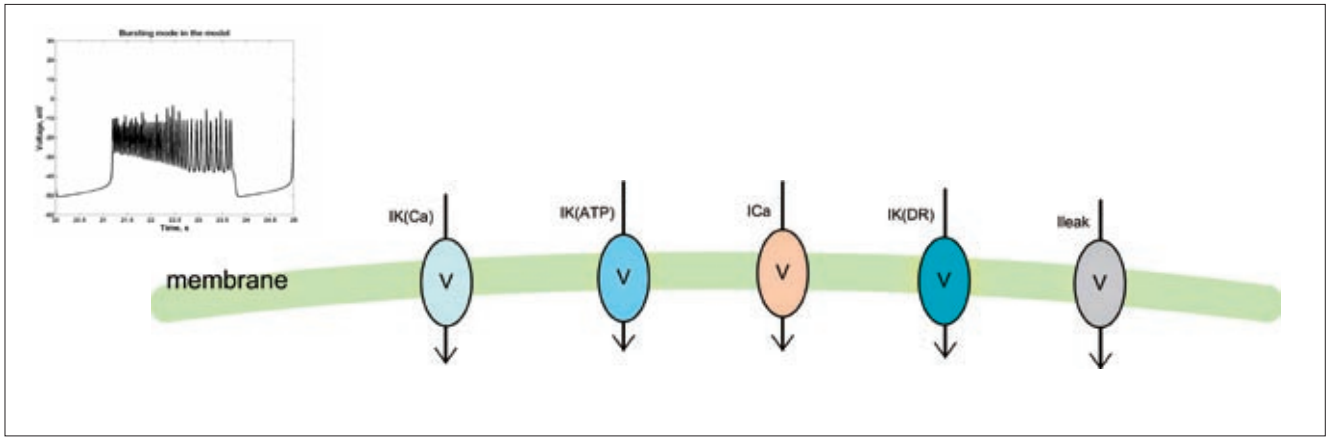


Figure 3. A small electro-chemical model of a beta-cell.

have also been put into understanding of its regulation during anaerobic muscle contraction. Another system that has been studied is that of free fatty acid homeostasis, which has mainly been done by model reduction of a previously developed model. This work has been done in collaboration with Novo Nordisk. Another system that has been studied by methods of model reduction is that of insulin production in pancreatic beta cells.

A minimal electro-chemical model of a beta-cell has been developed to test the role of a novel Ca-dependent potassium current, see figure 3. The model includes four ion-channels: ATP-dependent potassium current; delayed rectifier current; voltage-dependent Ca current; and a novel Ca-dependent potassium current. We have implemented the model and conducted a series of simulations with parameters taken from the litterature and experiments carried out by our BioSim partners in this particular workpackage. The model create bursts that are qualitatively similar to experimentally observed bursts in intact islets. Currently, the simulated bursts are too short and contains too many spikes within a single burst. However, a better fit between observations and simulated results to better understand the properties of the novel Ca-dependent potassium channel are the focus for subsequent work.

Bioinformatics

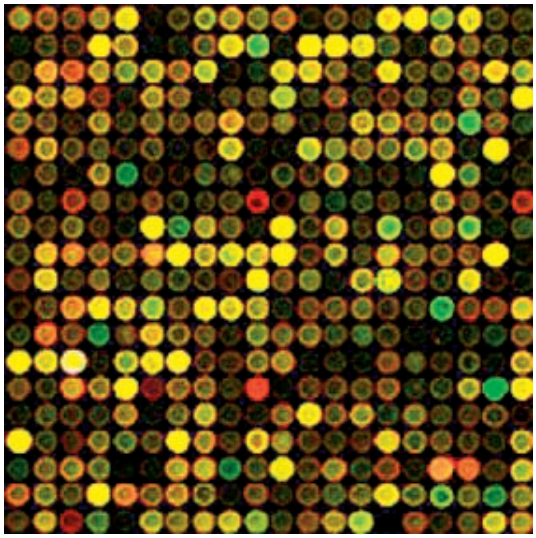
Bioinformatics combines genetics, mathematics and computer science to handle the sequence and gene expression data by the biotech and pharmaceutical industry. Biostatistics is partly overlapping with bioinformatics and is concerned with the development and use of statistical methods for the analysis of biological data. Our vision is to bring together the disparate disciplines and cultures of mathematics and biology, to help get a better understanding of the processes and residues involved in the organization of an organism.

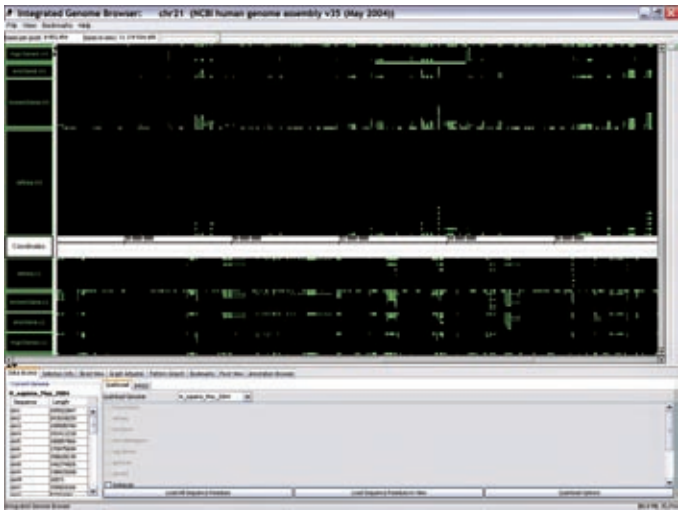
The structure and function of a gene is often revealed by studying their parallels in related organisms. With the microarray technology at hand today researchers focusing on a specific disease or cell process are often left with an extensive list of candidate genes.

Therefore, there is an increasing need to identify similarities and differences between the human and various model organisms, in order to identify and analyze factors involved in different processes.
We develop methods to identify complete gene structures, predict function and structure of the corresponding proteins, detect co-regulated gene candidates, and identify process-specific regulatory elements.

Furthermore, we are one of the key developers of cross-species gene finding software SLAM, and were part of the analysis group in the Mouse Sequencing Consortium and the Rat Genome Sequence Consortium.

The Agricultural Landscape of Southern Öland *is a living cultural heritage which was inscribed on the World Heritage List in 2000:*
"The landscape of southern Öland takes its contemporary form from its long cultural history, adapting to the physical constraints of the geology and topography. Southern Öland is an outstanding example of human settlement, making the optimum use of diverse landscape types on a single island."





Left: A typical image of a printed microarray comparing two sequence samples. The coloring of the spots give information about the relative expression of a gene in the two samples. Right: A screenshot of the IGB browser.

Development of an Enhanced Microarray Data Analysis Environment

With the ever increasing amount of DNA sequence data produced, the demand for efficient, high-throughput analysis methods is immense. Microarray experiments can be used to answer a wide range of biological questions by probing hundreds of thousands of genes or genome locations in one single experiment. Typical research applications include monitoring the expression level of genes when comparing two conditions (e.g. healthy vs. disease tissue), mapping tissue-specific genes and their encoded proteins, discerning the mechanisms of therapeutical agents in the search for suitable drug targets, clinical diagnosis and therapy outcome of genetic diseases etc.

Microarrays are microscope slides that contain an ordered series of samples (DNA, RNA, protein, or tissue). Since the samples are ordered on the slide, data obtained from the microarray experiment can be traced back to the corresponding gene or genome location. A typical microarray contains several thousands of genes and can be used to determine: (1) expression levels of genes in a sample, and (2) the gene sequences in a sample. Microarrays can be obtained from a variety of sources, and commercial ones are available for the most commonly studied organisms including human, mouse, rat, and yeast.

Affymetrix' GeneChip technology has become some sort of gold standard for analyzing complex genetic information using microarray technology. Affymetrix provide high-density microarrays as well as instrumentation, and data management and analysis tools. One such tool is the Integrated Genome Browser (IGB), which is a genome browser allowing visualization of local microarray and sequence data in a genome context and in comparison with annotations from multiple data sources. However, IGB is merely a viewer and does not allow the user to prepare and manipulating the data before viewing it in the browser.

Spotfire DecisionSite is a commercial software platform that provides an interactive approach to viewing and manipulating data in order to detect trends and patterns. DecisionSite for Functional Genomics (DSFG) comes with an additional set of tools specific for microarray and genomic data analysis. However, DSFG does not provide means to view the data in a full genomic context.

This project is a master thesis project performed at Spotfire AB in collaboration with Chalmers and FCC. The aim of the project is to integrate DSFG and IGB to enable the user to prepare microarray expression data in DSFG, using its various analysis and filtering tools, and then visualize genes of interest in its corresponding genomic context in IGB.

Årsredovisning

för tiden 1 januari 2005 - 31 december 2005

Resultaträkning (kSEK)	050101-051231
Intäkter	
Nettoomsättning	21 550
Övriga intäkter	27
Summa intäkter	**21 577**
Kostnader	
Externa kostnader	-6 214
Personalkostnader	-14 277
Avskrivningar av materiella anläggningstillgångar	-396
Summa kostnader	**-20 887**
Rörelseresultat	**690**
Resultat från finansiella investeringar	
Ränteintäkter och liknande	104
Räntekostnader och liknande	-27
Resultat efter finansiella poster	**767**
Bokslutsdispositioner	-84
Årets skatt	-201
ÅRETS RESULTAT	482

Balansräkning (kSEK)	051231
Anläggningstillgångar	
Maskiner och inventarier	559
Summa anläggningstillgångar	**559**
Omsättningstillgångar	
Kundfordringar	2 723
Förutbetalda kostnader och upplupna intäkter	1 584
Övriga kortfristiga fordringar	64
Kassa och bank	3 224
Summa omsättningstillgångar	**7595**
SUMMA TILLGÅNGAR	8 154
Eget kapital	
Eget kapital vid årets ingång	1 332
Årets resultat	482
Summa eget kapital	**1 814**
Obeskattade reserver	418
Kortfristiga skulder	
Leverantörsskulder	2 375
Övriga kortfristiga skulder	737
Skatteskulder	74
Upplupna kostnader och förutbetalda intäkter	2 736
Summa kortfristiga skulder	**5 922**
SUMMA SKULDER OCH EGET KAPITAL	8 154

Styrelsen för Stiftelsen Fraunhofer-Chalmers centrum för industrimatematik, FCC, får härmed avge följande redovisning över verksamheten under tiden 1 januari 2005 – 31 december 2005, stiftelsens fjärde verksamhetsår.

Stiftelsen bildades av Chalmers och Fraunhofersällskapet i juni 2001 och registrerades av Länsstyrelsen i Västra Götalands län i oktober 2001 som en svensk näringsdrivande stiftelse. Stiftelsen skall enligt strategiplan från oktober 2005 bygga upp en verksamhet som år 2010 omsätter tre och en halv miljon euro och omfattar 35 anställda.

Årets omsättning har varit drygt tjugoen miljoner kronor. Medeltalet anställda har ökat från 19 personer (varav fem kvinnor) 2004 till tjugofyra personer (varav sex kvinnor) 2005. Stiftelsen har ett rullande ettårigt hyresavtal med Fastighets KB Forskarbyn omfattande 818 kvm i Chalmers Teknikpark; nästa period löper till den 31 mars 2007.

Chalmers och Fraunhofersällskapet har under året beslutat fortsätta sin finansiering av centret till och med år 2010.

Styrelse och ledning den 8 mars 2006: Johan Carlson (biträdande föreståndare, FCC), Dieter Prätzel-Wolters (Fraunhofer ITWM), Jöran Bergh (Chalmers), Lars-Göran Löwenadler (Volvo), Nibia Aires (AstraZeneca), Peter Jagers (ordförande, Chalmers), Helmut Neunzert (vice ordförande, Fraunhofer ITWM), Tomas Lefvert (Vattenfall), Uno Nävert (föreståndare, FCC). Saknas på bilden: Gunnar Andersson (KP Pension & Försäkring).

FÖRVALTNINGSBERÄTTELSE

Stiftelsen Fraunhofer-Chalmers centrum för industrimatematik skall utveckla och anpassa matematiska metoder för industrin. Stiftelsen bedriver konkurrensneutral forskning och marknadsföring med finansiering från grundarna och genomför projekt definierade av företag och offentliga finansiärer på kommersiell grund.

Rörelsens intäkter har uppgått till 21 577 kSEK. Av detta utgör 41% industriprojekt, 25% offentliga projekt och 34% finansiering från grundarna. Årets resultat efter skatt är 482 kSEK. Eget kapital uppgick den 31 december 2005 till 1 814 kSEK.

Stiftelsens styrelse har under verksamhetsåret sammanträtt fyra gånger. Ersättning har utgått till ordföranden med 3 525 kronor per möte och till övriga ledamöter med 2 350 kronor per möte man deltagit i.

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

Result (kEUR)	050101-051231
Income	
Net sales	2 370
Others	3
Total income	**2 373**
Cost	
External cost	-683
Staff	-1 570
Depreciations	-44
Total cost	**-2 297**
Result of business	**76**
Result of financial investments	
Interest and similar income	11
Interest and similar cost	-3
Result including financial investments	**84**
Appropriations	-9
Tax	-22
TOTAL RESULT	**53**

Balance (kEUR)	051231
Fixed assets	
Machinery and equipment	61
Sum of fixed assets	**61**
Current assets	
Accounts receivables	300
Prepaid expenses and accrued income	174
Other current receivables	7
Cash and bank	355
Sum of current assets	**836**
TOTAL ASSETS	**897**
Equity capital and debts	
Equity capital at beginning of year	147
Result	53
Total equity capital	**200**
Untaxed reserves	46
Short-time debts	
Debts to suppliers	261
Other debts	81
Tax debts	8
Accrued expense	301
Sum of short-time debts	**651**
SUM OF DEBTS AND EQUITY CAPITAL	**897**

Göteborg den 8 mars 2006

Peter Jagers, ordförande
Jöran Bergh
Helmut Neunzert, vice ordförande
Dieter Prätzel-Wolters
Gunnar Andersson, adjungerad
Nibia Aires, adjungerad
Tomas Lefvert, adjungerad
Lars-Göran Löwenadler, adjungerad

Räkenskaperna har granskats av Deloitte.

Appendix

Presentations / Conferences

M Axelson-Fisk:
Comparative Gene Finding in Yeast, IBS Nordic Regional Conference, Oslo, June 2005.

J S Carlson:
Mathematics as Technology and Automatic Path Planning, VIPP ProViking Steering Commitee, February 2005.

J S Carlson:
9th CIRP International Seminar on Computer Aided Tolerancing, Phoenix, USA, April 2005.

J S Carlson:
Automatic Path Planning and Optimization, Executive Director GM Research and Development, April 2005.

J S Carlson:
Vad innehåller duglighetsindex? Möjligheter och fallgropar, Engineering lecture, Volvo Car Corporation, June 2005.

J S Carlson:
Banplanering för mätmaskiner, Vinnova, August 2005.

J S Carlson:
Simulation and Path Planning of Compliant Parts, GM Research and Development, August 2005.

J S Carlson:
Non-nominal path planning of assembly processes, ASME International Mechanical Engineering Congress & Exposition, Orlando, Florida, USA November 2005.

J S Carlson:
Path Planning and CMM, Wingquist annual seminar day, Göteborg, November 2005.

J S Carlson:
Factory-in-a-Box, IVA, Göteborg, November 26, 2005.

G Cedersund:
Improved methods for system identification of glycolytic oscillations, 4th European Workshop on Glycolysis, Amsterdam, February 2005.

G Cedersund:
System identification of the Glucose-Insulin Control System, BioSim Workshop at Novo-Nordisk, Måløv, March 2005.

G Cedersund:
Core-box modelling of insulin and glucose systems, BioSim Workshop at NovoNordisk, Måløv, May 2005.

G Cedersund, S Danø, P G Sørensen, and M Jirstrand, From in vitro biochemistry to in vivo understanding of glycolytic oscillations in Saccharomyces Cerevisiae, BioMedSim2005, Linköping, May 2005.

G Cedersund:
Identification of glycolysis in Saccharomyces Cerevisiae, Gothenburg Yeast Retreat, Rörbäckstrand, August 2005.

G Cedersund:
In vivo identification of yeast glycolysis, Yeast Systems Biology Workshop, Boston, October 2005.

G Cedersund, J Roll, E Ulfhielm, H Tidefelt, M Jirstrand, S Fagerholm, and P Strålfors:
Identifiability Analysis of Relative Kinase Contribution from Internalised Receptors in a Model for Insulin Signalling, 6th International Conference on Systems Biology 2005, Boston, October 2005.

E W Jacobsen and G Cedersund:
On Parametric Sensitivity and Structural Robustness of Cellular Functions - the Oscillatory Metabolism of Activated Neutrophils. In Proc. of the 44th IEEE Conf. on Decision and Control, Seville, December 2005.

F Edelvik:
Att vara doktorand vid ett kompetenscentrum, KTH och COMSOL seminarium - virtuell produktutveckling, Mars 2005.

F Edelvik:
Electromagnetic simulation up to the GHz range, ABB Corporate Research, Västerås, April 2005.

F Edelvik, K-H Kuefer:
Electromagnetic simulations and multiple criteria optimization, ABB Corporate Research, Baden, June 2005.

F Edelvik:
Elektromagnetiska beräkningar och koderna i GEMS, PSCI projekt nummer 24082-62591, STM höstmöte, November 2005.

E Höök:
Topology Optimization in a Commercial Perspective, invited talk for the optimisation group at ITWM, January 2005.

M Jirstrand:
Systems Biology at the Fraunhofer-Chalmers Centre, Konferens om svenskt forskningsledarskap, Stockholm, February 2005.

M Jirstrand:
Systems Biology – An Overview, Invited lecture at S2, Chalmers, Göteborg, May 2005.

M Jirstrand:
System Identification - The View of an Engineer, Invited talk at the conference Numbers to the models: Generating the data for Systems Biology, Göteborg, June 2005.

M Jirstrand:
Introduction to Computational Systems Biology, Invited lecture at the Bioinformatics seminar at Chalmers/GU, September 2005.

M Jirstrand, J Gunnarsson, and H Johansson:
PathwayLab - A Software for Modeling and Simulation of Biochemical Reaction Networks, 1st BioSim Conference, Mallorca, October 2005.

M Jirstrand:
Dynamic Models in Systems Biology - Their Construction and Use, Invited lecture at the Scheele Symposium, BiotechForum 2005, Stockholm, October 2005.

F Eriksson, H Noor, M Jirstrand, and S Nelander:
Epistasis Networks in Human Cancer, 6th Swedish Bioinformatics Workshop, Göteborg, November 2005.

M Jirstrand:
Decision Support for Product Development - Dynamic Systems and System Identification, STM höstmöte 2005, Göteborg, November 2005.

M Jirstrand:
Computational Systems Biology at the Fraunhofer-Chalmers Centre, Invited talk at the KTH Computational Science and Engineering Centre annual meeting, Lovik, December 2005.

P Johannesson:
An Extension of the Relative Miner Rule, the 9th International Conference on Structural Safety and Reliability, Rome, Italy, 19-23 June, 2005.

P Johannesson:
Extrapolation of Fatigue Loads, the 4th Conference on Extreme Value Analysis, Göteborg, August 15-19, 2005.

J Johansson:
FCC-internal course on life-insurance mathematics, April 29, 2005.

J Johansson:
Talk on correlation and risk management at an STM-meeting at FCC, May 19, 2005.

J Johansson:
Talk on ALM for Swedish pension funds at Kontaktdag Högskola-Industri, Chalmers, June 8, 2005.

J Johansson:
Talk on ALM for insurance companies at the ”Ekonomi och skatt” workshop arranged by the Swedish Insurance Federation and the Swedish Actuarial Association, November 16, 2005.

M Karlsson:
Modelling of Lateral Vehicle Loads for Fatigue Life Calculations, the 9th International Conference on Structural Safety and Reliability, Rome, Italy, June 19-23, 2005.

M Karlsson:
Statistical Parameterisation of Lateral Vehicle Loads, the 19th IAVSD symposium, Milan, Italy, August 28 - September 2, 2005.

M Karlsson:
Evaluation of Approximative Methods for Rainflow Damage of Broadbanded Non-Gaussian Random Loads, the 2005 ASME International Mechanical Engineering Congress and Exposition, Orlando, Florida, USA, November 5-11, 2005.

U Nävert:
Advantages and problems with trans-European joint ventures, 16. Internationaler Kongress der Österreichischen Mathematischen Gesellschaft Jahrestagung der Deutschen Mathematiker-Vereinigung, Klagenfurt, Austria, September 2005.

H Schmidt and M Jirstrand:
Systems Biology Toolbox for Matlab - A Computational Platform for Research in Systems Biology, 6th International Conference on Systems Biology 2005, Boston, October 2005.

H Schmidt and M Jirstrand:
A Systems Biology Toolbox for MATLAB, Tutorial at the 6th International Conference on Systems Biology 2005, Boston, October 2005.

H Schmidt:
Systems Biology and Matlab, Invited lecture for Systems Biology Students at Chalmers Technical University, Göteborg, November 2005.

A-B Strömberg:
Logistics, energy production and engine development - applications of optimisation, invited talk for the optimisation group at ITWM, January 2005.

A-B Strömberg:
Planering av strålbehandling - ett beslutsproblem med flera mål, invited talk at STM board meeting, May 2005.

A-B Strömberg:
Participation in 2005 SIAM Conference on Optimization, Stockholm, May 2005.

A-B Strömberg:
Simuleringsbaserad optimering, invited talk at STM-meeting at FCC, November 2005.

Publications

M Alexandersson, N Bray, L Pachter:
Pair Hidden Markov Models, Special review in Encyklopedia of Genetics, Genomics, Proteomics and Bioinformatics, John Wiley & Sons, Ltd. Editors: L B Jorde, P Little, M Dunn, and S Subramanian, 2005.

M Axelson-Fisk and P Sunnerhagen:
Gene Finding in Fungal Genomes, to appear in Topics in Current Genetics: Comparative genomics using fungi as models.

R Söderberg, L Lindkvist, J S Carlson:
Managing Physical Dependencies through Location System Design (accepted for publication in Journal of Engineering Design).

J S Carlson, R Söderberg, R Bohlin, L Lindkvist, T Hermansson:
Non-nominal path planning of assembly processes, Proceedings of IMECE'05, 2005 ASME International Mechanical Engineering Congress & Exposition, Orlando, Florida, USA November 5-11, 2005.

L Lindkvist, J S Carlson, R Söderberg:
Virtual Locator Trimming in Pre-Production – Rigid and Non-Rigid Analysis, Proceedings of IMECE2005, ASME International Mechanical Engineering Congress and Exposition, Orlando, Florida, USA, November 5-11, 2005.

G Cedersund and C Knudsen:
Improved parameter estimation for systems with an experimentally located Hopf bifurcation, IEE Proc. Syst. Biol., 152(3), pp 161-168, 2005.

G Cedersund:
Elimination of the initial value parameters when identifying a system close to a Hopf bifurcation, to appear in IEE Proc. Syst. Biol.
F Edelvik, T Weiland:
Stable Modeling of Arbitrarily Oriented Thin Slots in the FDTD Method, IEEE Transaction on Electromagnetic Compatibility, 47(3):440-446, 2005.

E Abenius, F Edelvik:
Thin Sheet Modeling Using Shell Elements in the Finite-Element Time-Domain Method (accepted for publication in IEEE Transaction on Antennas and Propagation).

T Rylander, F Edelvik, A Bondeson, DJ Riley:
Advances in Hybrid FDTD-FE Techniques, in Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rd edition, A Taflove, S Hagness (eds.), Artech House, Boston, MA, 2005.

P Hörfelt:
The moment problem for some Wiener functionals; corrections to previous proofs (with an appendix by H.L. Pedersen), Journal of Applied Probability, Vol. 42, No. 3, 2005.

P Hörfelt:
The error in the Monte Carlo pricing of some familiar path-dependent options, Mathematical Finance, Vol. 15, No. 2, 2005.

P Johannesson:
Extrapolation of Load Histories and Spectra, Fatigue and Fracture for Engineering Materials and Structures, In Press, 2005.

P Johannesson, T Svensson, J de Maré:
Fatigue life prediction based on variable amplitude tests - methodology, International Journal of Fatigue, Vol. 27, pp 954–965, 2005.

M Karlsson, B Johannesson, T Svensson, J de Maré:
Verification of safety critical components, presentation at the VDI conference: Trucks and Buses – solutions of reliability, sustainable environment and transport efficiency, Böblingen, Germany, June 2005.

S Lorén, M Lundström:
Modelling curved S-N curves, Fatigue & Fracture of Engineering Materials and Structures, Volume 28, Issue 5, pp 437-443, 2005.

H Schmidt, M Jirstrand, and O Wolkenhauer:
Information Technology in Systems Biology. Invited article for it–Information Technology, (accepted for publication).

H Schmidt and M Jirstrand:
Systems Biology Toolbox for Matlab: A computational platform for research in Systems Biology, Bioinformatics, doi:10.1093/bioinformatics/bti799, 2005.

M Ullah, H Schmidt, K-H Cho, O Wolkenhauer:
Deterministic Modelling and Stochastic Simulation of Pathways using Matlab, to appear in IEE Proc Syst. Biol.

H Schmidt, E W Jacobsen, and K-H Cho:
Identification of Small Scale Biochemical Networks Based on General Type System Perturbations, FEBS Journal, 272(9), 2141-2151, 2005.

M Holmgren, T Svensson, E Johnson, K Johansson:
Reflections regarding uncertainty of measurement on the results of a Nordic fatigue test interlaboratory comparison, Accreditation and Quality Assurance, Vol 10, pp 208-213, 2005.

T Svensson, P Johannesson, J de Maré:
Farige life prediction based on variable amplitude tests - specific applications, International Journal of Fatigue, Vol 27, pp 966-973, 2005.

PhD students

E Abenius (Uppsala University); co-adviser F Edelvik. Direct and Inverse Methods for Waveguides and Scattering Problems in the Time Domain, **PhD thesis**, November 2005.

J Andersson (Chalmers); adviser J de Maré, co-adviser T Svensson. Non-overlapping Germ-grain Models: Characteristics and Material Modelling, **PhD thesis**, December 2005.

N Andréasson (Chalmers, Volvo Aero); advisers M Patriksson and A-B Strömberg. Optimisation of Logistics for Cost Efficient Maintenance (in progress).

G Genet (PSA Peugeot Citroën, Chalmers); advisers J de Maré and P Johannesson. A statistical approach to multi-input equivalent fatigue (in progress).

R Halldin (Lund University); co-adviser A-B Strömberg. Stochastic Modeling and Optimization under Uncertainty of a Hydro Power System, **PhD thesis,** June 2005.

M Karlsson (Volvo Trucks, Chalmers); advisers J de Maré, T Svensson and P Johannesson. Statistical Modelling of Lateral Vehicle Loads (in progress).

P Lindroth (Volvo Trucks, Chalmers); advisers M Patriksson and A-B Strömberg. Product Configuration with respect to multiple criteria in a Heterogeneous and Dynamic Environment (in progress).

J Svensson (Volvo Aero, Chalmers); advisors J de Maré, T Svensson, D Anevski, and P Johannesson. Survival Estimation and Distribution Approximation for Optimal Maintenance (in progress).

Master students

F Eriksson (Chalmers, Göteborg University); supervisors M Jirstrand and S Nelander. Modelling Molecular Pathways by Combining Epistasis Analysis and Protein Interaction Data (in progress).

E Guðfinnsson and N Á Sigfússon (Chalmers); advisers A-B Strömberg and M Patriksson. Minimisation of the maximal stress in a linkage arm (in progress).

Johan Havner (Chalmers); supervisors J Carlson and R Bohlin. Automatic correction of surface normals on 3D models, **Master Thesis,** May 2005.

A Jauhiainen (Linköping University); supervisor M Jirstrand. Evaluation and Development of Methods for Identification of Biochemical Networks, **Master Thesis,** January 2005.

Ola Karlsson(Chalmers); supervisors J Carlson and R Bohlin. Automatic correction of surface normals on 3D models, **Master Thesis,** May 2005.

H Noor (Chalmers, Göteborg University); supervisors M Jirstrand and S Nelander. Network Identification and Regulatory Inference From Systematic Gene Perturbation Experiments (in progress).

E Yazdani and C Edlund (Chalmers, Spotfire); supervisors M Axelson-Fisk and M Jirstrand. Development of an Enhanced Microarray Data Analysis Environment (in progress).

A Zafar (Högskolan Dalarna); supervisor G Cedersund. Model Reduction and Other Preparations for System Identification of a Model for Pancreatic Beta Cells (in progress).

Other assignments

J S Carlson:
Member of the ProViking Steering commitee for Robust Design and Variation Simulation.

J S Carlson:
Reviewer for ASME International Design Engineering Technical Conferences.

J S Carlson:
Member of the reference board of Teknisk Matematik, Chalmers.

F Edelvik:
Reviewer for Journal of Computational Physics.

F Edelvik:
Reviewer for IEEE Transaction on Antennas and Propagation.

P Johannesson:
Opponent on Licentiate Thesis " Klas Bogsjö: Stochastic Modelling of Road Roughness", LTH, Lund University, December 16, 2005.

A-B Strömberg:
Deputy in the committee at M Grönkvist's dissertation. 13 September 2005 at the Department of Computer Science and Engineering, Chalmers. Title of PhD thesis: The tail assignment problem.

T Svensson and J de Maré:
Member of the technical committee ESIS (European Structural Integrity Society) TC20, chaired by Professor Yukitaka Murakami, Kyushu University, Japan. Within this committee TS and JdM have contributed to the publication "Technical recommendations for the extreme value analysis of data on large non-metallic inclusions in steels".

Courses

J Johansson:
Finansiell risk, Chalmers, Göteborg, 2005.

T Svensson: Measurement uncertainty (In Swedish: Mätosäkerhet), 3 days, Volvo Trucks, Göteborg, September 2005.

T Svensson: Measurement uncertainty for weighing practices (In Swedish: Mätosäkerhet, vägning). One lecture in a course for measurement laboratories, organized by the Swedish National Testing and Research Institute.

FCC staff on December 21, 2005.

Back row, from left to right; Peter Lindroth, Magnus Karlsson, Fredrik Ekstedt, Daniel Segerdahl, Rikard Söderberg, Robert Bohlin, Tomas Hermansson, Joachim Johansson, Sebastian Tafuri, Gunnar Cedersund. Middle row, from left to right: Sandra Kjeldsen, Marina Axelson-Fisk, Michael Patriksson, Pär Johannesson. Front row, from left to right; Johan Carlson, Robert Rundqvist, Mats Jirstrand, Erik Höök, Fredrik Edelvik, Domenico Spensieri, Annika Eriksson, Jenny Ekenberg, Sara Lorén, Uno Nävert. With bicycle: Jacques de Maré.

UNESCO´s World Heritage List includes fourteen Swedish sites, here used to illustrate our departments and research areas:

http://whc.unesco.org
http://www.raa.se

Fraunhofer-Chalmers Research Centre for Industrial Mathematics, FCC

Chalmers Science Park
SE-412 88 Göteborg
Sweden

Phone +46 (0)31 7724000
Fax +46 (0)31 7724260
info@fcc.chalmers.se
www.fcc.chalmers.se

The Fraunhofer-Chalmers Research Centre for Industrial Mathematics FCC has been founded by Chalmers and 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 co-operation with Chalmers in Göteborg and Fraunhofer ITWM in Kaiserslautern, shall be a leading partner for international industry and academia to mathematically model, analyse, simulate, optimise, 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.