Annual Report 2001-2002

FCC
Fraunhofer-Chalmers Research Centre for Industrial Mathematics
Contents

Preface 1
Profile 2-3
Acknowledgements 4
Clients and Partners 5
Fraunhofer-Gesellschaft 6-7
Chalmers 8-9
Computational Physics 10-11
Fatigue 12-13
Optimization 14-15
Quality Engineering 16-17
Signals and Systems 18-19
Annual account (in Swedish) 20-21
Appendix 22-24

Cover
A network model of fibres for finite element simulation of the properties of paper, cf page 11.

Annual Report 2001 - 2002
Fraunhofer-Chalmers Research Centre for Industrial Mathematics, FCC

Editors: Annika Eriksson, Uno Navert
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Preface

Mr Leif Pagrotsky, now Minister for Industry and Trade, inaugurated the Fraunhofer-Chalmers Research Centre for Industrial Mathematics on September 4, 2002.

In his speech Mr Pagrotsky said: We all know that mathematics is a key technology for industrial renewal. Not just in some sectors of industry, but almost all sectors of society with the help of computer simulation, mathematics has become a key tool, opening the door to immense possibilities when the knowledge developed in academic mathematics is applied in industry.

This power of mathematics is indeed underpinned by the fact that the Fraunhofer Society, when going European, has selected mathematics for one of its first initiatives.

The creation of FCC has been a very dynamic process. The Fraunhofer Society initiated the discussion in March 2000. Fifteen months later, in September 2001, the Centre started its operations.

In line with the Fraunhofer model, the profile of the Centre is controlled by its income structure.

The result of the first fiscal year July 2001 - December 2002 is most encouraging. It is well in line with the business plan of 2001, scientifically as well as commercially. In particular, the income from industrial projects has been above expectations.

Before ending this Preface, I take the opportunity to express my great appreciation of Professor Helmut Neunzert at Fraunhofer-ITWM. It is a privilege and an honour to take part in his vision for an industrial mathematics institution operating on a European scale.

Göteborg in June 2003

Uno Nävert
Director
The Fraunhofer Society and Chalmers have founded FCC to promote the application of mathematical methods in industry. To do so the Centre undertakes scientific research and marketing projects 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, prediction, control, optimization, and risk assessment.

**Entrepreneurial competence**

Experiences from Fraunhofer show that small and medium-sized companies constitute an important market for an industrial mathematics institute. The Centre has arranged a first SME day, which has resulted in several projects. The Swedish Society of Applied Mathematics, STM, is a consortium of big companies with business interests, cf. page 5. This consortium is the largest individual industrial client of FCC projects and almost half of the total industrial income.

During its first financial year, the Centre has served three international industrial clients, from France, Germany, and Norway.

**Professional networking**

The Centre has a very close relation to its founders Chalmers and Fraunhofer-ITWM, cf pages 6-9. Changing staff members, cooperating 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 page 15.
It also promotes research and education in industrial mathematics at institutions outside the Centre cf pages 8 and 15.

**Scientific competence**

The Centre undertakes scientific research projects and marketing of scientific results financed by its founders and public institutes. Respecting the confidentiality of data for customers, the Centre encourages the publication of results. FCC supports efforts to use its research for educational purposes 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.

The Centre has organized six research programmes within the technology areas. By the end of 2002 the staff was 40 full-time equivalents, including one scientist contracted from Fraunhofer-ITWM and six scientific advisers at Chalmers, each working 10% - 20% of full time at FCC.

**Financial mix**

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.

According to the business plan of 2001, the annual turnover of the Centre shall increase from 1700 kEUR in 2001 - 2002 (18 months) to 2000 kEUR in 2003. The outcome of the first fiscal year has been slightly above expectations. In particular, the industrial income has been higher than expected, cf pages 22 - 23.
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 Association 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 announcing support of one million euro for a public project where a future scientific leader is recruited to establish a research team at the Centre.
Clients and partners

FCC has successfully co-operated with enterprises of different sizes and from many branches. The following, those clients and project partners of the fiscal year 2001 - 2002, are listed who have accepted to be cited.

- ABB
- ABB Power Technologies
- Aerotech Telub
- AstraZeneca Molndal
- AstraZeneca Sodertalje
- Atlas Copco Rock Drills
- Bombardier Transportation
- Chalmers IndustriTeknik
- Chalmers Finite Element Centre
- Chalmers University of Technology
- Chalmers Wingquist Laboratory
- Elforsk
- Ericsson
- Ericsson Microwave Systems
- EU IST Consortium ViSiCADE*
- Fortum Power and Heat OY
- Fraunhofer-ITWM
- Front Capital Systems
- ITM
- IVF Industriforsknings
- Jernkontoret
- Kungliga Tekniska Hogskolan/PSCI
- Lund University, Mathematical Statistics
- NMCT
- Optimization Partner Stockholm
- PSA Peugeot Citroen (F)
- Saab
- Saab Automobile
- Safe Technology
- Saint-Gobain Sekurit Scandinavia
- Sandvik Steel
- Scania
- Simula Research Laboratory AS (N)
- SKF
- STM Forskningservice
- Swedish Insurance Federation
- SP Swedish National Testing and Research Institute
- StoraEnso Corporate Research
- Sydkraft
- Volvo Aero Corporation
- Volvo Car Corporation
- Volvo Trucks

* EU IST Consortium ViSiCADE

FRAUNHOFER IGD (co-ordinator)
Airbus
CS Systemes d’Information
CLRC Daresbury Laboratory
Centre Scientifit et Technique du Batiment
Chalmers University of Technology
TranscenData Ltd
ZF Friedrichshafen AG
Queens University of Belfast
ProSTEP GmbH

STM

The Swedish Society for Applied Mathematics (STM) has signed a letter of intent to finance projects at FCC with 700 kEUR in the period 2001 - 2004.

Members and shares 2001 - 2002:

**Engineering and transport**

Volvo (5)
SKF (5)
ABB (3)
Saab (3)
Scania (1)
Sveriges Provnings- och Forskningsinstitut SP (1)

**Pharmaceuticals**

AstraZeneca Molndal (5)
AstraZeneca Sodertalje (2)

**Telecommunications**

SaabTech Systems (1)
Ericsson Microwave Systems (1)
Ericsson Radio Systems (1)
Ericsson Utveckling (1)
FMV (1)
Telia Sonera (1)

**Energy**

Elforsk (5)

**Insurance and finance**

Swedish Insurance Federation (5)
Front Capital Systems (1)

**Wood, pulp, paper**

StoraEnso Corporate Research (1)

**Authorities**

Statistics Sweden SCB (1)

www.itm.se/stm.html
Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft is Germany’s leading organization of institutes of applied research. It undertakes contract research on behalf of industry, the service sector and government.

TheFraunhofer-Gesellschaft works within the framework of the European Union’s technology programs, striving to improve the competitiveness of European industry through the enhancement of technical systems and processes. Commissioned and funded by the Federal and State governments, the Fraunhofer undertakes strategic research projects which contribute to the development of innovations in key technologies and spheres of major public concern, such as energy, transport and the environment.

The Fraunhofer-Gesellschaft was founded in 1949 and is a recognized non-profit organization. It currently maintains 58 research institutes throughout Germany. A staff of 12500, the majority of whom are scientists and engineers, generate the annual research budget of more than 1000 million euros. Work focuses on specific tasks and a wide spectrum of research fields. Where systematic solutions are required, several institutes collaborate on an interdisciplinary basis.

The Institut für Techno- und Wirtschaftsmathematik (ITWM) in Kaiserslautern became a Fraunhofer institute on January 1, 2001, after an exceptional development. The budget increased from 1500 kEUR in 1996 to 5000 kEUR in 2000 and the staff increased from 34 to 81 in the same period. Director is Professor Deter Pätzelt-Warters.

The ITWM is organized into six departments, which also reflect key competence fields: Transport Processes, Models and Algorithms in Image Processing, Flow in Complex Structures, Adaptive Systems, Optimization, and Mathematical Finance.

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

Co-operation
A key element in the operation of FCC is to establish a close cooperation with Fraunhofer-ITWM. This co-operation is growing, but has not yet reached the expected volume.

Project acquisitions
Five of the six department heads of ITWM have visited FCC for joint project acquisitions during the first year. Professor Neunzert, who is senior adviser at FCC, has visited several Swedish companies together with the FCC management.

www.itwm.fhg.de
Projects have been secured in the areas transport processes (star 2003), flow in complex structures, image processing (star 2003), adaptive systems, and finance mathematics (star 2003). The names of the areas refer to the department structure of ITWM.

SME day
Together with the West Sweden Chamber of Commerce and Industry, FCC arranged a day on mathematics as a technology for small and medium sized enterprises in October 2002. FCC and ITWM together presented the potential of industrial mathematics, in particular in the areas surface inspection, filling processes, and logistics.

The meeting resulted in several projects in spite of a low number of participants. It also generated ideas for additional future initiatives and suggested suitable formats for their campaigns.

Exchange of staff
Dr Marco Günther from ITWM has spent thirteen months at FCC. One staff member from FCC has spent a month in Kaiserslautern to work on a project in finance mathematics.

Dr Günther mainly worked on the project described below. He also participated in projects within the computational physics field.

Parameter estimation in power networks
State estimation of a power system network is important for network control by Electrical Management Systems. The estimation makes it possible to calculate information required for state stability and power economy.

The state estimation is based on teleometered values collected from the power network. In periodic intervals the values are sent to the central control. Measurable quantities are voltage magnitude, real and reactive power flow, tap ratios at transformers and breaker settings.

The performance of the state estimation procedure strongly depends on the knowledge of the network parameters. The problem in that direction is that some of the model parameters can only be initialized by rough estimates. A second problem arises from time-varying effects in some of the network parameters.

The project has addressed different aspects of combining state estimation with parameter estimation. Different models and algorithms have been tested on a reference network consisting of 27 stations and 40 lines including 15 transformers.
The Chalmers University of Technology (Chalmers Tekniska Högskola) was founded in 1829 and is a non-profit, non-governmental university. With its more than 7000 students for engineering and architecture degrees, and more than 1100 PhD students it is one of Sweden’s two leading technology universities.

Most of Chalmers’ resources come from contracts with the state of Sweden (63%), but Chalmers also has support from non-governmental research organizations (29%) and industry (8%). The annual (2000) turnover is 210 Mio euro. More than two thirds of the budget allotted to research and to graduate studies. With its staff of 2500 full time equals, including 130 full professors, the university has strong and well-known departments in most fields of science and engineering.

Chalmers has made special effort 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 various mathematical fields, Chalmers Applied Mathematics comprises three more specialized centres.

Professor Peter Jägers was the resident of the Chalmers 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 six scientific advisers. Each adviser typically spends between 10 and 20 percent of full time at the Centre four advisers are senior scientists at the School of Mathematical Sciences and two are at senior scientists at the School of Mechanical Engineering.

In several cases FCC staff members act as co-advisers to PhD students at Chalmers. FCC also finances projects at Chalmers.

The co-operation has been particularly strong in four areas: Computational Physics, Fatigue Life, Optimization, and Quality Engineering. In different settings, Chalmers and FCC have worked together in externally financed projects, as described below by the scientific advisers.
Computational Physics
FCC interacts with activities in the Chalmers Finite Element Centre Phi, a centre focusing on the interdisciplinary development and application of finite element based computational technology. Examples of joint activities include the EU-project ViSiCADE, co-ordinated by Fraunhofer IGD, and a PhD project carried out by Rickard Bergström on finite element methods for electromagnetics, cf pages 10 - 11.

Statistical Fatigue of Materials
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.

The strategy has been to consider the fatigue group as one unit jointly supported by Chalmers and FCC. That way problems from industry are imported into the academic world and research results are exported to industry. This two-way communication has proved fruitful for the students at Chalmers, all as for the industrial partners, cf pages 12 - 13.

Optimization
Dr Ann-Brit Stömberg at FCC is the co-adviser of the Master of Science in Optimization at Chalmers. She also shares the responsibility for the course on optimization under uncertainty, given at the Department of Mathematics. The course incorporates a current project at FCC on the topic of optimization under uncertainty, thus bringing knowledge of the state-of-the-art of applied mathematics in practice to the students, cf pages 14 - 15.

Quality Engineering
Wingquist Laboratory was started in October 2001 as an important part of a major renewal and organization of the School of Mechanical and Vehicle Engineering at Chalmers. The motivation was to increase the collaboration with Swedish industry and to concentrate research in strategic areas.

The laboratory conducts interdisciplinary research within the field of virtual product realization, focused on modelling, simulation, evaluation and verification of product and production concepts. Research efforts are carried out in three closely related areas: 1) product- and production system modelling, 2) robust design and variation simulation, and 3) flexible production and automation systems, cf pages 16 - 17.
General
The FCC research in Computational Physics focuses on computer simulation of physical phenomena, including fluids, solids, and electromagnetics.

Geometry and Mesh Generation
The starting point of many industrial computations is the creation of a mesh with desired properties and quality. Often this task is difficult and time consuming due to bad quality of CAD data and lack of robust 3D mesh generators. Furthermore, special meshes, for instance boundary fitted or hybrid meshes are often desired in applications.

Adaptive Methods
Computer simulations enable rapid design and optimization of products. Design optimization may, for instance, involve choice of suitable materials, geometrical shape, and even topology. Typically these problems require rapid solvers and efficient optimization algorithms.

Modern finite element techniques for solution of differential equations are based on a multi-resolution approximation of the solution, where the local resolution is determined in an adaptive fashion. To obtain desired accuracy we employ techniques for estimation of the errors in the computations. Such computational error estimation techniques have developed rapidly during the last decade and it is now possible to control the global error measured in a norm or the error in particular quantities of interest. An illustrating example of such quantities of interest is the lift and drag coefficients of an airfoil.

Inverse Problems and Optimization
Inverse problems typically involve determination of quantities or objects from measured data, for instance detection of defects in a material using ultrasound measurements. Inverse problems are closely related to shape/topology and design optimization problems in engineering where we seek to determine an optimal design (in a suitable sense).

Multiscale Computations
Often physical problems exhibit multiscale behavior. For instance, a composite material may be described by fibers in a matrix on the microscale and perhaps linear elasticity on the macroscale. Multiscale computational methods are techniques used to handle such problems. Typically, these techniques involve solution at the microscale and computation of macroscopic quantities or the effect of the microscale on the macroscale.

Computational Electromagnetics
In computational electromagnetics, FCC is sub-contracted by Scientific Computing Institute, PSCI, project 24082-6100, for code development, cf the projects below.

Some projects
Development of Finite Element Software
High order finite elements, p-elements, are used to efficiently compute approximations to differential equations with high accuracy. Such elements have been implemented in the finite element software package Diffpack (registered trademark of Numerical Objects AS) during a project with Simula Research Laboratory AS Norway. In additions to the elements, high order quadrature rules as well as the necessary mesh and assembly infrastructure were implemented. The large systems of equations manufactured by the high order finite element method can be solved rapidly using iterative techniques including a recently developed multigrid technique.

VISICADE
In the EU project ViSICADE in the IST program, IST2000-28123, FCC takes part as a large subcontractor to Chalmers. The objective of the ViSICADE project is to develop an intuitive simulation framework based on visual reality.

The role of FCC is to develop fast finite element solvers enabling the user of the developed system to make interactive simulation. A technique for making interactive simulations is submodeling where the accuracy of the solution in a subdomain is enhanced by...
solving a local problem on the subdomain with data obtained from a coarse solution. Further the geometry or material properties in the subdomain may be changed providing the possibility to study the effect of design changes in real time.

**Computational Modeling of Paper**

Based on, for instance, pictures of microstructure of a material a mathematical model of the microstructure can be constructed and simulations of its properties can be done. Examples of simulations include fluid flow in a filter or the mechanical response of a small piece of a composite or foam material under load. Based on these computations estimates of parameters in macroscopic equations may be obtained. A natural next step is virtual design and optimization of materials where we instead seek to construct microstructures which gives desired macroscopic properties.

**SMART**

The objective of the SMART project is to develop a state-of-the-art software suite for Radar Cross Section (RCS) applications in order to compute and optimise the RCS performance of future low observable vehicles. The vehicles of interest are operational aircraft, unmanned aerial vehicles (UAV) and helicopters. The size of the objects range 2-15m and the relevant frequency range is 1-20 GHz. The monostatic RCS is optimised for a given system within selected intervals for the frequency and angle of incidence with respect to material parameters, one or more layers, and geometry.

**Multipoles Method**

We solve scattering problems with a boundary element method in frequency domain. The computational complexity of classical solution methods is proportional to the fourth to sixth power of the frequency and this prohibits us from solving really large problems. An important part of the project is the development of the Multilevel Fast Multipole Method (MLFMM) where the complexity is reduced to the order \( F\log(f) \) for Maxwell’s equations.

Computed surface current distribution on an 11 m long aircraft model illuminated with a 3 GHz (10 cm wavelength) plane wave. The resolution is 17 mm with 1042644 unknown variables. The problem was solved in 3 hours with MLFMM on an 24 processor SGI 3800 using 14.7 Gbyte of memory.

[Project 24082-6100 PSCI-CEM-Prog]

**The Computational Physics Research Group**

- Klas Samuelsson, PhD, mainly working on finite element technology
- Anders Ålund, Lic, mainly working on numerical methods and high speed computing
- Mats Larson, Docent in mathematics at Chalmers, scientific adviser at FCC

In a project supported by STM Research and StoraEnso we have developed such computer models of paper. The models focus on simulation of the mechanical properties of paper and are implemented in a demonstration software.

A network model of fibres for finite element simulation of the properties of paper.
**Fatigue**

**General: Fatigue from a Statistical Point of View**
Statistical methods can help to build a complete picture of the reliability of mechanical constructions with respect to fatigue resistance, and hence show where it is most efficient to take steps to improve the quality of a product.

The reliability is a combination of strength and loading. The strength is determined through fatigue tests, while the loadings are obtained through measuring loads in service or on proving grounds. The relation between loading, strength, and fatigue life is modelled using simple physical models. The determination of the strength as well as the loading is a difficult task, hence the two quantities are attached with a certain amount of uncertainty. A statistical perspective makes it possible to combine all uncertainties and variations in a total reliability analysis, and update the models with reports on failures in service. Especially the following areas can be identified:

- **Planning and evaluation of fatigue tests.** We apply well established statistical methods, like statistical design of experiments, regression analysis, prediction and confidence intervals, which we adopt to the particular engineering application.
- **Analysis of real service loads.** We use the theory of stochastic processes, RainFlow Count analysis, and work on questions concerning the relation between laboratory tests and service loads.
- **Uncertainties of empirical models.** Statistical methodology makes it possible to compare uncertainties of models with random variations in the loading and the material, in order to find an optimal complexity in the modelling. An important issue is to distinguish between systematic and random sources of variation.
- **Feedback of failure reports.** The use of Bayesian updating techniques makes it possible to improve future modelling of the phenomena.

**Some Projects**

**Fatigue Prediction at Variable amplitude without Constant Amplitude Tests**
In a cooperation project with five companies, a method for prediction of fatigue life for service loads is developed. Traditional methodology is based on testing in laboratory using load sequences with a constant amplitude. However, in service products are often exposed to loadings of a more stochastic nature, with variable amplitudes. By performing laboratory tests at variable amplitude the life predictions can be improved, but a difficulty is that service loads are not identical from one occasion to the other. In this project a methodology is developed for predicting the fatigue life based on tests at variable amplitude, which also includes a characterization of different kinds of load sequences by an equivalent amplitude.

This project is financed by Atlas Copco Rock Drills, Bombardier Transportation, Sandvik Steel, Volvo Cars, SP, and by STM (Swedish Society for Applied Mathematics).

**Extrapolation of Rainflow Matrices**
Within the automotive industry an important task is to determine the load profile of different customers. Such investigations give knowledge on the variation within different customer populations, and give the opportunity to adapt the constructions to different markets or usage. To find the fatigue life of a vehicle for a specific customer, one would need to measure during the full life of the vehicle, which is not possible. One is limited to quite short measurements compared to the full life. Hence, one question is how to

![Graph](image-url)
extrapolate the measurement to represent a full design life of the vehicle.

For fatigue analysis the information on the load process is often condensed to a distribution of load cycles, the rainflow matrix. Within this project we have developed a method for extrapolating such matrices, with a technique based on statistical extreme value theory (Johannesson and Thomas, 2001). Of special interest is to quantify the uncertainties in the load measurements. With this technique we have studied the variation between drivers on a test track, see Johannesson et al, (2002), and also made comparison between test tracks and real road measurements.

Within the area of reliability, statistical analysis and extrapolation of fatigue loads we have a long term collaboration with the Division of Automotive Research and Innovations at PSA Peugeot Citroën in Ris.

PhD projects

All the graduate students in the group (Sara Lorén, Chalmers, Jenny Andersson, Chalmers, Johan Svensson, Chalmers, Magnus Karlsson, FCC and Volvo Trucks, and Gwenaëlle Genet, Chalmers and PSA) are jointly supervised by FCC and Chalmers. Thomas Svensson has the main responsibility for Magnus Karlsson and Pär Johannesson for Gwenaëlle Genet. Both recruitments and the support by Volvo Trucks and PSA are results of the joint strength of FCC and Chalmers.

Visitors

Professor Igor Rychlik, Lund works part time in the group and Dr Ulla Machado has had a post doc position jointly supported by FCC and Chalmers. Furthermore, Bettie Joossens from the Catholic University in Leuven does par of her PhD project here.

The Statistical Fatigue Research Group

The statistical fatigue research group do consulting and perform research tasks, especially for the engineering industry. The group consists of

- Thomas Svensson, PhD, mainly working on variable amplitude fatigue, measurement uncertainty, and statistical methods in engineering
- Pär Johannesson, PhD, mainly working on modelling of fatigue loads, rainflowcount analysis, and reliability in engineering
- Magnus Karlsson, RD student, visual description of road environment of trucks, independent of vehicle and driver
- Jacques de Méé, Professor in mathematical statistics at Chalmers, scientific advisor at FCC

Extrapolation of a rainflow matrix. Vertical forces on the front wheel of a prototype car from PSA Peugeot Citroën. The loads from one lap on the test track is summarised in the rainflow matrix (blue lines). The load properties of the intended design life are estimated, giving the limiting rainflow matrix (red lines). The iso-lines enclose 10%, 50%, 90%, 99%, 99.99%, respectively, of the load cycles. The picture is taken from (Johannesson et al, 2002).
General
The area of industrial applications of optimization is very broad. Optimization problems arise as stand-alone problems in many contexts, and optimization is used in a large variety of fields in applied mathematics and natural, economical and technical sciences in order to model, solve and analyze (sub)systems. Twenty years ago, it has been said, linear programming was the scientific problem that ate the most computing power; optimization continues to have a large appetite.

The optimization group at FCC is small but is anticipated to grow, both because of more industrial contracts and, not the least important, because more and more applied projects at FCC will need efficient large-scale optimization.

Engineering Optimization
In engineering optimization, it is quite often the case that the objective value is a measure of the performance of a system which is described in terms of a simulation. The variables in the optimization problem correspond to design parameters that are used as input to the simulation, which may be in the form of a PDE/ODE system. For some simple such models, explicit (or numerical) derivatives of the "responses" (that is, the result of the simulation as a function of the parameter values) are possible to obtain, but they are usually not explicitly given as output from the simulation. Since derivative information is beneficial for a successful optimization, a long term goal of the research at Chalmers and FCC is the development of a toolbox in engineering optimization, which will integrate the simulation and optimization through the calculation of derivative information.

Logistics
The potential for optimization of resources in the area of logistics is huge. Through the West Sweden Chamber of Commerce and Industry we have received an indication of several branches where the introduction of planning tools utilizing optimization would lead to a potentially large increase in efficiency and profitability. Examples are people’s transportation, refuse collection and transportation of fragile products.

Some projects
Efficient Recruitment and Supervision of Subjects for Large Clinical Trials
From a pool of candidates one wishes to extract a sufficiently large patient population fulfilling prespecified properties, such as distribution of sex, (non)hypertension, etc. Each candidate undergoes a series of screenings where it is decided whether or not he/she may be enrolled in the patient population. The costs generated by the recruitment process consist of direct personal and material costs, the time between the first and last enrolment of patients and also ethical aspects; the aim is to minimize a weighted sum of costs. A mathematical network flow model simulates the flow of subjects in the recruitment process and compares the costs for different strategies for achieving desired properties of the population of patients enrolled.

Optimization of Power Systems under Uncertainty
The recent deregulation of the power market has led to a new situation for the power producers which necessitates the development of new planning and decision tools, incorporating management of portfolios of energy contracts, among others. This project focuses on seasonal planning of a power system with hydro and thermal power generation, and sales and purchase of power. It considers a time horizon of 1 - 1.5 years, with a time resolution of one week. The stochasticity of the reservoir inflows, the spot price of electricity, and the demand for electric power all have a large impact on the decision model at this time scale, and is therefore explicitly modelled.
The purpose of the project is to develop a tool for decision-making in power systems planning under uncertainty; this tool will yield an increased understanding of the effects of uncertainty in the inflows on the water release policies, and of connections to power prices and the pricing of energy contracts.

The optimization model that results from the problem definition is a multi-stage stochastic program defined on a scenario tree, which represents an approximation of the possible outcomes of the uncertain parameters during each week of the planning period.

The resulting large-scale optimization problem calls for advanced decomposition methods and high-performance computing. The optimization techniques employed are based on nested Benders decomposition, which attempts to partition the model into one planning problem for each week and scenario. These problems are, however, linked through balance constraints for the water and energy systems and for the contract portfolios. In order to receive a model that is computationally manageable the scenario tree is reduced using probability metrics.

The project runs from May 2002 until April 2004 and is a joint project between Optimization Partner Stockholm AB, the Department of Mathematical Statistics at Lund Institute of Technology, and FCC. The project is financed by STEM (the Swedish Energy Agency), and the industrial partners Elforsk, Fortum Power and Heat OY, STM Research, and Sydkraft.

PhD projects
Two PhD students have received co-advisement from FCC: Niclas Andréasson (Cost effective motor maintenance) and Fredrik Altenstedt (Asset liability management).

The Optimization Research Group
- Ann-Britt Strömberg, PhD, mainly working on combinatorial optimization and optimization under uncertainty
- Michael Patriksson, Professor of applied mathematics at Chalmers, scientific adviser at FCC
General

Sensitive product and production concepts often result in quality problems with delays in market introductions and lost revenue as a consequence. The opportunity to simulate and visualize variation and tolerance results, combined with tools for diagnosis are important success factors to improve quality. Less variation in products and processes gives a substantial return on investments in form of lower costs for adjustment, rejects and claims. Furthermore, since quality is one of the most important customer decision factors, employing quality as a part of the business strategy is highly motivated. This challenge, to produce high-quality products to low cost and with short lead-times, has increased the focus on quality engineering over the last decade.

Most organizations find it difficult to provide products without quality flaws, since manufacturing imperfections cause variability between different units of the same product. Additionally, during the expected life span of the product, deterioration and variability in environmental variables will cause variability in the product performance. A modern quality program aimed towards reducing variability provides tools for robust design and statistical process control combined with methods for diagnosis.

Quality engineering encapsulates all activities striving towards improved quality, including a number of areas and disciplines. Since mathematics is the most versatile of all sciences, it is uniquely well placed to contribute in all individual areas of quality engineering. Also, since a number of design tasks today are multidisciplinary in its character, including a large number of parameters, mathematics plays a critical role in the area of multidisciplinary optimization.

FCC operates to support a systematic reduction of variability in processes and products in the following key areas:

- Robust design
- Inspection planning optimization
- Process control and diagnosis
- Root cause analysis

Some projects

3D Tolerance Management

The project 3D TM within the Nutek's program “IT i verkningsindustri” started in 1997. The project is run by Wingquist Laboratory at Chalmers, IVF Industrial Research and Development Corporation, FCC, and Volvo Car Corporation.

The aim of the project is to reduce geometrical variation in assembled product in the automotive industry and others. In particular, geometrical variation in the structural frame of an auto body, body in white, causes quality problems in the final products such as wind noise, water leakage, door closing effort, gap and flush variation. The three focus areas, illustrated in the figure below, are: (I) robust design and variation simulation, (II) inspection planning and analysis, and (III) assembly diagnosis. The project combines advanced research with implementations in industrial environments.

The research group comprises the project manager Professor R. Söderberg and Dr L. Lindkvist from the Product and production development department at Chalmers, Dr J S Carlson from FCC, MSc F Wandeback and MSc P. Wahlborg from IVF.

Robust design and variation simulation: 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.

SPC and assembly root cause analysis: 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.

Inspection planning and 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.

The geometry assurance process.
Evaluation: The project has earned the highest rating by the British evaluation institute Technopolis. The Technopolis states that: “The 3D TM project is one of the most impressive, successful and well-managed in the whole program. The project has worked with scientific rigor and producing very applicable results at the difficult boundary between university and industrial research, making an important contribution both to engineering science and to industrial practice.”

Measurement System Analysis
Today, all subcontractors of the automotive industry are assumed to have implemented the quality management system QS 9000. An important part of QS 9000 is the Measurement system analysis which quantifies the capability of a measurement system. The aim of this project is to adopt and develop the analysis manual to CADCAM based measurement systems and its equipment, when using coordinate measurement machines.

Path Planning for Rigid Bodies and Industrial Robots
Path planning for industrial robots aims at automatically finding collision-free paths for robots, from the initial to the final configuration, minimizing cycle time, path length and joint wear. Visualization and simulation of assembly processes is also an area were the needs for automatic path planning is increasing with higher demands on reduced start-up times. Especially, path planning under non-nominal conditions is a future challenge where mathematics is considered to play a key role.

Simulation: Rapid and objective assembly simulations results in unbiased estimates for assembly sequencing and simplifies visualization.

Off-line programming: Automatic via-point generation and optimization eliminates tedious off-line programming and updates caused by design changes.

The Quality Engineering Research Group
- Johan Carlson, BD, Vice Director FCC
- Robert Bohlin, BD
- Rikard Söderberg, Professor, Director Wingquist Laboratoriet, scientific adviser FCC
General
The FCC research in this area focuses on the development of mathematical methods and algorithms in the following fields:
- Signal and image analysis
- Finance and insurance mathematics
- Bioinformatics and biostatistics

Signal and Image Analysis
Focus is on the modelling and analysis of signals and images, e.g.,
- Detecting the presence of an object or phenomenon in the signal
- Classification of a signal or objects in an image
- Enhancement, i.e., supressing unwanted features in the signal while keeping others intact or even strengthening them
- Compression, i.e., reducing the data size of the signal, usually to the price of losing some information
- Systems parameter identification

Finance and Insurance Mathematics
Focus has been on the pricing of financial derivatives.

Bioinformatics and Biostatistics
Bioinformatics is a brand new discipline striving towards the seamless integration of genetics, mathematics, statistics and computer science. From the sequencing of the DNA to the development of a new drug or therapeutic method there is a long way, and efficient bioinformatics is crucial in each step. It involves research, development and application of computational tools and approaches to expand the use of biological, medical, behavioral and health data, including retrieving, storing, organizing, analyzing and visualizing such data.

Some projects

DNA Microarray Images
Microarray techniques have become increasingly important to analyze the expression of genes in cells, to measure which genes are active in a certain tissue, and to what extent. This information could give new insight into the underlying mechanisms of a disease, and propose new ways of treatment.

On a microarray chip, thousands of genes are tested simultaneously, each test occupying a small rectangular area. The activity of each gene is measured using fluorescent technique and a CCD camera, resulting in an image where active genes will appear as bright rectangles and inactive genes as dark.

The genes are spread out in a random (but known) manor. A non-defect image will then appear as white noise.

Sometimes regions of increased or decreased intensity appear, probably artifacts generated by the experiment. These may cover several test elements, and may therefore, if not accounted for, obscure the true outcome of the experiment. It is therefore of vital importance to be able to recognize, and exclude, such areas in the image.

Today, detection of artifacts is done by visual inspection, which is both time-consuming and subjective.

In this project with AstraZeneca, FCC has developed an automatic algorithm to detect artifacts and has successfully evaluated it on a number of test images.

The Signal and Image Research Group
- Fredrik Ekstedt, Lic
- Tomas Gustavsson, Professor, scientific adviser FCC
**Option Pricing**

FCC, financed by Front Capital Systems and STM Research, coordinates a PhD project in option pricing at Chalmers. The project is carried out by MSc Eng Per Hörfelt under the supervision of Professor Christer Boell.

**SSF project in Bioinformatics**

The Swedish Foundation for Strategic Research finances a project at FCC along the same lines as in the programme "Future Scientific Leader". Project leader is Dr Marina Alexandersson. She joined FCC in September 2002 to build a group in bioinformatics.

A great interest is anticipated from the biotech industry for both direct aid in analysing their data as well as in developing software products. Important research areas include:

*Computational sequence analysis:* The sequencing of a genome provides the foundation for genetics and bioinformatics, but a far more difficult phase is to understand cellular biochemistry and mechanisms of disease. The first step is to organize, classify and parse the immense amount of sequence data. Computational sequence analysis methods include sequence alignment and profile searches, analysis and coordination of EST libraries, identification of functional elements such as genes and regulatory regions, identification of analysis of mutational processes, homology searches and phylogenetic inference.

*Functional genomics:* Although the most reliable way of determining the function of a gene is by direct experiments, this is often very difficult. An enticing approach would therefore be to computationally infer biological function from sequence alone. Functional genomics is characterized by experimental methodologies combined with statistical and computational analysis, and involves assessing structure and function from the primary sequence structure of the genes.

*Proteomics:* To create a drug for a disease a target has to be identified. For this we need to know what forms a protein can take, what other proteins it concurs with, and what pathways it is involved in. Proteomics and functional genomics involves the identification, characterization and quantification of proteins involved in certain pathways, cells, tissues or organs, and will have a major impact on the future development of clinical diagnostics and pharmaceutical therapeutics.

*Biostatistics and statistical genetics:* At this point bioinformatics adjoins the fields of biostatistics and statistical genetics. Both areas study individuals with respect to their disease status and genotypic status, and aim at inferring which genes are involved in the development of a disease, and in other interesting features such as for instance in the severity of the disease, in the age of onset for the disease or in the visual of the affected individual.

**The Bioinformatics Research Group**

- Marina Alexandersson, PhD, research leader
- Dragi Anevski, PhD, from January 2003
- Sofia Andersson, PhD, from February 2003
- Sture Holm, Professor em., scientific adviser FCC

Statistical genetics treat both quantitative and qualitative phenotypic measurements in individuals, and aim at pinpointing the position in the human (or other species) genome where there are genes affecting the disease. Interaction of genetic effects with environmental factors is of a particular interest.

Biostatistics and in particular survival analysis is involved with discovering genetic and environmental effects on the life length of individuals or in the age at onset for diseases.
### Arsredovisning

**for tiden 1 juli 2001 - 31 december 2002**

<table>
<thead>
<tr>
<th>Resultaträkning 2001-2002 (kSEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intakter</strong></td>
</tr>
<tr>
<td>Erhållen basfinansiering</td>
</tr>
<tr>
<td>Fsg tjänster - ind proj</td>
</tr>
<tr>
<td>Fsg tjänster - publ proj</td>
</tr>
<tr>
<td>Fsg tjänster - EU proj</td>
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<tr>
<td>Övriga intakter</td>
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<tr>
<td><strong>Summa intakter</strong></td>
</tr>
<tr>
<td><strong>Kostnader</strong></td>
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<tr>
<td>Personalkostnader</td>
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<td>Konsulter</td>
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<td>Lokaler</td>
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<tr>
<td>Kontorskostnader</td>
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<td>Resor och representation</td>
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<tr>
<td>Avskrivningar</td>
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<tr>
<td>plan inventarier</td>
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<tr>
<td><strong>Summa kostnader</strong></td>
</tr>
<tr>
<td><strong>Rørelseresultat</strong></td>
</tr>
<tr>
<td>Resultat från finansiella</td>
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<tr>
<td>investeringar</td>
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<td>Räntaintakter och liknande</td>
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**Balansräkning (kSEK) 010701-021231**

<table>
<thead>
<tr>
<th>Anläggningsstillgångar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventarier</td>
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<td>Övriga fordringar</td>
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<td>Forutbetalda kostnader</td>
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<td>och upplupna intakter</td>
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<tr>
<th>Eget kapital och skulder</th>
</tr>
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<tr>
<td>Balancerat resultat</td>
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<tr>
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<td>Upploppa kostnader</td>
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**SUMMA SKULDER OCH EGET KAPITAL**

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<th>Summa skulder och eget kapital</th>
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<td>5 681</td>
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Uppbyggnaden av verksamheten har i stort sett haft ensidigt och tillsätt för Chalmers och Fraunhoferföreningets beslut att bilda stiftelsen.
FORVALTNINGSBERATTELSE

Stiftelsen Fraunhofer-Chalmers centrum för industrimatematik skall utveckla och anpassa matematiska metoder för industriinfödelsen bedriver konkurrensneutral forskning med basfinansiering från under- darna och genomför projekt definierade av företag och offentliga finansiärer på commerciell grund.

Rörelsens intäker har uppgått till 16 226 kSEK. Detta utgör 45% basfinansiering, 35% industriprojekt, 17% offentliga projekt, 2% EU-projekt och 1% övrigt.


Stiftelsens styrelse har under årsombudsmannets sammanträde fem gånger. Beslutet har utgått till föranden med 4500 kronor per möte och till övriga ledamöter med 2250 kronor per möte värda.

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

Göteborg den 7 mars 2003

Peter Jagers, ordförande
Jon Bergh
Helmut Neunzert, vice ordförande
Dieter Pratze-Wolters
Gunnar Andersson, adjungerad
Tomas Lefvert, adjungerad
Lars-Goran Lowenadler, adjungerad

Result (kEUR) 2001-2002

<table>
<thead>
<tr>
<th>Income</th>
<th>2001-2002</th>
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<tbody>
<tr>
<td>Basic funding</td>
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<tr>
<td>Projects - industry</td>
<td>617</td>
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<tr>
<td>Projects - public</td>
<td>299</td>
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<tr>
<td>Projects - EU</td>
<td>42</td>
</tr>
<tr>
<td>Others</td>
<td>24</td>
</tr>
<tr>
<td>Total income</td>
<td>1 771</td>
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</table>

Cost

| Staff             | -1 004    |
| Consultants       | -327      |
| Premises          | -192      |
| Office            | -113      |
| Travel and entertainment | -81     |
| Depreciations     | -54       |
| Total cost        | -1 771    |

Result of business

| Interest and similar income | 15       |
| Interest and similar cost   | -7       |
| Result including financial investments | 8       |

TOTAL RESULT 8

Balance (kEUR) 010701- 021231

| Fixed assets       | 28        |
| Computers          | 42        |
| Sum of fixed assets | 69       |

Current assets

| Cash              | 242       |
| Customer claims   | 237       |
| Other claims      | 1         |
| Prepaid costs and due income | 71     |
| Sum of current assets | 551     |

Total assets 620

Equity capital and debts

| Balanced result    | 0         |
| Result of the year | 8         |
| Total equity capital | 8       |

Long-time debts 100

Sum of long-time debts 100

Short-time debts

| Debts to supplies  | 181       |
| Other debts        | 43        |
| Due costs          | 288       |
| Sum of short-time debts | 512     |

SUM OF DEBTS AND EQUITY CAPITAL 620

Rakenskaperna har granskats av Deloitte & Touche.
Appendix

Presentations / Conferences

M. Alexandersson:
Bioinformatics, Chalmers, FCC inauguration
September 4, 2002.

M. Alexandersson:
Dynamic Programming Applied to Gene Finding and Alignment, Algorithms seminar;

M. Alexandersson:
Picking Alignments from Steiner Trees, Matematik Statistik, Chalmers, October 10, 2002.

M. Alexandersson:
Genetning och Dolda Markov-modal; Statistik inst, Orebro universitet, Orebro,
October 17, 2002.

M. Alexandersson:
Cross-species Gene Finding and Alignment with Generalized Pair Hidden Markov Models,
AstraZeneca, Molndal, November 18, 2002.

M. Alexandersson:
Cross-species Gene Finding and Alignment with Generalized Pair Hidden Markov Models,

J. S. Carlson:
Kvalitetsteknik-Geometrisaktning, kvalitetsgradering och Robotik, STM Annual meeting;

J. S. Carlson:
Mindre variation i sammansatta produkter;
Invited speaker to seminar on “Variation kostar”, Swedish Statistical Association,

J. S. Carlson:
Matematik som Teknologi, Vastsvenska Industri- och Handelskammaren, Goteborg,
October 18, 2002.

J. S. Carlson:
3D-Tolerance Management
Invited speaker to A Stochastic Network Seminar, Goteborg, November 12, 2001.

J. S. Carlson:
Diagnosis of Sources of Variation,
Invited lecture to Workshop on Reduced Geometrical Variation in all Stages arranged

J. S. Carlson:
Visit Engineering department at University of Michigan, Ann Harbour, USA, April, 2002.

J. S. Carlson:
Visit Ford Motor Company, Dear Born, USA,
April, 2002.

J. S. Carlson:
Visit GM, Detroit, USA, April, 2002.

J. S. Carlson:
ASME International Design Engineering Technical Conferences, Montreal, September
29, 2002.

P. Johansson:
Extrapolation and Scatter of Test Track Measurements, Presentation of paper at the Eight
International Fatigue Congress, Stockholm, June 2 - 6, 2002.

P. Johansson, T. Svensson, J. de Mare,
M. Karlsson:
Four presentations at the Fraunhofer institute
LBF, Darmstadt, Germany, November 29, 2002.

P. Johansson, J. de Mare:
Utmattning, belastning och tillforlitlighet,
Problem driven statistikkurs (a course in
statistics for Swedish industry), 4 half-days in
November 2002.

J. de Mare, T. Svensson:
Presentation of a glossary on the statistics of extremes and its application to inclusion ratings,
Meeting of the ESIS technical committee TC20, Milan, Italy, September 6, 2002.

M. Patriksson:

A-B. Stromberg:
Optimization of power systems under uncertainty for the board of STM, Goteborg, May
A-B Stromberg:
Optimization in logistics at the day of SME, West Sweden Chamber of Commerce and Industry. October 18, 2002.

T Svensson:
Crack closure dynamics for random load processes - a key issue for engineering fatigue, Invited lecture at the Sture Holm seminar, September, 2001.

T Svensson, P Johannesson, J de Mare:
Participating in Course Fatigue Design by Keith Miller; Sheffield, UK. Trollhattan, October 22 - 24, 2001.

T Svensson, P Johannesson, J de Mare:

T Svensson:
Crack closure at variable amplitude fatigue - a simplified approach, presentation of paper at the Eight International Fatigue Congress, Stockholm, June 2 - 6, 2002.

T Svensson, P Johannesson:

T Svensson:
Invited lecture on fatigue limit estimation procedures at AB Volvo Trucks, Goteborg, September 17, 2002.

T Svensson, J de Mare:
Participating in Course Material Science for fatigue and fatigue life prediction by Reinhard Pippan, University of Leoben, Austria. Trollhattan, October 21 - 23, 2002.

T Svensson, J de Mare:

T Svensson:
One lecture on measurement uncertainty and two lectures on measurement system analysis at a course about measurement systems for Swedish industry arranged by SP, Boras, November 19 - 20, 2002.

T Svensson:
Invited lecture on quality engineering at AB Sandvik Steel, Sandviken, November 27, 2002.

Publications

M Alexandersson:

R Bergstrom:

R Bergstrom, MG Larson:

R Bergstrom, MG Larson:

J S Carlson and R Soderberg:
Assembly Root Cause Analysis: A Way to Reduce Dimensional Variation in Assembled Products. Accepted for publication in IFIPS Special Issue on Quality and Reliability: Modeling and Analysis for Complex Production Systems.

J S Carlson, R Soderberg and L Lindkvist:
Geometrical Inspection Point Reduction Based on Combined Cluster and Sensitivity Analysis. Accepted for publication in 2003 ASME International Mechanical Engineering Congress and Exposition November 16-21, 2002 Washington, DC.

L Lindkvist, R Soderberg and J S Carlson:

F Ekstedt:

M Gunther:
Parameter estimation in power network, FCC report 606-020625-102.

M Gunther, K Samuelsson, MG Larson:
Macroscopic properties of paper by micro-structural simulations, FCC report 203-020919-104.

P Johannesson, J-J Thomas:

P Johannesson:

P Johannesson, J-J Thomas, J de Mare:

L Belina, K Samuelsson, K Ahlander:

P Ingelstrom, T Rylander, K Samuelsson, A Bondeson:

YQ Liu, A Bondeson, R Bergstrom, C Johnson, MG Larson, K Samuelsson:

YQ Liu, A Bondeson, R Bergstrom, MG Larson, K Samuelsson:
Edge element computations of Eddy currents in laminated materials, accepted for publication by IEEE Trans Mag in 2003.
Appendix

P Heintz and K Samuelsson:

T Svensson:
Matosakerhet, FCC report 302-020816-103.

T Svensson:

T Svensson:
Cumulative fatigue damage taking the threshold into account, Fatigue Fracture of Engineering Materials Structures 25, pp. 871-876, 2002.

T Svensson:

PhD students advisement

J S Carlson adviser of Kristina Warmeford:
Inspection Data Feedback and Analysis, Saab Automobile AB.

T Svensson adviser; and P Johannesson
co-adviser of Magnus Karlsson:
Parametrisation of Vehicle Operating Environment, Chalmers.

T Svensson co-adviser of Johan Svensson:
Optimal planning of maintenance on air engines, Chalmers.

T Svensson co-adviser of Sara Loren:
Statistical aspects on fatigue limit, Chalmers.

T Svensson co-adviser of Jenny Andersson:
Crack growth in random grain structures, Chalmers.

A-B Stromberg co-adviser of Niclas Andreasson:
Optimization of aircraft engine maintenance, Chalmers.

A-B Stromberg co-adviser of Fredrik Altenstedt:
Asset-liability management via stochastic programming for a Swedish life insurance company (supported by Nordea Liv), Chalmers.

A-B Stromberg co-adviser of Roger Hallin:
Scenario trees for inflow modelling in stochastic optimisation for energy planning, Lund University.

Masters thesis advisement

M Alexandersson co-adviser of Erik Hemberg and Joel Eriksson:
On optimal evolutionary distance for comparative gene finding, Chalmers.

J S Carlson supervisor of Ulrika Larsson:

J S Carlson supervisor of Martin Lorentsson:

J S Carlson supervisor of Johan Svensson:
Kvalitetsstyrsing och diagnos av geometriska variation i sammansättningssystem Saab Automobile AB, November 2001.

P Johannesson adviser of Carl-Eric Strengell:
A Survey of Experimental Design with Applications, Chalmers.

K Samuelsson adviser of Henrik Sandstrom and Mattias Shamlo:
Development of ADRIAN Joint Analysis Software, Chalmers and Volvo Cars.

T Svensson co-adviser of Per Kalling and Anders Karlstrom:
Statistical Approach to Fatigue Life Prediction of Spot Welds, Chalmers and Volvo Cars.

A-B Stromberg adviser of Cecilia Hansryd:
Integrated solution of two crew scheduling problems, Chalmers.

A-B Stromberg adviser of Anna Svanberg:
Improving lower bounds for winter road maintenance problems, Chalmers.

Other assignments

J S Carlson:
Reviewer for IEEE Transactions on Robotics & Automation.

J S Carlson:
Reviewer for ASME Journal of Manufacturing Engineering.

J S Carlson:
Reviewer for IIE Transactions.

PhD students Kristina Warmeford (advised by J Carlson and partly financed by FCC), Niclas Andreasson (co-advised by A-B Stromberg, FCC), Johan Svensson (co-advised by T Svensson, FCC), Magnus Karlsson (advised by T Svensson, FCC), and Per Horfelt (partly financed by FCC).
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-TWM in Kaiserslautern, shall be a leading partner for international industry and academia to mathematically model, analyse, simulate, optimize, and visualize phenomena and complex systems in industry and science, to make development of products and processes more efficient and secure their technological and financial quality.