Computational Mathematical Modelling: Chalmers Finite Element Center

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Research Programme

Introduction and overview

Computer-based modelling and simulation today offer new tools to science and technology in a process of *automatization of computation* complementing that of automatization of production behind the industrial society. Products may be developed and manufactured through computer simulation on time scales and at costs considerably smaller than using traditional techniques, and computational modelling is rapidly finding new applications in medicine, environmental sciences, economy and finance markets. At the heart of the new simulation techniques lie fields of Computational Mathematical Modelling CMM such as Computational Mechanics, Physics, Fluid Dynamics, Electromagnetics, Chemistry, Biology, Economy and Finance, all based on computational solution of systems of differential equations, combined with geometric modelling/CAD. The new technology of CMM crosses borders between traditional scientific and engineering disciplines, and is stimulating basic changes in both research, technical development and education.

Chalmers Finite Element Center Φ is an interdisciplinary unit at Chalmers formed in 1997 with SSF-support, joining forces of the groups of the proposers including Computational Mathematics (Johnson, Larson, Larsson), Solid and Structural Mechanics (Runesson and Wiberg) and Electromagnetics (Bondeson), with the goal of tackling central problems in CMM. Φ continues the strong tradition at Chalmers in the development and application of the finite element method as a general technique for the computational solution of differential equations, with focus on *adaptivity* with feed-back from computation to reach goals of *optimization* concerning both solution, modelling and computation. Φ conducts interdisciplinary research in CMM including a variety of academic and industrial cooperative efforts.

Φ has developed a new educational program in CMM from basic to graduate level, including a reformed mathematics education which is in operation since 2001 for all students of Chemical Engineering at Chalmers [9]. The interdisciplinary nature of the educational program is further exploited in cooperation with the School of Chemical Engineering in the pedagogical project "Integration of Mathematics, Chemistry, and Chemical Engineering", which is the largest project funded within Chalmers Strategic Effort on Learning and Teaching C-SELT.

Φ is hosted by the new Department of Computational Mathematics (within the School of Mathematical Sciences), which was formed 2002-01-01 around the applied mathematics group behind Φ (Johnson-Larson-Larsson). Φ enjoys a 3 year grant of 2 mkr/year 2001-03 from the Chalmers Foundation showing the strong support to Φ from the President of Chalmers.

Φ cooperates closely with the new *Fraunhofer-Chalmers Research Centre for Industrial Mathematics*, where M. Larson serves as a scientific advisor, e.g. through joint participation in the EU-program *Visicade* (K. Samuelsson, O. Tullberg). Cooperation with the new *Center for Process Engineering CPE* at Chalmers is being developed, with momentum from both education and research.

The present proposal concerns the continuation and further development of Φ, where support from SSF is as important as in the formation in 1997. Φ plays a crucial role for the new Department of Computational Mathematics and the group of Computational Electromagnetics, and is of vital importance for Solid/Structural Mechanics. The mid-term evaluation of the SSF/NTM-program was very positive to Φ.

We now present topics of focused research starting with general aspects of finite element solvers and continuing with different specific applications. We emphasize the generality of the computational mathematical methodology and unity of approach for a wide range of applications, and the related necessity and effectiveness of a close cooperation between researchers with basis in mathematics and engineering science. The research topics belong to the fore-front of international research and play a central role for the groups involved.

We formulate our GOAL as automatization of CMM with respect to the key features of (i) modelling, (ii) discretization, (iii) meshing/error control, (iv) algebraic solution and (v) optimization.

We have shown that stabilized Galerkin finite element methods offer solutions to (ii), goal-oriented a posteriori error estimation through duality offers solutions to (iii), multigrid and GMRES offers solutions to (iv), gradient and quasi-Newton methods combined with duality offer solutions to (v), and we have done preliminary work on (i), indicating in particular that (i) may be given fresh attacks once (ii)-(iv) are handled. Altogether, (i)-(v) are coupled and **our over-all GOAL is to optimize and automatize the coupled process (i)-(v)**. To reach our GOAL we have to develop **methods** and **algorithms** including implementation in **computer codes**.

This proposal concerns the further development of (ii)-(v) following lines of our previous research, and the new topic of *computational modelling* focusing on (i). We propose work on both basic mathematical aspects and different key applications in fluid/solid mechanics, electromagnetics and chemical engineering. The proposed projects will generally engage researchers with both mathematics and electromagnetics/mechanics/chemics background, as is made clear in the Project organization below. For web information on Φ and the groups involved, we refer to `www.phi.chalmers.se`, including preprints and a list of publications, `www.math.chalmers/cm`, `www.am.chalmers.se`, `www.sm.chalmers.se`, `www.elmagn.chalmers.se/elmagn/CEMgroup`.

Research Topics

A. Basic Tools of Adaptive Finite Elements

We have developed a general methodology for computational solution of differential equations based on stabilized space-time, continuous/discontinuos Galerkin finite element methods, including goal-oriented a posteriori error estimation through duality, GMRES/multigrid algebraic solvers, adaptive mesh generation, and coupling of mesh generation to CAD. Multi-scale computations on a hierarchy of meshes play an important role in both adaptivity and algebraic solvers. We propose further work on the crucial topics of software, multi-scale/subgrid modelling and optimization/identification, common to specific applications presented below:

A1. Software

We have invested considerable effort over the years (Levenstam/Samuelsson) to develop a software platform on the basis of our general methodology, which is now being materialized as the GNU-GPL licensed modular C++ adaptive solver DOLFIN (Dynamic Object-oriented Library for FINite Elements) by Hoffman/Logg available at www.phi.chalmers.se/dolfin. In particular, DOLFIN presents solutions to (i)-(iv), and thus in particular automatically generates codes for execution from differential equation input. We thus now have a software platform for frontline 3d simulations of complex systems and a very rich field of applications lies open. We propose further work on various aspects of DOLFIN including library of elements, adaptive selection of stabilization parameters, adaptive meshing, adaptive algebraic solvers, and coupling to pre/post processors Visicade (our EU-project) and GID (through our cooperation with CIMNE/Barcelona). Our goal is to develop DOLFIN into useful tool for research and education, and we have the necessary technology and man-power for this purpose.

A2. Multi-scale/subgrid modelling

A basic challenge in computational mathematical modelling concerns problems with subgrid (small scale) features, for which direct numerical simulation is computationally too costly, and subgrid modelling is necessary. An outstanding problem of this nature is turbulence modelling, se below, but the need for subgrid modelling arises in many important applications. A common problem is to estimate the quality of different subgrid models, which fits into our general framework of a posteriori error estimation through duality including errors from both computation and (subgrid)-modelling. Thus, by solving a linearized dual problem we may get information on computational errors from computational residuals and modelling errors from modelling residuals. We have in recent work shown that solving dual problems for 3d time-dependent problems is feasible, and thus our general methodology of a posteriori error estimation is applicable to complex problems. In particular, we expect to be able to predict subgrid modelling errors, where the subgrid modelling residuals are obtained by extrapolation from coarser scales with fine scale solutions as reference. This opens the possibility of automatically comparing the quality of different subgrid models, with corresponding automatic choice of a best model in a specific application. This is one of the two central problems of subgrid modelling, the other being the design of subgrid models. In both cases multi-scale computation using a hierarchy of different scales will play an important role, which fits into our general methodology. We thus seek methods to automatize subgrid modelling, where there will always be room for innovations in the design of subgrid models. We return to different specific applications below. We also propose to work on *model reduction* connecting to subgrid modelling, with now the objective of finding a coarse grid approximate model capturing certain gross features as well as possible.

A3. Optimization and Identification

We consider optimization problems where the solution $(u, \lambda, p) \in V$, with u the *state*, λ the *costate* and p the *control*, is characterized as a saddle point of a Lagrangian $L(u, \lambda, p)$, or a *stationary point* satisfying

$$L'(u, \lambda, p)(v, \mu, q) = 0 \quad \text{for all } (v, \mu, q) \in V, \tag{1}$$

with L' the gradient of L and V a space of functions, corresponding to an *equation of state*, an *adjoint equation of costate*, and an equation expressing that the gradient with respect to the control vanishes. The problem (1) is extremely rich and includes both problems of optimal design and inverse problems, some of which are addressed below.

To solve (1) we use a Galerkin method to discretize in space-time and we use an optimization algorithm to compute a corresponding optimum (iterative method to solve (1)). We let h be a parameter defining the space-time discretization and and α an optimization parameter such as the a step length in a gradient method. In inverse problems we may also need to regularize and let ϵ be a regularization parameter. Altogether, we need to determine the parameters h, ϵ, and α as function of space-time during the computation. Following our general adaptive philosophy, we should determine these parameters from adaptive feed-back from the computation with the goal of finding the best combination to optimize the whole computational process. We propose to extend our a posteriori error estimation for adaptive determination of h to include as well α and ϵ. A main idea is thus to couple the adaptivity in h and ϵ to the optimization in α. For example, initiating optimization of the control p on coarse grids enable efficient global optimization, followed by local detailed optimization on the fine final mesh. In our full perspective, we also include adaptive selection of stabilization and modelling parameters.

B. Inverse Problems and Optimal design

B1. Inverse scattering

We have developed an adaptive finite element solver for 3d inverse scattering problems, where we reconstruct the location and geometry of unknown objects from measurements over time of scattered acoustic waves [1]. We couple automatic mesh adaptivity, with refinement of an unstructured mesh around the scatterer using a uniform mesh in the surrounding medium to improve efficiency, with optimization using gradient and quasi-Newton methods. This is an important basic type of problem arising in nondestructive testing of materials, ultrasound imaging, seismics and many other areas. We propose further work applying our inverse scattering solver to demanding concrete problems, partly in cooperation with the Dept. of Applied Mechanics (J. Niklasson). The coupling of mesh adaptivity to optimization opens a rich field of research. In particular we propose a study on the use of focusing waves to increase the information carried by the scattered wave. We also propose extension to electromagnetic waves.

B2. Reconstruction of source data

We propose to apply our adaptive solvers to elliptic reconstruction problems connected to Electrocardiograms (ECG) and Electroencephalograms (EEG), which give information of the electric activity of the heart or brain from noninvasive measurements on the chest or scalp. Mathematically, this involves computing a source (e.g. dipole) in a 3d Poisson type problem from measured boundary data of electric potentials and geometric information obtained by scanning. We propose to tackle this type of problem (which involves complex 3d geometry and adaptive meshing) with the indicated combination of (a) adaptivity, (o) optimization and (r) regularization.

B3. Inverse diffusion

We propose a study of the basic inverse problem of the backward heat equation where the objective is to determine an initial temperature from measurements of a final temperature, which arises in image restoration, geology, and oceanography. Again, the objective is to improve the efficiency by a systematic coupling of (a), (o) and (r) with key focus on the interplay between (a) and (r).

B4. Optimal design

We propose to apply our general methodology to optimal design problems of linear elasticity with the objective of determining material coefficients, shape, and topology to reach optimal performance described by some cost function (e.g. maximal stiffness). This topic couples to our VR-project joint with Applied Mechanics on Biomechanics. We also propose a study of optimal design of MEMS structures in cooperation with Imego, see `www.imego.com`. Our ongoing work on optimal design is presented in [10].

C. Computational Fluid Dynamics/Turbulence/Reactive Flow

We have developed (using DOLFIN) an adaptive solver for 3d transient incompressible flow including a posteriori error estimation through duality [6]. Our work shows in particular that a posteriori error control through duality is feasible also for complex 3d transient problems. We are now applying this solver to a variety of complex flows including studies of the basic problem of *transition to turbulence* in parallel flow. We are also tackling the the out-standing multi-scale/subgrid modelling challenge of *turbulence modelling*, which is the problem of modelling the *Reynold's stresses* $R^h_{ij}(u) = u^h_i u^h_j - (u_i u_j)^h$, where u_i is the true velocity in the x_i-direction, and u^h_i an average of u_i over a scale h, or rather the corresponding forcing term $F^h_i(u) = \sum_j \frac{\partial}{\partial x_j} R^h_{ij}(u)$ The Reynold's stresses have the form of *h-covariances* and represent the influence on the scale h of scales finer than h (subgrid scales). In *Dynamic Large Eddy Simulation* DLES one seeks to model $R^h_{ij}(u)$ or $F^h_i(u)$ with feed back from computations resolving as many scales as possible. The basic models of DLES are turbulent viscosity models and scale similarity models, or combinations thereof.

C1. DNS of complex flows/transition to turbulence

We have computed the basic problem of transition from laminar to turbulent flow in 3d Couette and Poiseuille flow using Direct Numerical Simulation DNS (resolving all flow features without turbulence model) [7]. We have also developed a reduced ode-model for transition, including basic features of the transition process such as the Taylor-Görtler mechanism. We propose further work with a more detailed study of the transition process (finer mesh) with extensions to boundary layer flow. This work is essential for the study of turbulence modelling, since after transition we have a "real" turbulent flow, which we can subject to analysis, and which has not been artificially induced by introducing significant "turbulent noise" in inflow or forcing.

C2. Turbulence modelling

We have implemented DLES models in our flow solver, using in particular similarity models to directly model the individual forcing terms $F_i^h(u)$ (or Reynold's stress terms $R_{ij}^h(u)$). We have in earlier work tested such subgrid models for a variety of convection-diffusion-reaction problems with promising results [5]. In a similarity model we extrapolate an approximation $\hat{F}_i^h(u_h)$ of $F_i^h(u)$ from computations of $F_i^{2h}(u_h)$ and $F_i^{4h}(u_h)$, where u_h is a computed solution with mesh size h. We seek to estimate the modelling residual, that is, the error in $F_i^h(u) - \hat{F}_i^h(u_h)$ by extrapolation from an approximation of the corresponding error with mesh size $2h$ of the form $F_i^{2h}(u_h) - \hat{F}_i^{2h}(u_{2h})$. The basic idea here is thus to extrapolate the modelling error residual from coarser scales with finest-scale computations as reference.

We propose to continue our work on turbulence modelling implementing in particular *mixed models* combining selective Smagorinsky-type artificial viscosity models and similarity model based on extrapolation. With a mixed method we may model back-scattering (energy flow from small to large eddies) through the similarity model, and monitor dissipation avoiding excessive damping on coarser scales using a Smagorinsky-type viscosity operating on high-frequency components only. We propose to computationally estimate the modelling residuals by extrapolation as indicated, and then the modelling error by duality, with the objective of comparing models and finding a best model in a specific problem.

We are well positioned with all the necessary ingredients available (solvers, adaptive methods, subgrid models, personnel), to tackle a central problem in science and engineering.

C3. Computational Chemical Engineering/Reactive Flow

We propose extension to turbulent reactive flow in cooperation with our partners in CPE. This is a very rich field of research and application with the challenge of modelling h-covariances of convective terms of the form $\nabla \cdot (cu)$, with c a species concentration and u a flow velocity, or reactive terms in the form of products of factors c^α with c a concentration and α a stochiometric coefficient. We will follow the main direction given above of subgrid modelling of 3d turbulent flow using a combination of artificial viscosity and similarity models with computational estimation of modelling errors as indicated. Preliminary work is done in [5].

D. Computational Electromagnetics CEM

CEM has developed rapidly over the last 15 years with today a variety of applications ranging from optical and microwave components, antennas and microelectronic circuits, to electrical machines and generators EMC and electromagnetic detection. The main challenges concern accurate and efficient computation of electrically large systems with complex 3d geometry, such as machines and generators, complex circuit boards, or the radar cross section of an entire airplane.

We have developed the first stable time-domain hybrid method combining the FDTD (Finite-Difference Time-Domain) on a structured part of the mesh, with finite elements on an unstructured part using edge elements on tetrahedrons [14, 15]. The hybrid combines the high efficiency of the FDTD in regions of open space, with the superior modelling of complex geometry offered by finite elements. We avoid instabilities present in earlier hybrids, without resorting to numerical dissipation, by viewing FDTD as a finite element method with edge elements on a hexahedral grid, lumped by trapezoidal integration, and using a layer of pyramids to couple the hexahedrons and tetrahedrons, and thus achieve a curl-conforming representation of the electric field. The algorithm has been implemented in a C++ code, which is now equipped with ports and mode solvers for arbitrarily shaped waveguides, a Huygens surface to launch plane waves, near-to-far-field transformation and absorbing boundary conditions (sponge layer). It has been extensively used in radar cross section calculations, and recently it has been applied to optimize microwave circuits. Negotiations are underway with the Swedish car industry and the Swedish National Testing and Research Institute to apply the hybrid solver to EMC problems in vehicles, e.g., to resolve a small antenna by finite elements together with a more coarse-grained FDTD model of the entire vehicle. Our hybrid algorithm has also been implemented elsewhere, for example, in the GEMS (General ElectroMagnetic Solver) project at PSCI (Parallel and Scientific Computing Institute at the Royal Institute of Technology and Uppsala University).

In an ongoing ABB-supported project concerning electrical generators, we have developed a highly efficient solver for eddy current problems [16]. We use edge elements and both scalar and magnetic vector potentials, with an "ungauged formulation", that strongly improves the convergence of iterative solvers, and mesh-adaptivity based on *a posteriori* error estimates using the grid generator developed by K. Samuelsson. We have found that hexahedral grids are better suited for eddy current problems involving thin layers of a skin depth. We also find significant advantages of hexahedral grids when the material properties are anisotropic.

We have also developed a least-squares solver for Maxwell's equations using nodal elements and successfully applied the solver to industrial problems within the ABB-cooperation, [11].

We participate in the project SMART (Signature Modelling And Reduction Tools) supported by Saab Avionics, with the task of developing optimization algorithms for minimizing a radar cross section. We follow our general strategy for optimization here applied to Maxwell's equations formulated in the frequency domain.

We propose the following topics of research continuing our earlier work:

D1. Adaptive methods for microwave and eddy current problems, Fast Multipole

We propose to develop an efficient *h*-*p* higher order adaptive solver for microwave and eddy current problems using edge elements on a combination of tetrahedral and hexahedral meshes to handle anisotropy, complex geometry and variable material properties. For eddy current problems we propose to implement a multigrid solver.

We propose to extend the solver to include subgrid models for thin wires and slots, which is needed for many EMC problems with small details, and study the accuracy of such models both theoretically and computationally. This project is strongly related to our VR-supported project in CEM.

We also propose to develop an integral equation solver using the fast multipole method (FMM) and related time-domain methods. Our experience from differential equation solvers for microwave problems indicates that time-domain solvers are more efficient than frequency domain solvers when broad frequency bands are involved. We expect the same to hold for integral equations.

D2. Optimization of electromagnetic devices

We propose to develop computational optimization in electromagnetics using the general methodology indicated above (gradient or quasi-Newton methods based on solving adjoint equations), which has been successfully applied for in particular problems of optimal shape or topology in solid mechanics, but so far has only rarely been used in electromagnetics. With such methods it should be possible to design e.g. antennas with prescribed radiation patterns and bandwidths, or microwave filters whose transmission coefficient are given functions of frequency, and many other devices with optimized features. The importance of this development for Swedish industry can be very high.

We are well positioned for developing optimization tools for electromagnetic design, e.g. with our hybrid code is a versatile tool for obtaining results over wide frequency bands, and we have preliminary results on shape optimization for Maxwell's equations. We collaborate with the Microelectronics at Chalmers on optimization of microwave components, with Saab Avionics which partly funds a graduate student (Y. Yang) on RCS optimization, and for low frequency problems with Chalmers Power Engineering and ABB.

D3. Micro Electro Mechanical Systems MEMS

MEMS are currently developed for applications in sensing and microelectronics. A few applications are mature (e.g., quartz watches and ink jet printers), but MEMS technology is only beginning to develop. There is very little software available to simulate the coupled processes in MEMS and we propose to contribute to fill this gap.

We thus propose to develop simulation tools for MEMS using our entire platform for electromagnetics/mechanics/mathematics. One graduate student (E. Svensson) is funded by Imego, `www.imego.se`, a research institute located on the Chalmers campus, developing MEMS products. We plan to initiate further cooperation with Imego.

E. Computational Solid and Structural Mechanics

Computational Mechanics at Φ includes research groups at Applied Mechanics at the School of Mechanical and Vehicular Engineering (Runesson, Hansbo), and Structural Mechanics at the School of Civil Engineering (Wiberg). The coupling to the applied mathematics group (Johnson) is strong and dates back to the 70s with the rapid development of the finite element method as a general mathematical technique from pioneering work in Structural Mechanics. The cooperation has kept Chalmers in a leading position in the world of finite elements, with a combined strength on both engineering and mathematical aspects.

The research covers a wide spectrum from material modelling to structures: We have developed constitutive models for large strain inelasticity [8], creep, damage and fracture [19]. Further we have developed adaptive computational methods for problems with localized failure and shear banding, using higher order continuum theory [20] (gradient theory and nonlocal theory) to model material micro structures. Current applications of high industrial significance concern high-temperature alloys, hard metals, stainless steel in ball-bearings, railway ballast, and railway steel in wheels and rail. Computational strategies for the fatigue life prediction of spot welds in car components, gas-turbine blades and railway components are under development. We have developed Arbitrary-Lagrangian-Eulerian (ALE) [4] techniques with application to fluid-structure interaction problems including large deflections and free fluid surfaces, with industrial applications to sloshing in fuel tanks. Another ongoing project concerns wave propagation along railway tracks.

We propose research on the following topics:

E1. Adaptive methods for nonlinear and time-dependent materials under large deformations

We propose to further develop our work on this topic with particular focus on the choice of relevant error measures of engineering significance such as the J-integral in fracture mechanics. We propose a similar study for coupled thermo-mechanical problem arising from impact loading, with an important technical application being the emerging manufacturing technology known as "cold forging". This subproject is part of a quite extensive collaborative effort between Chalmers and SKF.

We propose to develop our work in multiscale modelling of polycrystalline materials, in particular two-phase stainless steel, whereby the analysis of a Representative Volume Element (RVE) in 3D on the mesolevel is coupled to balance equations on the macroscopic level. The response of the RVE represents a homogenized macroscopic material response, thus avoiding an a priori explicit specification of a macroscopic constitutive model requiring elaborate calibration.

We also propose to further develop our modelling/computational work on gradient theory of (visco)plasticity to deal with size effects in material modelling such as those apparent from micro-hardness tests.

E2. Contact and fracture

We propose to develop new computational methods for problems of contact and fracture using Discontinuous Galerkin methods in space (following [3]) allowing slip and separation. Our interest will be focused on two types of contact: The first type is rolling contact with friction, with applications in railway mechanics. The second type of contact relates to the closing of macroscopic cracks under cyclic loading, whereby the crack surfaces come into contact and form an internal boundary. To develop robust adaptive finite element techniques for the modelling/computation of propagating cracks is of considerable engineering interest.

E3. Adaptive methods in dynamics

We propose to develop space-time continuous/discontinuous finite elements for nonlinear vibrating mechanical systems with adaptive error control of quantities of engineering interest such as amount of energy dissipation. An important application is wave propagation in connection with high speed trains on soft soil foundations creating shock waves.

Eigenvalue problems arise in, for example, vibration analysis, buckling analysis, and heat conduction, and there is a need for efficient solution techniques for large scale linear/nonlinear cases. We propose to develop adaptive methods for eigenvalue calculation and response simulation via mode superposition, based on suitable a posteriori error estimation, see [13].

E4. Coupled thermo-hydro-mechanical problems in porous media

Reliable computational methods for coupled thermo-hydro-mechanical behavior of a porous medium consisting of several phases are needed in civil engineering to make reliable life time predictions of roads, and railway structures. We propose to develop adaptive methods for such problems with full use of our arsenal of techniques. We also propose to further develop our work of level set methods for two-phase flow with sharp interfaces, allowing accurate tracking of interfaces on a fixed mesh.

E5. Biomechanics

We have recently initiated a research project on Computational Biomechanics based on support from a VR-grant. The project focuses on simulation of motion and dynamic load situations on various implants and prostheses, for instance, total knee or hip replacements, using an advanced finite element model. In particular, such computer simulations can be used to improve design and performance of the prostheses, leading to improved quality of life for the patient and economical savings. Key aspects include modelling of material properties of bone, remodelling of bone under load, complex geometries, and optimization. Industrial contacts with Integrum, see `www.integrum.se`, has been established. We propose to support one graduate student in this area.

F. Computational Finance

This is a new booming area with strong connections to the numerical solution of (stochastic) differential equations. Φ is now supporting one graduate student (G. Foufas) in this area and we propose to develop our activity in this field in cooperation with the group of A. Szepessy at Nada/KTH.

Importance of proposed research for participating inst.

The Φ-cooperation on CMM has developed into a broad activity in both research and education of prime importance for all the groups involved. The SSF-support of Φ has been crucial and SSF-support will continue to be crucial in times when university funding is very sparse and resources for cooperative efforts are not given highest priority. Moreover, progress in the area of CMM today requires a a close cooperation of computational mathematics and sciences, for which the traditional department structure at Chalmers (and other universities) is not well suited. The need for an interdisciplinary unit in CMM is thus very clear, and Φ has an important mission to fill in both research and education. Negotiations are under way to create a joint mathematics/electromagnetics position for Prof. Anders Bondeson coupled to Φ, which reflects the new role of CMM.

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Proposed Budget and Financing

Personnel

The research personnel today associated with Φ are listed below together with corresponding department at Chalmers. For graduate students, the expected year for graduation is given.

Tenured senior researchers: Doc. M. Azadsadeh (Math), Prof. A. Bondeson (Electro), Doc. K. Eriksson (Math), Prof. P. Hansbo (Mech), Prof. C. Johnson (Math, director of Φ), Doc. S. Larsson (Math), Dr. P. Möller (Mech), Prof. K. Runesson (Mech), Doc. N. Svanstedt (Math) Prof. N-E. Wiberg (Structural Mech).

Non-tenured senior researchers (Assistant Prof. (forskarassistent)): Dr. M. Larson (Math), Dr. Y. Liu (Electro), Dr. K. Samuelsson (Fraunhofer-Chalmers), Adj.Prof. O. Tullberg (Struct. Mech), Dr. T. Svedberg (Solid Mech).

Graduate students: L. Beilina (Math 2003), R. Bergström (Math 2002), N. Eriksson (Math 2002), T. Ekevid (Struct Mech 2003), G. Engström (Struct Mech 2006,Chalmers) T. Hellström (Volvo TU/Math 2002), P. Heintz (Mech 2006), J. Hoffman (Math 2002), J. Hermansson (Mech 2003), P. Ingelström (Electro 2004), G. Foufas (Math 2005), F. Larsson (Mech 2003), R. Lillbacka (Mech 2006), A. Logg (Math 2003), A. Målquist (Math 2006), T. Rylander (Electro 2002), E. Svensson (Math, 2005), N. Sharif (Struct Mech 2002), Y. Yang (Electro 2003).

Leadership

Prof. C. Johnson, assisted by Dr. M. Larson, will be the director of the Research Program, including responsibility of allocation of resources to different research projects.

Project organization

We indicate here the primary researchers involved in the projects proposed above. The project leader is indicated by PL.

Inverse problems/Optimal Design A1,A3, B1-4: M. Larson (PL), K. Eriksson, C. Johnson, L. Beilina, A. Målquist, new grad stud.

CFD/Turbulence/Reactive Flow/Turbulence modelling A1-2, C1-3: C. Johnson (PL), S. Larsson, N. Svanstedt, J. Hoffman, A. Logg, new grad stud.

CEM A1, D1-2: A. Bondeson (PL), R, Bergström, P. Ingelström, M. Larson, Y. Liu, T. Rylander, Y. Yang, new grad stud.

MEMS A1,A3,D3: A. Bondeson (PL), K. Runesson (PL), M. Larson, S. Larsson, E.Svensson, new grad student.

Adaptive techniques for large deformations A1, E1: K. Runesson (PL), P. Hansbo, C. Johnson, F. Larsson, R. Lillbacka, new grad stud.

Computational modelling of contact and fracture A1, E2: P. Hansbo (PL), P. Heintz, M. Larson, F. Larsson, K. Runesson, new grad stud.

Biomechanics A1, E5: M. Larson (PL), J. Niklasson, and new graduate student.

Adaptive techniques in dynamics E4: N-E. Wiberg (PL), T. Ekevid, P. Hager, P. Kettil, new graduate student.

Coupled thermo-hydro-mechanical problems in porous media E5: N-E. Wiberg (PL), Johan Olsson, Gustav Engström, new grad student.

Computational Finance F1: M. Larson (PL), G. Foufas.

Budget

In the table below we present a preliminary allocation of resources indicating percentage of a full time and cost. No funding from SSF is requested for tenured positions. We expect to allocate from SSF 25% for Researchers and 50% for graduate students with complementing funding from Chalmers, VR, and industrial cooperation. The total cost for an Assistant Professor is approximately 800 kSEK per year and 500 kSEK per year for a graduate student. These figures are based on a total 2.25 overhead factor and salaries of 360 kSEK and 220 kSEK per year. The total overhead factor consists of department/university overhead (2.00) including social taxes and research group overhead (0.25) covering travel, computing, and other costs (including department/university overhead). In the table below we indicate the size of the SSF allocated resources as well as other sources of funding when known. For brevity we use the following notation: VR (Vetenskaps rådet), CTH (position at Chalmers including both research and teaching), CF (support allocated by the President of Chalmers from the Chalmers Foundation), Charmec (Research program in the Mechanics Department on railway mechanics).

Personnel	Project	Activity(%)	Year 1	Year 2	Year 3
Researchers					
M. Larson	ABCDEF	25 (VR, CTH)	200	200	200
Y. Liu	D1-3	25 (EU, CTH)	200	200	200
New researcher	A-E	25 (CTH)	200	200	200
Post Doc/Visitor	A-E	25 (CTH)	200	200	200
PhD Students					
L. Beilina	A1B1	50 (CF)	250	250	
T. Ekevid	E3	50	250	250	
G. Foufas	F1	50 (CF)	250	250	250
P. Heinz	E1-2	50 (Charmec)	250	250	
J. Hoffman	A1C1-3	50 (VR)	250		
F. Larsson	E1E2	50 (VR)	250	250	
A. Målquist	B2-4	50 (CF)	250	250	250
Y. Yang	D1-3	50 (CTH)	250	250	250
New student	A1B1-4	50	250	250	250
New student	A1C1-2	50	250	250	250
New student	A1C3	50	250	250	250
New student	A1C3	50			250
New student	E1-5	50			250
New student	E1-5	50			250
New student	D1-2	50	250	250	250
New student	D3	50	250	250	250
New student	D3	50		250	250
New student	A-F	50			250
Total			4050	4050	4050

Research Group Survey

A. Principal investigators and students

Principal investigators:

- Prof. A. Bondeson (Electro, Chalmers 60%, EU 40%),
- Prof. C. Johnson (Math, Chalmers 100%),
- Doc. S. Larsson (Math, Chalmers 70%, TFR 30%),
- Dr. M. Larson (Math, Chalmers 50%, TFR/VR 40%, Fraunhofer-Chalmers 10%),
- Prof. K. Runesson (Applied Mech, Chalmers 100%),
- Prof. N-E. Wiberg (Structural Mech, Chalmers 100%).

Association and financing indicated.

Graduate students:

- L. Beilina (Math, Johnson, 2003, VR 80%, KTH 20%),
- R. Bergström (Math, M. Larson, 2002, ABB 50%, TFR 50%),
- N. Eriksson (Math 2003, Johnson, Chalmers),
- T. Ekevid (Struct Mech 2003, Wiberg, NGSSC 50%, Banverket 50%)
- G. Engström (Struct Mech 2006, Wiberg, Chalmers 50%, VR 50 %)
- T. Hellström (Volvo TU/Math, Johnson, 2002, Volvo TU),
- P. Heintz (Mech 2006, Runesson, Charmec 50%, VR 50%)
- J. Hermansson (Mech 2003, Hansbo, IVS 100%)
- J. Hoffman (Math 2002, Johnson, VR 50% , Chalmers 50%),
- P. Ingelström (Electro, Bondeson, 2004, VR 80% , Chalmers 20%)
- G. Foufas (Math 2005, M. Larson, Chalmers),
- F. Larsson (Mech 2003, Hansbo, VR 100%),
- R. Lillbacka (Mech 2006, Runesson, VR 100%)
- A. Logg (Math 2003, Johnson, VR 50%, Chalmers 50%),
- A. Målquist (Math 2006, K. Eriksson/Johnson, VR 50% Chalmers 50%),
- T. Rylander (Electro 2002, Bondesson, NGSSC 50%, LIFT 50%),
- E. Svensson (Math 2005, S. Larsson, ECMI/Imego)
- N. Sharif (Struct Mech 2002, Wiberg, Chalmers),
- Y. Yan (Math 2003, Larsson, Chalmers 100%)
- Y. Yang (Electro 2003, Bondeson, Chalmers 100%).

Association, advisor, expected year of PhD and financing indicated.

B. Curriculum vitae for applicants

Curriculum vitae: Anders E. Bondeson

born December 12, 1953 in Mariestad, Sweden.

Department of Electromagnetics
Chalmers University of Technology
S-41296, Göteborg
Sweden

phone +46-31-772 1578
fax +46-31-772 1725
email elfab@elmagn.chalmers.se

A. Professional preparation

1975-79 Ph.D. in Plasma Physics, Chalmers University of Technology, Göteborg.

1971-75 Master of Engineering (Technical physics), Chalmers University of Technology.

B. Appointments

1995/9 - present	Professor of Electromagnetic Field Theory, Chalmers University of Technology.
1993/11 - 95/8	Professor of Theoretical Electrotechnics, Dep. of Technology, Uppsala University.
1988/4 - 93/10	Adjoint Scientifique at Centre de Recherches en Physique des Plasmas, Ecole Polytechnique Federale de Lausanne (EPFL), Lausanne, Switzerland.
1986/1 - 86/10	Invited Professor, EPFL, Lausanne, Switzerland
1982/6 - 85/12	Extra Professor of Theoretical Fusion Plasma Physics, Chalmers U. of Technology
1981/7 - 82/5	Assistant Professor, Physics Department, University of Maryland, College Park, Md.
1979/8 - 81/6	Research Assoc., Laboratory for Plasma and Fusion Energy Studies, U. of Maryland

D. Other merits of relevance to the project

Research

Over 90 papers in refereed journals on magnetohydrodynamic stability, numerical methods and computation (MHD and Electromagnetics), Plasma Physics, gyrotrons (coholder of 4 patents).

29 invited talks at international conferences and workshops.

Coordinator of EU work in MHD for ITER 1993-99.

Advisor to PhD/Lic. Theses

E. Salinas, PhD 2001, Mitigation of Power-Freq. Magnetic Fields (coadvisor for CEM part)

T. Rylander, Lic. 2000, Computational Electromagnetics, FEM-FDTD hybrid method

D.H. Liu, PhD 1999, Computational MHD. Stability of 2D equilibria

H.X. Xie PhD 1996, Resistive MHD instabilities in tokamaks

Z.X. Jiang, PhD 1994, Hydromagnetic Stability studies of straight pinch configurations

M. Benda, PhD 1993, Numerical study of the axisymmetric ideal MHD stability of EXTRAP

H. Lütjens, PhD 1992, MHD stability of internal kink modes in tokamaks: Application of an equilibrium code using bicubic finite elements

R. Iacono, PhD 1990, Equilibrium and stability of rotating plasmas, MHD and guiding center results.

M Persson, PhD 1988, Resistive stability for rotating plasmas

J. Sobel, Lic. 1984, Linear investigation of resistive tearing modes in cylindrical geometry.

Currently advisor for 5 graduate students in Computational Electromagnetics and MHD

Committees

Associated member SNRV (Swedish National Committee for Radio Science), section B

Member NFR "beredningsgrupp" 1994, NFR Physics Committee 95-00, VR "beredningsgrupp" 01

Reviewed computational applications for US Department of Energy 2001, Science Foundation Ireland 2002, and, on numerous occasions, promotions at Princeton Plasma Physics Laboratories

Specialist editor of Computational Electromagnetics for Computer Physics Communications 1998-2001

Member EURATOM Fusion Physics Committee, 1995-2000

Member NFR Committee for Fusion Research, FFK 1995-2001

Board member, Chalmers Finite Element Center Φ

Board member, Chalmers consortium for numerical computations

Awards

John Ericsson Medal, Chalmers University of Technology, 1975.

Winner Svenska Dagbladets Matematiktävling (National mathematics cont. high-school students) 1970

Teaching

Undergraduate and graduate courses in Electromagnetics at Chalmers, Uppsala and Maryland Univ.

Undergraduate and Masters Program courses in Computational Electromagnetics at Chalmers

Undergraduate course in Optics at Maryland University

Undergraduate and graduate courses in Plasma physics at Chalmers, Uppsala University and EPFL

Graduate courses in Magnetohydrodynamics at EPFL and international workshops/summer schools

Curriculum vitae: Claes G. L. Johnson

born November 18 1943 in Mölndal, Sweden.

Department of Mathematics
Chalmers University of Technology
S-41296, Göteborg
Sweden

phone	+46-31-772 35XX
fax	+46-31-772 3595
email	`claes@math.chalmers.se`

A. Professional preparation

Master of Engineering, Chalmers Univ. of Technology, 1969,

Ph.D. in Mathematics, Chalmers Univ. of Technology, 1973,

Docent in Numerical Analysis, Chalmers Univ. of Technology 1978.

B. Appointments

Assistant, Mathematics Dept., Chalmers Univ. of Techn. 1969-73,

Instructor, Mathematics Dept., The University of Chicago 1974-76,

Assistant Professor, Dept. of Computer Science, Chalmers Univ. 1976-80

Visiting Prof, Ecole Polytechnique, Paris, April-June 1976

Visiting Prof Universite Paris VI, April-June 1978

Professor of Applied Mathematics, Dept. of Mathematics, Chalmers University of Technology 1981- , permanent position

Visiting Prof Mathematics Dept., Univ. of Michigan 1983-84

Visiting Prof Ecole Polytechnique, Paris, Oct-Nov 1987

Visiting Prof Ecole Polytechnique, Paris, Jan-June 1991

Visiting Prof Univ. of Stuttgart, Heidelberg, 12 months 1991-94

Visiting Prof Univ. of Pavia, Italy, Febr-March 1997

Visiting Prof CRS4, Sardinia, March-June 1997.

D. Other merits of relevance to the project

Editorial duties:

Computer Methods in Applied Mechanics and Engineering

Mathematical Models and Methods in Applied Sciences

Services

Director of Chalmers Finite Element Center

Advisor to Ph.D./Lic thesis(at Chalmers)

U. Nävert, A finite element method for convection-diffusion problems, 1982

S. Waserbrot, Discont. finite element methods for plasticity problems, 1984

M. Asadzadeh, Num. meth. for neutr. trspt. and Vlasov eq., 1986

J. Lennblad, Adaptive methods for parabolic problems, 1989.

A. Szepessy, Convergence of the streamline diff. fem for cons. laws, 1989.

Robert Sandboge, Adaptive fem for reactive compressible flow, 1997

Mats Larson, Analysis of adaptive finite element methods, 1997.

N. Eriksson, A study of transition to turbulence, 1998.

E. Burman, Finite element methods for reactive two-phase flow, 1998.

J. Hoffman, Adaptive Computational Subgrid Modelling, 2000.

A. Logg , Multiadaptive Galerkin Methods for ODEs, 2001.

Awards

Albert Wallins pris, Göteborgs Kungl. Vet.- och VitterhetsSamhälle, 1985

Humboldt Forschungspreis 1990.

Research

75 scientific articles on applied mathematics, partial differential equations, finite element methods and numerical analysis.

Books

Numerical Solution of Partial Differential Equations by the Finite Element Method, Studentlitteratur/Cambridge University Press, 1987.

Computational Differential Equations (with Eriksson, Estep and Hansbo), Studentlitteratur/Cambridge University Press, 1996.

Applied Mathematics: Body & Soul 2002, I-III, (with Eriksson and Estep), Springer, 2002.

Current research contracts

SSF : Chalmers Finite Element Center (Director) -01

NGSSC: Adaptive finite element methods for electromagnetics -01

VR: Multi-scale adaptive methods 02-04

Teaching experience

A variety of courses in mathematics, applied mathematics and numerical analysis from beginning undergraduate to advanced graduate level.

Curriculum vitae: Mats G. Larson

born September 10, 1968 in Kungälv, Sweden.

Department of Mathematics
Chalmers University of Technology
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Sweden

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fax	+46-31-772 3595
email	mgl@math.chalmers.se

A. Professional preparation

Ph.D., Applied Mathematics, Chalmers University of Technology, 1997, advisor: Professor Claes Johnson, thesis: *Analysis of Adaptive Finite Element Methods.*

Tekn. Lic., Applied Mathematics and Certificate from the European Consortium for Mathematics in Industry (ECMI), Chalmers University of Technology, 1995.

M. Sc., Mechanical Engineering and Applied Mathematics, Chalmers University of Technology, 1991.

B. Appointments

Assistant Professor, Department of Mathematics, Chalmers University of Technology, Sweden, Oct. 1999 – present.

Scientific Advisor, Fraunhofer-Chalmers Research Centre for Industrial Mathematics, Sep. 2001 – present.

Project Leader, Institute of Applied Mathematics, Sweden, Jan. 2000 – Dec. 2001, project funded by ABB.

Post Doc. Fellow in the Mechanics and Computation Department at Stanford University (Prof. T.J.R. Hughes group), USA, funded by STINT. Oct. 1997–Sep. 1999.

Research assistant, Department of Mathematics, Chalmers University of Technology, Sweden, Jul. 1992–Sep. 1997.

D. Other merits of relevance to the project

Research

More than 30 papers and technical reports.

Grants

Computational Biomechanics, three year grant (02–04), 380 kkr per year, with Jonas Niklasson, from the Swedish research council.

Multiscale Computations, three year grant (02–04), 350 kkr per year, with Claes Johnson (principal investigator), from the Swedish research council.

Computational Wave Propagation, two year grant (Jul. 00–Jun. 02), 400 kkr per year, with Claes Johnson (principal investigator) and Jonas Niklasson, from the Swedish Research Council for Engineering Sciences.

Computational Mathematical Modelling, Two year grant (99–01), 400 kkr per year, from the Foundation of Strategic Research, with Claes Johnson (principal investigator).

Two year (97–99) Post Doc. Fellowship from STINT for research at Stanford University.

Advisor experience

Advisor for Ph.D. candidates R. Bergström (Lic. 99, PhD expected 02) and G. Foufas (Lic. expected 02) at the Department of Mathematics, Chalmers, Sweden.

Coadvisor for Ph.D. candidates M. Lindberg, and J. Ivarsson at the Department of Mathematics, and P. Heintz at the Department of Applied Mechanics, Chalmers, Sweden.

Other experience

Several extended international research visits. Most recently visiting scientist NASA Ames, USA, funded by RIACS, Aug.–Sep. 2001.

Consultant for industry. Jul. 97–present.

Member of the Informal Steering Group of the Mathematics Department. Oct. 00–Dec 01. Member of Graduate Committee Jan. 02 – present.

Organizer of the Computational and Applied Mathematics Seminar (with Stig Larsson) , Chalmers.

Reviewer for various academic journals.

Chalmers University of Technology, participated in pedagodical development of the Mathematics course program for the Masters Programs in Chemistry with Physics and Biology, Sep. 99–present.

Military service in the Swedish army as mathematician and cryptoanalyst, Jun. 91–Aug. 92.

Curriculum vitae: Stig Larsson

born July 11, 1952, Värnamo, Sweden

Department of Mathematics
Chalmers University of Technology
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Sweden

phone	+46-31-772 3543
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url	`www.math.chalmers.se/~stig`

A. Professional preparation

MSc in Engineering Physics ("civilingenjör F"), Chalmers University of Technology, 1976

PhD in Mathematics, Chalmers University of Technology, 1985 (supervisor: Vidar Thomée)

B. Appointments

Assistant of mechanics, Chalmers University of Technology, 1974–1979

Assistant of mathematics, Chalmers University of Technology, 1979–1985

Visiting assistant professor of mathematics,University of Michigan, Ann Arbor, 1985–1987

Lecturer of mathematics, Chalmers University of Technology, 1987–1992

Associate professor ("docent") of mathematics, Chalmers University of Technology, 1992–

D. Other merits of relevance to the project

Award

Chalmers University's award for teaching 1991

Fellowships and research grants

Scholarship for graduate study from the Swedish Institute for Applied Mathematics (ITM), 1982–1985

Half salary paid by a research grant from the Swedish National Board for Technical Development (STUF), 1988–1992

Half salary paid by research grants from the Swedish Research Council for Engineering Sciences (TFR), 1992–1998.

INTAS 1997–2000 "Perturbations of invariant sets in infinite dimensional dynamical systems"

TFR 1998–1999 "Finite element methods for parabolic problems in science and engineering".

TFR 2000–2001 "Finite element methods for parabolic problems in science and engineering".

TFR 2000–2001, "Numerical modelling of viscoelastic materials using integro-differential equations" (with Mikael Enelund, Department of Solid Mechanics, Chalmers).

Research students

Mats Boman, tekn dr 2000

Johan Ivarsson, tekn lic 1998, tekn dr 2002

Currently supervising three graduate students: Y. Yan, E. Svensson, and B. Hakberg

Administration

Head of the Department of Computational Mathematics 2002–.

Project leader for the pedagogical project “Integration of Mathematics, Chemistry and Chemical Engineering” within the Chalmers Strategic Effort on Learning and Teaching C-SELT.

Member of the TFR selection committee for applied mathematics 1999–2000.

Coordinator of the educational program “Engineering Mathematics” 1992–1997, chairman of its steering committee 1997–.

Organizer of the Computational and Applied Mathematics Seminar (with M. G. Larson).

Curriculum vitae: Kenneth Runesson

born November 26, 1948, Moheda, Sweden.

Department of Applied Mechanics
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S-41296, Göteborg
Sweden

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A. Professional preparation

M.Sc. in Civil Engineering, CTH, 1972

Ph.D. in Civil Engineering, CTH, 1978

Docent in Structural Mechanics, CTH, 1978

B. Appointments

1979-84	Research Fellow, Structural Mechanics, CTH
1979	Visiting Research Affiliate, Civil Engineering, University of Sydney
1981-82	Visiting Research Fellow, Civil Engineering, University of Sydney
1984-92	Associate Professor, Structural Mechanics, CTH
1987-89	Visiting Professor, Civil, Environmental and Architectural Engineering, University of Colorado at Boulder
1991-92	Acting Professor, Engineering Materials, LTH
1993-	Professor, Solid Mechanics, CTH
1996-97	Visiting Professor, Civil, Environmental and Architectural Engineering, University of Colorado at Boulder

D. Other merits of relevance to the project

International scientific publications

75 published or accepted papers in international journals (reviewed),

7 papers under review,

74 papers published in books and proceedings of international conferences (reviewed).

Supervised graduate students

Main adviser of 6 Ph.D. dissertations at Chalmers University of Technology and coadviser (factual main adviser in most cases) of 8 Ph.D. dissertations at Chalmers University, University of Lund and University of Colorado at Boulder. Main adviser of 5 Tech.Lic. dissertations at Chalmers University and University of Lund.

Selected academic services

Editorial board member of 3 international journals (Int. J. Numerical Methods in Engineering, Int. J. Plasticity, Int. J. Numerical and Analytical Methods in Geomechanics).

Reviewer for 12 international journals.

Opponent at 7 Ph.D. dissertations and 6 Tech.Lic. dissertations at Sweden, Denmark, Norway and Finland.

Member of examination committees for Ph.D. at 23 occasions in Sweden, Denmark, Norway, Finland, Germany, Holland, Spain and USA.

External reviewer for academic positions at several universities in Sweden, Denmark and USA.

Member of the Board of the Swedish National Association for Mechanics (1995-2001).

Member of the President's Advisory Committe for Promotions and Academic Strategies at Chalmers University (1994-2000).

Chairman of the Board of Chalmers Finite Element Center (current).

Curriculum vitae: Nils-Erik Wiberg

born November 27, 1938, Vibyggerå, Sweden.

Department of Structural Mechanics
Chalmers University of Technology
S-41296, Göteborg
Sweden

phone +46-31-772 1970
fax +46-31-772 1976
email `new@sm.chalmers.se`

A. Professional preparation

1964, MsC in Civil Engineering, Chalmers University of Technology

1968, Techn lic in Structural Mechanics, Chalmers University of Technology

1970, PhD in Structural Mechanics, Chalmers University of Technology

1970, Docent in Structural Mechanics, Chalmers University of Technology

B. Appointments

1970, Research Assistant Structural Mechanics, Chalmers

1970 University Lecturer In Structural Mechanics, Chalmers

1972 Professor (half time) in Structural Mechanics, Chalmers

1978 Full Professor in Structural Mechanics, Chalmers, 1983-

Head of department of Structural Mechanics, Chalmers, 1983-

D. Other merits relevant to the project

Research

Author/co-author of 7 books in Structural Mechanics and FEM.

Author/co-author of about 60 internationally published papers.

Selected services

1979-, Chairman of the Center of Computer Calculations at Chalmers,

1988-2000, Chairman of the Nordic Association in Computational Mechanics (NoACM)

1996-, Vice president of European Community for Computational methods in Applied Sciences (ECCOMAS)

Arranged about 80 seminars of one day or more within the field of Computational Mechanics

On Editorial board for 4 international journals.

Reviewer for a number of well established scientific journals (20 review articles/year).

Member of President's Advisory Committee for promotions and Academic Strategies at Chalmers University (2001-) Member of Chalmers Faculty Committee (1992-).

Supervised graduate students

Main adviser of 12 PhD 6 TechLic dissertations at Chalmers University of Technology.

Further information

As can be seen above I have during all my professional work actively worked with transferring knowledge of computational techniques by writing several textbooks and arranging numerous courses and conferences directed to researches as well as industrial people. I have also created a very extensive international contact network by work in international organizations like ECCOMAS (European Community of Computational Mechanics in Applied Sciences) and NoACM (Nordic association of Computational Mechanics) where I have leading positions.

It is noteworthy that, during the last 20 years, 9 Professors and 4 University lecturers in various fields of mechanics at Swedish universities (CTH, KTH, LiTH, LuTH) received their Research Education from our department. This shows the impact by the Structural Mechanics group at Chalmers on the computational mechanics community within Sweden.

In spring 2000 the field of Computational Modelling and Simulation at Structural Mechanics was after a broad evaluation process appointed to be a center of excellence at the School of Civil Engineering, Chalmers. It was said that this is a field of priority for the School, it has a well-established co-operation internationally and with industry, and integration with VR-techniques was interesting.

C. Scientific output - group

PhD and Lic degrees 97-01

1. R. Sandboge (adv Johnson) PhD 1997.
2. M. Larson (adv. Johnson) PhD 1997.
3. E. Burman (adv Johnson), PhD 1998.
4. N. Eriksson (adv Johnson) Lic 1999.
5. R. Bergström (adv M. Larson) Lic 1999.
6. J. Hoffman (adv Johnson) Lic 2000.
7. A. Logg (adv Johnson) Lic 2001.
8. J. Ivarsson (adv S. Larsson) PhD 2002.
9. M. Boman (adv S. Larsson) PhD 2000.
10. E. Salinas (adv Bondeson), PhD 2001, (joint with Electrical Power Engineering).
11. T. Rylander (adv Bondeson), Lic. 2000.
12. D.H. Liu (adv Bondeson), PhD 1999.
13. H.X. Xie (adv Bondeson) PhD 1996.
14. Patrik Cannmo (adv Runesson) PhD 1997.
15. Lennart Mähler (adv Runesson) PhD 1999.
16. Thomas Svedberg (adv Runesson) PhD 1999.
17. Magnus Ekh (adv Runesson) PhD 2000.
18. Lars Jacobsson (adv Runesson) Lic 1999.
19. Fredrik Larsson (adv P. Hansbo) Lic 2001.
20. Joakim Hermansson (adv P. Hansbo) Lic 2001.
21. Ulrika Wendt (adv Samuelsson) PhD 1997.
22. Behzad Soltani (adv Samuelsson) PhD 1997.
23. Patrik Hager (adv Wiberg) Lic 1998.
24. Per Kettil (adv Wiberg) Lic 1999.
25. Sigurdur Ormarsson (adv Petersson) PhD 1999.
26. Mats Ander (adv Samuelsson) PhD 1999.
27. Per Kettil (adv Wiberg) PhD 2001.
28. Nina Lautersztajn-S (adv Samuelsson) PhD 2001.
29. Patrik Hager (adv Wiberg) PhD 2001.
30. Nahidh Hamid Sharif (adv Wiberg) PhD 2002.
31. Jonas Larsson (adv Wiberg) Lic 1997.

32. Peter Eriksson (adv Friberg) Lic 2000
33. Torbjörn Ekevid (adv Wiberg) Lic 2000.
34. Johan Olsson (adv Wiberg) Lic 2000.
35. Mats Svensson (adv Mattiasson) Lic 2001.

Renewal of basic and graduate education.

Φ has developed a new program for applied mathematics education from basic to graduate level including books and software, which is now used in the chemical engineering education at Chalmers, and is stimulating a reform from basic to graduate level to include modern tools of CMM in engineering courses. Further, Φ has developed a new interdisciplinary graduate education in CMM at Chalmers including international cooperation with Hannover and Barcelona with exchange of students. We expect new graduate students under the present proposal to this program. Φ also contributes to the NGSSC course program with an introductory finite element course, and has the ambition to extend to advanced courses.

Main publications group (10)

1. D.J. Estep, M.G. Larson, and R.D. Williams, Estimating the error of numerical solutions of systems of nonlinear reaction-diffusion equations, Mem. Amer. Math. Soc. 146 (2000), no. 696, 109 pp.
2. P. Hansbo and M.G. Larson, Discontinuous Galerkin methods for nearly incompressible elasticity by Nitsche's method, Comput. Methods Appl. Mech. Engrg., 191 (2002), 1895–1908.
3. T. Rylander and A. Bondeson, Stability of Explicit-Implicit Hybrid Time-Stepping Schemes for Maxwell's Equations, J. Comput. Phys., accepted (2002) (Preprint, 2002-3, Chalmers Finite Element Center).
4. Y.Q. Liu, A. Bondeson R. Bergström, C. Johnson, M.G. Larson, and K. Samuelsson, Eddy current computations using adaptive grids and edge elements, IEEE Trans. Magn. (to appear, March 2002) (Preprint 2001-17, Chalmers Finite Element Center).
5. T. Rylander and A. Bondeson, Stable FEM-FDTD hybrid method for Maxwell's equations, Comput. Phys. Comm. **125**, 75 (2000).
6. J. Hoffman, and C. Johnson, Adaptive finite element methods for the incompressible Navier-Stokes equations, Agard/VKI course, to appear in Springer Lecture Notes, 2002, (Preprint 2001-18, Chalmers Finite Element Center).
7. L. Beilina (adv C. Johnson), An adaptive hybrid FEM/FD for inverse scattering problems, Preprint 2002-5, Chalmers Finite Element Center.
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E. Present Activity and Financing

Computational Mathematics

Researchers:

C. Johnson (100% Chalmers)

M. Larson (50% Chalmers, 40% TFR/VR, 10% Fraunhofer)

S. Larsson (70% Chalmers, 30% TFR)

K. Eriksson (100% Chalmers)

N. Svanstedt (100% Chalmers)

Graduate students:

L. Beilina (80% VR, 20% KTH)

R. Bergström (50% TFR, 50% ABB)

G. Foufas (100% Chalmers)

N. Eriksson (100% Chalmers)

J. Hoffman (50% VR, 50% Chalmers)

A. Logg (50% VR, 50% Chalmers)

A. Målquist (100% Chalmers)

E. Svensson (100% Imego)

Y. Yan (100% Chalmers)

Granted financing:

1. VR-621-2001-2765, Multiscale adaptive methods 455 kSEK/year 2002-2004
2. VR-621-2001-2730, Computational biomechanics 494 kSEK/year 2002-2004
3. ViSiCade (subcontracted to Fraunhofer-Chalmers total: 154.214 Euro during three years).
4. Φ-support Chalmers Foundation 650 kSEK/year 2001-03

No support from SSF presently. The present proposal is closely connected to 1-2. The proposed support corresponds to 50 % of expected total research support.

Applications:

1. NGSSC, Inverse problems, 500 kSEK total over 2002-2005.

Computational Electromagnetics

Researchers:

A. Bondeson (60% Chalmers, 40% EU)

Y.Q. Liu (60% Chalmers, 40% EU)

Graduate students:

P. Ingelström (grad. stud 80% VR, 20% Chalmers)

T. Rylander (grad stud) 40% NGSSC, 20% NTM, 20% VR, 20% Chalmers)

Y. Yang (100% Chalmers)

S. Isaksson (AB coadvisor) (50% NGSSC, 50% LIFT)

D. Gregoratto (Fusion, Computational MHD, 80% VR, 20% Chalmers)

Financing:
No support from SSF presently The present proposal is closely connected to 1-5. The proposed support corresponds to 25% of expected total research support.

	Contract	Subject	Amount kSEK	Until
1	VR 621-2001-3498	Adaptive and optimization methods	650	2004-12
2	Saab Avionics - SMART	Radar Cross Section Optimization	350	2004-6
3	Chalmers School of EE	Seed money for CEM	1000	2002-12
4	Chalmers Foundation	support for Φ	450	2003-12

Table 1: Granted research resources for CEM

	Agency	Subject	Amount kSEK	Period
5	Vinnova	Hybrid comp for EMC in cars	220	2002-2004

Table 2: Applications in CEM

	Contract	Subject	Amount kSEK	Until
6	NFR F 5102-1288	MHD project	75	2002-12
7	NFR F 5102-20005658	MHD grad. Student	347	2002-12
8	EU	Fusion	715	2002-12
9	NFR F 5102-20005659	Fusion	396	2002-12

Table 3: Granted external contracts, fusion research

Computational Solid Mechanics

Researchers:

K. Runesson (100% Chalmers)

P. Hansbo (100% Chalmers)

T. Svedberg (100% Vinnova-Raufoss)

Graduate students:

P. Heintz (Charmek, Chalmers)

R. Lillbacka (VR)

F. Larsson (VR)

J. Hermansson (IVS)

Granted financing:

1. VR, Meso-mechanics, 494 kSEK, 2002-2004
2. VR, Adaptive FEM for large deformation, 494 kSEK, 2002-2004
3. Charmec, Methods for contact and crack formation, 450 kSEK, 2002-2003
4. Vinnova and Raufoss, Fluid structure interaction, 839 kSEK, 2002-2003
5. Φ-support Chalmers Foundation, 450, 2001-2003
6. IVS, Acoustics of fluid-structure interaction, 600 kSEK,

No support from SSF presently. The present proposal is closely connected to 1-4. The proposed support corresponds to 30% of expected total research support.

Computational Structural Mechanics

Researchers:

N.E. Wiberg (100% Chalmers)

O. Tullberg (25% ITBOFF, 25% EU)

M. Ander (100% Chalmers)

K. Mattiasson (20% Volvo)

U. Wendt (50% Chalmers, on leave)

M. Connel (50% EU)

P. Kettil (50% SBUF)

Graduate students:

G. Engström (50% VR, 50% Chalmers)

T. Ekevid (50% NGSSC, 50% Banverket)

N. Sharif (100% Chalmers)

J. Olsson (50% Vägverket, 50% SBUF)

S. Woksepp (100% ITBOFF)

M. Svensson (70% Volvo, 30% VR)

E. Omersphaic (100%, Volvo)

L. Lu (100% Stipend)

Granted financing:

1. Road Mechanics- Finite element modelling of Roads (Vägverket) 600, 0.
2. Road Mechanics- Finite element modelling of Roads (SBUF) 500, 275.
3. Road Mechanics- Coupled analysis (VR) 494, 494.
4. Wave propagation under high speed trains (Banverket) 525, 770.
5. Nonlinear wave propagation (TFR) 462, 0.
6. PARAMIX- Asphalt mixtures (EU) 391, 411.
7. Applied Virtual reality (IT Bof 2002) 449, 204.
8. Φ-support from Chalmers Foundation) 450, 450.
9. NGSSC (Ekevid) (TFR) 181,
10. VISICADE- Coupling CAD-FEM-VR (EU) 650, 0.
11. FEM-simulering av fogning (VR) 293, 293.

Figures are research support (in kSEK) during year 2002 and 2003. No support from SSF presently. The present proposal is closely connected to all listed projects. The proposed support corresponds to 10 % of expected total research support.

F. International cooperation

We have close cooperation since many years with e.g.

Prof. Rannacher in Heidelberg,

Prof. Wriggers/Stein/Stephan in Hannover,

Prof. Miehe in Stuttgart,

Prof. Steinmann in Kaiserslautern,

Prof. Hughes in Stanford,

Prof. Suli in Oxford,

Prof. Estep at Fort Collins

Prof. Pitkäranta in Helsinki,

Prof. Winther in Oslo,

Prof. Nedelec in Paris,

Prof. Brezzi in Pavia,

Prof. Onate in Barcelona,

Prof. Scott in Chicago.

Prof. Carey in Austin.

We also have collaboration on MHD codes with MIT, Princeton Plasma Physics Laboratories and EPFL.

With joint participation mathematics/structural mechanics we are partners of the EU project ViSiCade on scientific/industrial modelling/visualization which started in Dec 2001, which we have partially subcontracted to Fraunhofer-Chalmers (K. Samuelsson).

We have formed a joint PhD program together with the Universities of Hannover and Barcelona with exchange of students starting the Fall 2002 (special support from DFG).

We have excellent possibilites of supporting students under the ECMI-program in cooperation with Fraunhofer-Chalmers Research Centre for Industrial Mathematics.

G. Industrial contacts

Φ has established a close cooperation with Fraunhofer-Chalmers Research Centre for Industrial Mathematics and a cooperation with the new Chalmers Center for Process Engineering is being developed, both connecting to industry. In particular, the connection to the Fraunhofer-Chalmers Centre provides a new platform for conducting industrial research as well as a natural channel for transfer of knowledge and technology to industry. We are very enthusiastic about these possibilities.

Φ is cooperating with industrial partners on finite element solvers for electromagnetics (ABB) and fluid flow (Volvo TU, Raufoss), radar (Saab Avionics), mechanics (SKF, Alstom Power, Sandvik Steel), structural mechanics (Skanska, NCC, Volvo, Scania). We expect our industrial cooperation to expand as our computational platform develops.

Description for the Public

The roots of the *Industrial Revolution* leading into the *Industrial Society* goes back to the *Spinning Jenny* and *Watt's Steam Engine* both from 1769, representing *automatization/mechanization of production*. Today the Industrial Society is developing into the *Information Society*, which is based on *automatization/mechanization of computing* performed by *computers*, which are electronic machines for transmitting/receiving and handling *Information* in *digital form* as strings of 0s and 1s. Documents of words, pictures, movies or music can now be brought to digital form and be transmitted/duplicated/manipulated and retrieved on a computer screen, and the whole World is suddenly connnected through an *Internet*.

The *World of Simulation* is booming in science, technology, society, and entertainment industry, from computer-simulations of the collisions of two stars, the weather over Scandinavia the next 24 hours, the crash of a newly designed car only existing in the computer, electronic games and computer-animated movies, to the computer tomography at the hospital giving pictures of your brain, all of it boiling down to computing on strings of 0s and 1s representing e.g. pixels of an image. These are all examples of *Computational Mathematical Modelling* CMM, which essentially concerns *solving systems of differential/algebraic equations*.

For example, a weather forecast by SMHI is made by modelling the atmosphere (pressure, temperature, wind speed and direction, moisture, clouds) as a system of *partial differential equations* over a certain area (or the whole globe) expressing fundamental balance laws of physics at each point for mass, heat and forces and then *discretizing* these equations on a *computational mesh* subdividing the volume of atmosphere into a finite number of pieces or *finite elements* to get a system of equations for the computer to solve. The solution then gives a prediction of the evolution of the atmosphere from measured values of the temperature and wind velocity at the start of the simulation. This process of computational modelling is subject to errors in data, modelling and discretization and we all know that predicting the weather over say Göteborg more than a couple of days ahead (or less) may be very difficult, although a very powerful *super-computer* is used by SMHI.

Chalmers Finite Element Center Φ is an interdisciplinary unit at Chalmers formed in 1997 with support from the Foundation for Strategic Research, joining forces of groups from Computational Mathematics, Solid/Structural Mechanics and Electromagnetics with the goal of tackling central problems in CMM. Φ continues the strong tradition at Chalmers in the development and application of the finite element method as a general technique for the computational solution of differential equations, now with particular focus on *adaptivity* with feed-back from computation to reach goals of *optimization* concerning both solution, modelling and computation.

The GOAL of Φ is to develop advanced tools for computational simulation of complex systems in solid mechanics (e.g. crash of a car), fluid mechanics (e.g. turbulent flow), electromagnetics (e.g. electromagnetics waves for cellular telephones or electromagnetic fields in a Volvo S80), chemistry (formation of molecules and proteins through chemical reactions), and other applications. Φ also supports a reform program for mathematics education bringing together symbolic mathematics (formulas) with computational mathematics (numbers). For an overview of the activity of Φ and examples of different simulations, see www.phi.chalmers.se/presentations/phi.

In more technical terms the GOAL of Φ may be described as *automatization* of the following elements of CMM: (i) *discretization*, (ii) *meshing*, (iii) *solving algebraic equations*, (iv) *optimization*, (v) *modelling*. The finite element method gives a solution to (i), by feed back from the computation we can determine the right mesh to keep the *discretization error* within a given *tolerance* and thus solve (ii), by using very efficient *multigrid* methods we can approach (iii), using efficient *optimization algorithms* we can approach (iv), and with (i)-(iv) in hand we can approach the over-all problem of (v), e.g., the outstanding problem of *turbulence modelling*.

Strategic Impact

Computational mathematics coupled with the power of modern computers lie at the foundation of the emerging Information Society based on automatized computation and digital techniques. The crucial role of computational modelling in Swedish industry is expressed in the *Brain Power* slogan of ABB representing a shift from heavy production industry to sophisticated high-tech IT: design a new virtual car or mobile telephone ready for the production line, or simulation and testing of products and systems on-line by the customer. Recently, financial markets have brought inflated IT-dreams back to a reality, but the impact of the IT-revolution tomorrow will most likely go way beyond the dreams of today.

To remain internationally competitive in this development, Swedish industry needs qualified scientists and engineers well trained in computational modelling and capable of developing and exploiting state-of-the art software. This requires high quality research and a modern education from basic to graduate level including new computational tools on a solid basis of mechanics, physics and engineering disciplines.

The new information technology gives mathematics a stronger role in the education than ever, and a reform of the mathematics education to include the modern tools of computational mathematics will stimulate a reform of courses in science and engineering in the same direction. The new technology also stimulates interdisciplinary work since the true power comes from an interplay of computational mathematics and science/applications: the qualified engineer and scientist must be able to master both advanced computational tools and applications. Further, basics and principles become more important as traditional design tools lose power, and research is again brought in direct contact with basic education, as during the industrial revolution.

Φ builds on interdisciplinary research and education combining computational mathematics and applications. The research of Φ has international impact and covers important parts of the field of computational mathematics/applications. The educational reform developed at Φ includes an interdisciplinary graduate program in CMM, and a new engineering mathematics program from basic to master level.

The combined interdisciplinary research and educational program at Φ can play an important role in assisting Swedish industry and research to remain competitive by contributing the following key elements:

1. Research at the international front-line giving access to latest technology and attracting top students.

2. Training of interdisciplinary PhDs capable of developing and spreading state-of-the-art computational modelling in science and industry.

3. Reform of undergraduate education in science and engineering to include modern tools of computational modelling and form a broad basis for 1 and 2.