# Department of Mechanics

KTH, SE-100 44 Stockholm, Sweden

# Activity Report
# 2002

**Contents**

## Preface

This report was compiled to a large extent from information in our data base that forms the platform for our web-pages. Special thanks go to Jan Pralits and Jerome Hoepffner for extracting this information from the data-base. The report reflects the activities of the tenth budget year of the (new) department of mechanics in education, research and other areas.

Stockholm, May 2003

Arne Johansson, department chairman
Gustav Amberg, department vice chairman

# 1 Introduction

This is the tenth annual activity report of the new mechanics department and covers the year 2002. The mechanics department (web address: http://www.mech.kth.se) has about 80 employees and a yearly turnaround of about 65 MSEK. It is also host department for the Faxén Laboratory, a VINNOVA competence centre for the fluid dynamics of industrial processes.

The head of department ('prefekt') is professor Arne Johansson and vice *ditto* ('proprefekt') is professor Gustav Amberg. The study rector ('studierektor') is Hanno Essén.

The department board consists of: Nicholas Apazidis, Fritz Bark, Dan Henningson, Arne Johansson (chairman), Lars Thor, Ingunn Wester, Peter Gudmundsson (prof. Dept of Solid mechanics, external board member), Johan Gullman-Strand (grad. stud. repr.) and an undergraduate student representative.

The teaching activities comprise courses in basic mechanics at almost all parts of KTH, and a large number of higher level and graduate courses on many different aspects of mechanics of solids as well as of fluids.

The final steps towards establishing a new International Master Program in Engineering Mechanics were taken during 2002. This is a joint effort with the Department of Solid Mechanics and is coordinated by Jean-Marc Battini.

The research activities can essentially be classified into major areas of "Fluid mechanics", "Theoretical and Computational mechanics", and "Biomechanics", although no strict boundaries exist between them. During 2002 there were more than 40 active graduate students at the department (about a third of which are associated with the Faxén Laboratory) and more than ten external graduate students in industry and research institutes. Four doctoral degrees and ten licentiate degrees were awarded during 2002.

The Faxén Laboratory (started July 1995) is directed by Professor Fritz Bark. The centre comprises activities at five different KTH departments ('Kemiteknik', 'Materialens Processteknologi', 'Mekanik', 'Pappers- och Massateknik' and 'Hållfasthetslära') and 19 industrial partners. The activities are divided into the program areas of Electrochemistry, Material process technology and Paper technology (for details see section 8).

The Mechanics department has the coordinator role for the Nordic ERCOFTAC Pilot Centre. The coordinatorship is held by Professor Gustav Amberg. A number of partners from the different Nordic countries are members of the centre.

The mechanics department has gradually broadened its research profile. The aim is to have a strong basis in fundamental research in the general area of engineering mechanics and to have a good flexibility and width of application areas. The area of Biomechanics was defined as a strategically important area for the department, where we seek to expand the activities.

The external funding has developed well during the last two years and appears to remain strong, at least, for the near future. During 2002 the department was successful in obtaining new grants from VR, Biofibre Materials Centre, SSF (Applied Mathematics program), EU, STEM, CECOST, private industry, KAW (a large grant for new optical measurement equipment), . . . .

The broadened range of research applications is signified well by the fact that the Mechanics Department had project cooperation (with 'exchange of money') with 11 other departments at KTH, with five other universities in Sweden and with more than 20 companies in Sweden and several other countries.

*Personel related matters 2002 and miscellaneous*

Two new adjunct professors started their (20%) positions during 2002, namely Said Zahrai (ABB) and Per-Olof Thomasson (Thyréns). Said Zahrai is active in the Faxén Laboratory with various aspects of fluid mechanics for the process industry. Per-Olof Thomasson's area is applied structural mechanics.

Daniel Söderberg was appointed as adjunct lecturer ('adjungerad lektor') in Fluid Mechanics with paper manufacturing applications.

Erik Lindborg was appointed as senior lecturer ('lektor') in Fluid mechanics with geophysical applications.

Michael Vynnyky was awarded the Docent degree.

Five new graduate students started.

At the end of 2002 a new position as 'biträdande lektor' in Structural mechanics, a new (20%) position as adjunct lecturer ('adjungerad lektor') in Fluid Mechanics with turbulence model applications, and two new research associate positions were about to be filled.

Prof. em. Sune Berndt passed away on Dec. 15, 2002 at an age of 79 years. Sune Berndt was professor of Gas Dynamics during the period 1977–1989, at the Gas Dynamics department that in 1992 was merged with the departments of Hydrodynamics and Mechanics.

Lars Block, previously a lecturer at the Mechanics Department passed away on July 25, 2002 at an age of 77 years.

The department board met on Feb. 6.

A number of the 'ledningsgruppsmöten' and 'samverkansgruppsmöten' were also held.

Department meetings followed by dinner were held towards the end of the spring and fall semesters.

## 2 Personnel

### Professors

- Henrik Alfredsson, PhD in mechanics, KTH 1983 and Docent there 1985. At KTH since 1977. Extra professor 1986 and professor in Fluid Physics 1989. Research in fluid mechanics, in particular laminar-turbulent transition. Dean of KTH.
- Gustav Amberg, PhD in fluid mechanics, KTH 1986, Docent at KTH 1990. Professor in fluid mechanics 1999. At KTH since 1982. Research in fluid mechanics and heat and mass transfer, in particular with application to materials processes. Department vice chairman.
- Fritz Bark, Ph.D. in Applied Mechanics at KTH 1974. Extra professor in Applied Mechanics 1979, professor in Hydro-mechanics, 1985, all at KTH. Research in fluid mechanics, in particular convection in electrochemical systems and processes in paper technology. Director of the Faxén Laboratory.
- Anders Eriksson, PhD in steel structures, KTH 1981 and Docent there 1988. At KTH since 1976. Professor in structural mechanics 1992. Research in non-linear structural mechanics, in particular computational modelling of instabilities. Vice president of KTH.
- Dan Henningson. M.Eng. MIT 1985, Ph.D. KTH 1988, Docent KTH 1992, Ass. Prof. Appl. Math. MIT 1988-1992. Adj. Prof. Mechanics (20 %) KTH 1992-1999. Professor in fluid mechanics (60 %) 1999- . Research on flow control, linear and non-linear hydrodynamic stability and numerical simulation of transitional flows.
- Arne Johansson, PhD in mechanics, KTH 1983 and Docent there 1984. At KTH since 1977. Extra professor 1986 and professor in mechanics 1991. Research in fluid mechanics, in particular turbulence and turbulence modelling. Department chairman.
- Martin Lesser, Ph.D in Aerosp. Eng. 1966 at Cornell; Bell Labs 1966–71; Inst. Cerac in Lausanne 1971–75; 1975–84 docent and prof. at LuTH; 1984–87 Chairman and full prof. at Dept of Mech. Eng. & Appl. Mech. at Univ. of Penn.; 1987 professor in Mechanics at KTH; research on multibody mechanical systems and the use of computer algebra in mechanics.

### Adjunct professors, guest professor and ‘Biträdande professor’

- Said Zahrai, PhD in Mechanics 1992, Docent KTH 1998, Employed 20% as Adj. Prof. in Fluid Mechanics at KTH (from April 2002) and 80% at ABB Corp. Res. Research on Mechatronics and Fluid Mechanics
- Per-Olof Thomasson, PhD in ‘Stålbyggnad’ 1978, Docent KTH 1978, Employed 20% as Adj. Prof. in Applied Structural Mechanics at KTH (from October 2002) and 80% at TYRéNS AB
- Laszlo Fuchs. Ph.D. in Gasdynamics KTH 1977, Docent KTH 1980. Adj. prof. Applied CFD (50 %), KTH 1989–1994 IBM Sweden (50 %) 1989-1992. Prof. Fluid Mechanics LTH 1994–. Guest Prof. (20%) at the Mechanics Dept, KTH 1994– Research in CFD methods and models, with application to compressible flows and combustion in engines and furnaces.

- Bengt Enflo, PhD and Docent 1965 in theoretical physics, Univ. of Stockholm. Two years at Nordita and one year at CERN. 'Biträdande professor' at KTH since 1996. Research in theoretical acoustics, nonlinear waves, acoustic diffraction. 'Biträdande professor' since 1996. Retired in 2000, but continues on a part-time basis.

**Senior Lecturers** (in Swedish: lektorer)

- Nicholas Apazidis, PhD in mechanics, KTH 1985, Docent at KTH 1994. At KTH since 1977. Research in two-phase flow and shock wave focusing in fluids.
- Anthony Burden, PhD in applied mathematical physics, Univ. of Göteborg 1984. Research on two-point closures for turbulence and computational models for turbulent combustion.
- Ian Cohen, PhD and Docent 1982 in theoretical physics, Univ. of Stockholm. Research in general relativity and computer algebra applications in physics.
- Anders Dahlkild, PhD in mechanics 1988 and Docent 1992 at KTH. Research on two-phase flow. Scientific secretary of the Faxén Laboratory.
- Hanno Essén, PhD in theoretical physics Univ. of Stockholm 1979. Three years in England and Canada. Docent 1986. At KTH since 1988. Research on general relativity and on non-holonomic systems.
- Richard Hsieh, PhD in mechanics 1978, Docent at KTH 1980, at KTH since 1973. Research on continuum mechanics and mechanics of materials.
- Arne Karlsson, TeknL.
- Göran Karlsson, PhD in quantum chemistry 1970 Univ. of Uppsala. Canada and US 1971. At KTH since 1973. Research on education didactics, computer aided learning, distance eduction, computer information systems.
- Erik Lindborg, PhD in Mechanics KTH 1996, Docent at KTH 2001. Senior Lecturer in 'fluid mechanics with geophysical applications' since July 2002. At KTH since 1991. Research in turbulence and fluid mechanics with geophysical applications.
- Arne Nordmark. PhD in mechanics 1992. At KTH since 1984. Docent 1999. Senior lecturer 2001. Research in the dynamics of mechanical systems with discontinuous or impulsive forces.
- Christer Nyberg, PhD in mechanics 1979 KTH. Research in acoustics.
- Lars Söderholm, PhD and Docent 1970 in theoretical physics, Univ. of Stockholm. Two years at Nordita. At KTH since 1980. Research on relativity and continuum mechanics: Klein-Alfvén cosmology, relativistic temperature, material frame indifference, constitutive relations and kinetic theory.
- Anders J Thor. TeknL in mechanics, KTH 1964. At KTH since 1956. Work on standards for quantities and units. Retired 2001, but continues work on standards and some teaching.

- Lars Thor, PhD in mechanics at KTH 1973. At KTH since 1965. One semester of teching in Australia 1990.
- Karl-Erik Thylwe, PhD 1981 in theoretical physics, Univ. of Uppsala. Four years at Univ. of Kaiserslautern and Manchester. Docent 1987. At KTH since 1988. Research on Regge-pole theory and semi-classical phenomena of atom-molecule collisions, nonlinear phenomena of dynamical systems, asymptotic methods.

**Lecturers and researchers** (in Swedish: biträdande lektor, förste forskare, adjunkter, 1:e fo.ing.)

- Jean-Marc Battini ('fo.ing och vik. bitr. lektor'), PhD in Building Mechanics 2002, at KTH since 1994. Research in non-linear finite elements and instability
- Gunnar Maxe, ('adjunkt')
- Pär Ekstrand, Responsible for the department's computer system
- Nils Tillmark, TeknD 1995, Responsible for the department's lab. facilities
- Michael Vynnycky ('förste forskare'), PhD Univ. of Oxford, Lecturer at Univ. of East Anglia, Norwich 1991-92, Extended research visits in Japan 1992-96, Docent at KTH 2002, at KTH from 1997.
- Barbro M. Klingmann, PhD in Fluid Physics, KTH 1991. Postdoc at EPFL Lausanne and Novosibirsk 1992-94 and at Volvo Aero. 1994-1996. Docent at KTH 1996, Research on transition and turbulent separation.

**Adjunct Lecturers** (20% of full time position)

- Daniel Söderberg, PhD in Fluid Mechanics 1999. Adjunct lecturer in fluid mechanics with paper manufacturing application, since December 2002.

**Technical and administrative staff** (in Swedish: TA-personal)

- Lars Bjernerstam
- Marcus Gällstedt
- Ulf Landén
- Katti Lindfors
- Anne-Mari Olofsson

- Hans Silverhag (chefsadm./ekonomiansvarig)
- Stefan Skult
- Viviana Wallin
- Ingunn Wester (chefsadm./personalansvarig)

**Professors emeritii**

Bengt-Joel Andersson
Sune Berndt (died on December 15, 2002)
Stig Hjalmars

**Graduate students** (in Swedish: doktorander)

Daniel Ahlman
Anders Ahlström
Kristian Angele
Jean-Marc Battini
Karl Erik Birgersson, Faxén Laboratory
Karl Borg
Luca Brandt
Arnim Brüger
Carl-Ola Danielsson
Minh Do-Quang
Jessica Elfsberg, Faxén Laboratory
Johan Eriksson
Luca Facciolo
Aleksandar Filipovski
Jens Fransson
Kazaya Goto
Olof Grundestam
Johan Gullman-Strand
Astrid Herbst
Jérôme Hoepffner
Richard Holm, Faxén Laboratory
Claes Holmqvist, Faxén Laboratory
Thomas Hällqvist
Nulifer Ipek, Faxén Laboratory
Jenny Kron, Faxén Laboratory
Mats Larsson, Faxén Laboratory
Ori Levin
Björn Lindgren

Irina Loginova
Fredrik Lundell
Olivier Macchion, Faxén Laboratory
Davide Medici
Gustaf Mårtensson, Faxén Laboratory
Sofia Nilsson
Per Olsson
Petri Piiroinen
Jan Pralits
Henrik Sandqvist
Junichiro Shiomi
Timmy Sigfrids
Gunnar Tibert
Olle Törnblom
Roland Wiberg, Faxén Laboratory
Tom Wright
Jan Östlund

**External graduate students** (not employed by department of mechanics)

Leonard Borgström, Alfa Laval, Tumba
Mattias Chevalier, FOI/FFA
Jan Eriksson, Vattenfall Utveckling AB, Älvkarleby (FLA)
Jan-Erik Gustafsson, STFI
Jonas Gunnarsson, Bombardier (FLA)
Marco Hyensjö, Metso Paper (FLA)
Ulrike Windecker, ABB, (FLA)
Hans Moberg, Alfa Laval, Tumba
Andreas Möller, FOI/FFA
Lars Tysell, FOI/FFA
Ulrike Windecker (FLA) ABB Corp. Res.
Federica De Magistris, STFI

There are further graduate students associated with FLA but employed at other departments at KTH (see section 8).

# 3 Laboratory facilities, computers

## 3.1 Laboratory facilities

The department has a laboratory with several experimental facilities for research and student laboratory exercises. Among the larger research facilities the following are of interest for the present project:

- MTL subsonic wind tunnel, 7 m long (1.2 m $\times$ 0.8 m) test section, max. speed 69 m/s
- BL subsonic wind-tunnel, 0.5 m $\times$ 0.75 m test section, max. speed 48 m/s
- plane Couette flow apparatus with and without system rotation
- asymmetric diffuser facility for studies of turbulent separation and control
- plane Poiseuille flow apparatus (2m$\times$0.8m) for transition and control studies, etc. (not operational at present)
- two-dimensional contraction for studies of turbulence undergoing strain and also relaminarizing boundary layers
- Maragoni convection set up for studies of stability and control in an annular geometry (flow cell has diameter of 6 mm).
- rotating pipe flow apparatus (6 m long, 60 mm diameter) for studies of rotation effects of pipe flow and swirling jets
- new shock-tube for shock wave focusing experiments is under construction and is planned to be taken into operation during 2003

A major facility is the MTL wind-tunnel, which is a low-turbulence wind-tunnel with outstanding flow quality - the turbulence level is as low as 0.02 %. It is and has been used for a variety of long-term research projects on hydrodynamic stability and laminar-turbulent transition, flow separation, turbulence structure and control. Eight PhD-thesis, where the experiments have been carried out in the tunnel, have been completed since the tunnel became operational in the beginning of the 1990's. Several projects engaging two PhD students and two post-docs are presently active in the tunnel (May 2003). The tunnel has also been instrumental in attracting guest researchers and post-docs to the department from various countries (e.g. Germany, Italy, Japan, Russia, USA, England, France Uruguay).

A smaller wind tunnel (BL wind-tunnel) based on the same concept as the MTL-tunnel was taken into operation during 1999 both for research and education purposes. This tunnel is especially suitable for optical measurement techniques since it allows easy optical access. It is also possible to fit with various test sections, and has been used for studies of separating turbulent boundary layers.

The department also shares a continuously running supersonic wind-tunnel, 0.1m×0.1m test section, with ‘continuously’ variable Mach number (0.3–2.5). The wind-tunnel is located at the Department of Energy Technology, KTH.

The measurement techniques used in the laboratory comprise most standard and as well as modern measurement techniques. The laboratory has developed the hot-wire anemometry technique systematically, especially regarding probe manufacturing and miniaturizing. Recent development work deals with using hot-wires also in transonic and supersonic flows.

Flow visualization techniques, based on smoke visualization have been developed for boundary layer transition work, and pictures from these flow visualizations has been well received and are nowadays appearing as introductory material in many lectures at conferences. The laboratory also has some equipment for flow visualization in compressible flows, such as a Schlieren system with possibility for short duration double flash exposure, and a high speed camera (up to 500 frames per second). Development has also been made regarding temperature sensitive paint for determining surface temperature distributions in connection with heat transfer measurements. Recently work has started in order to evaluate the use of pressure sensitive paint.

In terms of optical measurement techniques the laboratory has access to Laser-Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV). PIV has since its introduction in the laboratory found its use in many different projects ranging from large wind-tunnel studies to very small measurement volumes. A significant amount of development work has been ongoing both for seeding techniques and data evaluation. The results from PIV have been extremely valuable and could not have been obtained with other methods.

## 3.2 Computers

The department has a computer system consisting 32 AMD Athlon 2400+ and 2000+ workstations running Debian Linux. There are also around 70 PC:s/Mac:s and a Compaq AlphaServer ES40 to serve as a number cruncher. It has four EV6 500MHz processors and a total of 3 GB shared memory. Eight Debian Linux servers and two Windows 2000 servers provide services for the Department like mail server and file storage.

The department also has an active role in the Kallsup consortium that has access to a large IBM SP-machine with 36 Nighthawk II nodes.

# 4 Economy

A brief overview of the different categories of incoming resources to the department is given below for 2002. The FLA sum does not inlude in-kind contributions.

INCOME (in Mkr)

| | *Dept. total* |
|---|---|
| Education (GRU) | **16** |
| Research (FOFU) | **20** |
| External | **19** |
| FLA (external) | **10** |
| $\Sigma$ | **65** |

The external funding is mainly composed of grants from VR, STEM, VINNOVA, SSF, MISTRA, BIMAC, The Göran Gustafsson Foundation and private industry.

A strong external funding is a key factor behind the presently strong economical situation for the department, and for the FoFu side in particular.

# 5 Teaching activities

## 5.1 Undergraduate courses

**Basic courses (grundkurser)**

| School | Year | Course no. | Credit | Name |
|---|---|---|---|---|
| K | 1 | 5C1102 | 4 | Mechanics, Smaller Course |
| F, V , I , M , T , VBI | 1 | 5C1103 | 6 | Mechanics, Basic Course |
| D | 2 | 5C1105 | 4 | Insights in Mechanics; Modelling and simulation |
| E, T , B | 2 | 5C1111 | 4 | Mechanics, Continuation Course |
| B, M | 2 | 5C1112 | 4 | Mechanics, Continuation Course |
| F | 2 | 5C1113 | 4 | Mechanics, Continuation Course |
| V, VBI | 2 | 5C1114 | 4 | Mechanics, Continuation Course |
| T | 2 | 5C1201 | 8 | Fluid Mechanics with Thermodynamics, for T |
| F | 3 | 5C1202 | 4 | Fluid Mechanics, Introductory Course |

**Structural mechanics (Byggnadsstatik)**

| School | Year | Course no. | Credit | Name |
|---|---|---|---|---|
| V | 3 | 1C1103 | 5 | Structural Mechanics III |
| V | 2 | 1C1109 | 5 | Structural Mechanics I |
| V | 2 | 1C1115 | 5 | Structural Mechanics II |
| V | 4 | 5C1840 | 5 | Structural Dynamics |
| V | 4 | 5C1850 | 5 | Finite Element Methods |
| V | 4 | 1C5032 | 5 | Structural Dynamics, Advanced Course |
| M, T, V | 4 | 5C1860 | 5 | FEM Modelling |

**Advanced courses (högre kurser)**

| School | Year | Course no. | Credit | Name |
|---|---|---|---|---|
| B, M , T | 3 | 5C1121 | 4 | Analytical Mechanics |
| B, F , M , T | 4 | 5C1122 | 4 | Continuum Mechanic |
| F, T , M | 4 | 5C1123 | 4 | Mathematical Methods of Mechanics, General Course |
| T, M , F | 4 | 5C1125 | 2 | Mathematical Methods of Mechanics, Intermediate Cours |
| F, T , M | 4 | 5C1400 | 5 | Nonlinear Dynamics in Mechanics |
| M, F , T | 4 | 5C1902 | 4 | Advanced Dynamics of Complex Systems |
| F, T , M | 4 | 5C1904 | 4 | Advanced Modern Mechanics |
| F, T , M | 4 | 5C1980 | 4 | Applied Mechanics |
| | | | | |
| T, F | 3 | 5C1203 | 4 | Fluid Mechanics, General Course |
| M, F , T | 4 | 5C1205 | 4 | Compressible Flow, General Course |
| M, T , F | 4 | 5C1207 | 5 | Boundary Layer Theory and Thermal Convection |
| T, F , M | 4 | 5C1208 | 2 | Fluid mechanics, continuation course |
| F, M , T | 4 | 5C1209 | 2 | Compressible flow, continuation course |
| T, M , F | 4 | 5C1210 | 4 | Experimental Methods in Fluid Mechanics |
| F, T , T , M , F , M | 4 | 5C1211 | 4 | Vehicle Aerodynamics |
| E, F , M , D , T | 4 | 5C1212 | 5 | Computational Fluid Dynamics |
| D, F , E , T , M | 4 | 5C1213 | 2 | Applied Computational Fluid Dynamics |
| M, I | 3 | 5C1921 | 4,5 | Fluid Mechanics for Engineers |
| F, M , T | 4 | 5C1992 | 4,5 | Turbulence |

## 5.2 Graduate courses

During 2002 the following graduate courses ('forskarutbildningskurser') were given (some of which were given in combination with the corresponding undergaduate course). In addition several reading courses were given.

5C5105 Fluid Mechanics, Advanced Course
5C5112 Turbulence
5C5113 Compressible Aerodynamics
5C5114 Numerical Methods in Fluid Mechanics
5C5118 Boundary layer theory and thermal convection
5C5130 Micro Fluid Mechanics
5C5001 General and analytical mechanics
5C5003 Relativistic mechanics
5C5006 General continuum mechanics
5C5107 Mathematical methods of mechanics
5C5045 Non-linear oscillations and dynamical systems
1C5049 FEM modelling
1C5020 Finite Element Methods, Advanced course.

### 5.3 Master thesis projects ('examensarbeten')

- Dobo, Alexander, "Modellering och dimensionering av passagerarlandgångar i ROBOT Millennium". Master Thesis Rep. 02/01 (Advisor: A. Eriksson)
- Cardano, Davide, "Experimental analysis of the turbulence development inside a two-dimensional contraction". Master Thesis Rep. 02/02 (Advisor: H. Alfredsson)
- Karlsten, Per & Larsson, Fredrik, "Modeling Impact Loads on Structural Columns". Master Thesis Rep. 02/03 (Advisor: A. Eriksson)
- Nilsson, Sofia, "Simulation of Bone Mechanics". Master Thesis Rep. 02/04 (Advisor: A. Eriksson)
- Eriksson, Fredrik, "Dynamically adjusted manoeuvre profiles for reducing residue vibrations in a few-body flexible joint manipulator arm". Master Thesis Rep. 02/05 (Advisor: K.-E. Thylwe)
- Kamberovic, Edin, "On parametric manipulation of harmonic oscillations by an asymmetric pulse". Master Thesis Rep. 02/06 (Advisor: K.-E. Thylwe)
- Stålberg, Erik, "A Preconditioning Method for a Compressible Navier-Stokes Code". Master Thesis Rep. 02/07 (Advisor: D. Henningson)

# 6 Research areas - short project description

## 6.1 Theoretical and computational mechanics

### Shock wave propagation in fluids

*Researcher(s):* Martin Lesser, Nicholas Apazidis

*Sponsor(s):* VR

This project deals with propagation of shock waves in liquids and liquid impact problems. Generation, reflection and convergence of shock waves in confined chambers of various forms is investigated on the basis of Whitham‘s non-linear theory of geometrical shock dynamics. This theory has been extended by a new theoretical and computational method, developed by Apazidis & Lesser (1996). The method can be applied to the propagation of shocks arbitrary in strength and form into a medium with no-homogeneous flow conditions. Calculations based on the new approach have been applied to the problems of shock reflection and convergence in various types of confined chambers. It is shown that by an appropriate choice of the form of the reflector boundary one may obtain reflected shock waves having desirable shapes, for example a near-square shape. Also reflectors with parabolic geometry are considered. A cylindrical wave is generated at the focus of the parabolic cross-section. It is shown that contrary to the linear case the reflected wave is no longer planar. Experimental investigations of shock focusing in a thin confined chamber with a reflector boundary in the form of a slightly perturbed circle have been carried out. Experimental results confirm the possibility of producing polygonally-shaped converging shocks. Technological and medical applications of the project may be found within the fields of shock wave propagation, shock induced collapse of cavities, erosion, disintegration of kidney and bladder stones by means of a shock wave attenuation in lithotriptor devices.

### Human and machine locomotion

*Researcher(s):* Harry Dankowicz, Arne Nordmark, Petri Piiroinen

The inherent dynamics of a bipedal, kneed mechanism are studied with particular emphasis on the existence of stable three-dimensional gait in the absence of external, actively regulated, control. Suitable modifications of geometry and mass distributions are suggested to afford implementation of walking in complicated and potentially changing terrain. Originating in the pioneering work by McGeer and others, the approach is based on the assumption that satisfactory walking motion under actuation can be achieved more efficiently once the mechanism‘s natural dynamics have been accounted for. Thus, the need for actuation is minimized by controlling the system about a motion dynamically achievable by the passive system, rather than imposing a behavior far from such a motion.

*Publication(s):* (2), (54)

**Theoretical investigations of underwater sound**

*Researcher(s):* Bengt Enflo

*Graduate student(s):* Henrik Sandqvist

*Sponsor(s):* KTH

The project is to study theoretically the propagation of underwater sound under conditions similar to those occurring in realistic applications. That means that refraction and the stratification of the medium are taken into account. Nonlinear effects are taken into account: low frequency narrow beams are assumed to be produced by nonlinear interaction of fundamental monochromatic waves (so called parametric radiators). Attempts are made to find, numerically and analytically, solutions of generalizations of Burgers‘ equation, which describe sound beams in dispersive and inhomogeneous media.

**Diffraction of sound by noise barriers**

*Researcher(s):* Bengt Enflo

*Graduate student(s):* Ivan Pavlov, Henrik Sandqvist

*Sponsor(s):* BFR, KFB

Noise from traffic, fans, motors etc. is often shielded by barriers. In normal design the top edge of a noise barrier is straight. The edge may act as a string of highly correlated point sources. The effectiveness of the barrier is reduced by the coherence of these secondary sources. Experiments at The University of Texas show that the effectiveness of the barrier can be increased if it is made irregular. The project aims at understanding of these phenomena by theoretical methods. It will continue with theoretical and experimental investigations of possibilities of increasing the effect of sound barriers.

**Dynamics of Moderately and Highly Rarefied Gases**

*Researcher(s):* Lars Söderholm

*Graduate student(s):* Karl Borg

*Sponsor(s):* KTH

When the size of a body in a gas approaches that of the mean free path, the continuum description of the Navier-Stokes equations no longer holds. In particular, in the limit where the body is small compared to the mean free path, the physics of the flow is very different from ordinary fluid dynamics. One example is that a thin wire, which in the continuum regime will be cooled by the flow, in the opposite regime instead is heated. A well-known transport in a rarefied gas is thermophoresis, which is caused by a temperature gradient. It has been studied for a long time, but mostly for spherical particles. In the present project thermophoresis of axially symmetric particles is considered. A new phenomen, named shearing phoresis, has been discovered, a transport which occurs when the gas is shearing. The transport of rotating spherical bodies is also studied, in particular the Magnus force in a rarefied gas.

*Publication(s):* (1)

### Relativistic dissipative dynamics of gases

*Researcher(s):* Lars Söderholm

Relativistic fluid dynamics has to be applied when macroscopic or thermal speeds are comparable to the speed of light.There is a rather straightforward relativistic generalization of the compressible Navier-Stokes equations, which is often used. It is, however, unsatisfactory in the sense that it is non-causal. The system of equations is partly parabolic. Shear disturbances propagate with infinite speed in the rest frame of the gas, which means backward in time in other frames. To overcome this problem, equations closely related to a truncated Grad system for the Boltzmann equation have been constructed by Müller, Israel and Stewart and later developed into a mature mathematical theory by Hiscock, Lindblom and others.

As, however, a truncated Grad system is not correct even to first (Navier-Stokes) order in the Knudsen number, a first step in the present investigation was to derive from the Boltzmann equation a modified 14 moments system, which is correct to first order. For this system, all modes propagate as waves. A next step is the study of the nonrelativistic limit of the Müller-Israel-Stewart equations. A kinematic concept is introduced, related to Fermi-Walker propagation, which considerably clarifies the nonrelativistic limit of the equations. A basic object of the continuing investigation is to determine the physical accuracy of the different equations.

### Semiclassical Mechanics

*Researcher(s):* Karl-Erik Thylwe, H. Korsch

*Sponsor(s):* NFR

In order to understand details of atoms and molecules interacting with external fields, it is essential to understand the underlying classical theory of timedependent Hamiltonian systems. Theoretical research in this area is of basic importance for interpreting and predicting a growing body of experimental data obtained by the most sophisticated experiments. The semiclassical research topics include: * New time-dependent normal forms for resonant dynamics. The usual semiclassical theory of tunnelling through chaotic separatrix regions, resulting in the splitting of degenerate quasi energies, gives merely a rough estimate of the spectrum and would benefit from a more detailed level of approximation. * A unified complex angular momentum theory for scattering models used in analysing spectra of quantized biliard systems. This would clarify the identification of classical and non-classical (ghost) contributions. * The development of new semiclassical approximations for field switching in single and more-dimensional states. These provide an understanding of nonadiabatic effects beyond the perturbation theory and provide transparent link between transition probabilities and switching profiles in quantum optics models.

**Nonlinear wave propagation in fluids**

*Researcher(s):* Lars Söderholm

*Sponsor(s):* KTH

The focus in this project is on the study of higher order effects in nonlinear wave propagation. Such effects are responsible for many important wave phenomena. One example is that of the generation of a wave propagating in the direction opposite to the original wave. This is an effect, which particularly takes place at a discontinuity. A further phenomen is that of the generation of a constant component, related to acoustic streaming. An equation for nonlinear acoustics has been derived from the compressible Navier-Stokes equations. It is exact in the Mach number and correct to first order in the dissipative (Knudsen) number. Terms of the order of Mach number times the Knudsen number are neglected. When the Mach number is of the order of the Knudsen number, the derived equation reduces to the well-known Kuznetsov equation of second order nonlinear acoustics. The equation is applicable to any equation of state. This equation is the basis of the continuing study. Within the same range of approximation, waves propagating in one direction are being studied.

*Publication(s):* (44)

**Optimization of Middle Ear Replacement Device**

*Researcher(s):* Martin Lesser

*Graduate student(s):* Tom Wright

*Sponsor(s):* KTH

The object is to find possible simple replacement mechanisms that will replicate as far as possible the functions of the middle ear bone linkage. This involves both determining an appropriate model of the middle ear and a study of simplified models which show the same dynamic behaviour.

**Dynamic simulation of wind power plants (VindSim)**

*Researcher(s):* Anders Eriksson

*Graduate student(s):* Anders Ahlström

*Sponsor(s):* STEM

The project aims at developing and evaluating simulation models for complete wind power structures. The objective is to use these models for evaluation of strength and stability aspects of the structures, giving an improved understanding of estimated life spans and safety margins. The simulation models should utilize common modelling descriptions, typically finite elements, in order to allow different building paradigms. For the utilization of results from stochastic simulations, the modelling must be balanced in accuracies. The project is expected to give an improved understanding of the structural mechanical aspects of wind power structures, thereby improving the possibilities for quantitative descriptions of final or suggested configurations. This can eventually lead to optimization methods for the structures, under given assumptions on position and environment. A few examples will be shown in the project.

**Buckling and collapse behaviour of optimised thin-walled structures (cont.)**

*Researcher(s):* Anders Eriksson

*Graduate student(s):* Aleksandar Filipovski

*Sponsor(s):* VR

Consideration of non-linear phenomena is a necessary consequence of structural optimisation. Coupled with resulting instabilities and dynamic phenomena, a pronounced sensitivity with respect to initial imperfections, and to parametric variations will normally be present. Basic numerical procedures for treatment of structural non-linear problems have been developed in previous and the ongoing project. The proposed continuation project aims at the verification of the numerical models, when compared to performed experiments on failure behaviour of optimised, thin-walled aeronautical structures. The main parts of the work will be directed towards the inclusion of more relevant material descriptions in the developed finite elements, the dynamic and static instability investigations of the structures, and the further improvement of the unique numerical algorithms for the parameterised response description of the structures. The project will be closely connected to the main lines of development within the group.

**Active and Passive Damping with Applications in Manufacturing.**

*Researcher(s):* Göran Karlsson

*Sponsor(s):* Swedish Institute

Sponsor: Swedish Institute Project 2657/2001. This project is a three year project in cooperation between Dept. of Mechanics, Dept of Industrial Production, KTH,Stockholm (Mihai Nicolescu) and Institute of Solid Mechanics of the Romanian Academy, Bucharest. The project started in September 2001 and it objectives are:

(i) Development of passive and active vibration control based on damping technologies to substantially improve the dynamic behavior of manufacturing systems.

(ii) Theoretical studies and practical applications of damping materials, such as viscoelastic and piezoelectrics, for increasing dynamic stability of manufacturing systems.

(iii) Modelling and analysis methodologies and tools for viscoelastic and piezoelectric materials.

(iv) Establish a reference base on the subject.

(v) Organize common workshop, conferences or meetings.

(vi) To facilitate the access of young researchers from Romania to KTH/facilities that are essential for high quality research.

(vii) To improve the scientific and technological level and to contribute to attainment of a general level of scientific excellence (PhD courses, workshops and meetings).

(viii) To give the opportunity to young Romanian scientists to work at their doctor‘s thesis at KTH.

**Simulation of Flexible Structures**

*Researcher(s):* Gunnar Tibert

*Sponsor(s):* VR

Using the concept of deployable structures, and in particular inflatable space antennae, as a background target area, a few basic areas of computational structural modelling are studied. The specific objective for the space structures is to create minimum weight, minimum volume solutions for transport into and deployment to operational form in space. The simulation of these structures demand several computational analyses of dynamic and instability behaviour. The main work in the proposed project is the development of computationally accurate and efficient elements, primarily for thin membranes, using theories for large rigid deflections, and small but finite elastic deformations. Also, the control mechanisms for the deployment, are of major computational interest. The project parts will, together with previous and ongoing work in the group, give basic simulation tools, presently not available in commerical software, and an improved phenomenological understanding of the mechanical behaviour of these structures. Although primarily aiming at space structures, the studies are also highly relevant for many other types of optimized structures, including robotics, and the mechanical studies of biological tissues, but also for medi-technical small-scale applications.

**New measurement techniques of complex attractors of mechanical systems**

*Researcher(s):* Arne Nordmark, Annika Stensson

*Graduate student(s):* Johan Eriksson

*Sponsor(s):* VR

The objective of this work is to develop devices for the measurement of the dimension of attractors of mechanical systems. This is intended as an analytical tool for determining the causes of seemingly random behaviour in actual mechanical systems such as vehicles. The main idea is to develop definitions of dimension that connect with the measurement process and retain a close relation to more classical dimension concepts like correlation dimension.

**Modelling, simulation and control of nonsmooth dynamical systems - SICONOS**

*Researcher(s):* Arne Nordmark, Annika Stensson, Lars Drugge, Jenny Jerrelind, Anders Klarbring

*Sponsor(s):* EU

The purpose of the project is to develop algorithms and software for the simulation and feedback control of dynamical systems which are nonsmooth, and more specifically so-called complementarity dynamical systems. Nonsmoothness is usually introduced into the system either by some nonsmooth control action or by the presence of nonsmooth events at a macroscopic level (such as impacts or switchings). Nonsmooth models abound in many engineering systems such as sliding mode or hybrid control and rigid body mechanics such as rattle of automotive components and other mechanical freeplay, and switching circuits in power electronics.

The research will tackle two fundamental issues head on. Firstly, that smooth numerical methods fail on nonsmooth systems. Algorithms need to be developed that deal with hit crossings, impacts, complementarity problems, sliding and chatter in a robust and easily applicable way. Secondly, the qualitative understanding of the dynamics including the design of feedback and robust control algorithms requires specific methods and cannot be solved with simple adaptations of known techniques for smooth linear or nonlinear dynamical systems.

## 6.2 Biomechanics

### Biomechanical simulations of the Skeleto-muscular system

*Researcher(s):* Anders Eriksson, Kazuya Goto

*Sponsor(s):* KTH

This trans-disciplinary project aims at an improved understanding of the skeleto-muscular system in the human body. It takes as its background clinical and experimental knowledge on the behaviour of muscles and muscle cells, and connects this to the computational modelling of mechanical systems. The background knowledge is used to develop relevant and computationally efficient numerical models for skeleton muscles in the human body. These numerical models are created for the use in a general mechanical simulation context, focussing on the description of dynamic loading and movement situations. Aspects of the motor control systems will also be considered in the project, in particular with reference to the force distribution in synergistic muscles. A special interest will be directed towards the fatigue aspects of muscles, and their effects on the force-movement relations in the muscle model. The project will lead to an improved knowledge on the behaviour of the skeleto-muscular system, when subjected to impact or sustained high loading conditions. Due to its trans-disciplinary approach, it will lead to new development in the mechanical understanding of human locomotion and work, but also to new ideas for the physiological experimentation on muscle behaviour. The aim is also, in addition to developing the framework of a general simulation algorithm, to give at least some result of clinical interest on the damage or injury of a human joint.

### Simulations of post-surgical upper limb capacity

*Researcher(s):* Anders Eriksson

*Graduate student(s):* Sofia Nilsson

*Sponsor(s):* KTH

This trans-disciplinary project aims at an improved modelling of the capacity of the upper limb, with a primary application to post-surgical capacity after restorative surgery, including only a subset of original muscles. This modelling can be assumed to be a useful planning tool for surgeons, in the treatment of more or less fully paralyzed patients. The project essentially consists of three parts, where the development of a kinematical description of upper limb movement patterns and algorithms for the distribution of forces between synergistic muscles are the two theoretical, numerical parts. The third part of the project is a clinical, experimental verification of the developed model.

**Biomechanical modelling of eye accomodation**

*Researcher(s):* Anders Eriksson, Daria Lioubimova

*Sponsor(s):* KTH

The project deals with the mechanical modelling of accommodation of a human eye. Using clinical and experimental data concerning the behavior of an eye as a background, and combining this with technical shell modelling knowledge, a few basic areas of computational structural modelling are studied. The background knowledge is used to accurately describe the geometry of the lens and its parts, but also to develop relevant and efficient numerical models.

The main work in the proposed project will be done in the context of a general mechanical simulation, using non-linear analysis and considering small but finite elastic deformations. Material data of the constituent parts are an important part of work. Aspects of presbyopia and its relation to age will also be considered in the project. Special interest in the simulations will be directed towards the influence of the vitreous and its effects on the force-movement relations in the model.

The project will lead to an improved phenomenological understanding of the mechanical behavior of the structure and will give improved knowledge on the process of accommodation. In addition to developing the framework of a general simulation algorithm, the aim is also to give at least some results of clinical interest concerning the process of accommodation in connection to the reversal of presbyopia and the prevention of glaucoma and cataract.

## 6.3 Fluid mechanics

### Experiments on wall bounded shear flows

*Researcher(s):* Henrik Alfredsson, Nils Tillmark, Alessandro Talamelli, Shuya Yoshioka

*Graduate student(s):* Fredrik Lundell, Jens Fransson, Luca Facciolo, Davide Medici

*Sponsor(s):* VR, STEM, Carl Tryggers stiftelse, KTH

This project deals with the transition to turbulence in laminar boundary layers, and various methods to control and hopefully delay the transition process. Several studies in our laboratory have dealt with the receptivity of the laminar boundary layer to free stream turbulence, through detailed velocity measurements in the MTL wind tunnel, where free stream turbulence is generated by different grids. Both flow visualisation and hot-wire measurements (one and two-point) have shown that the interaction with the boundary layer gives rise to elongated structures of high and low velocity. The streaks are susceptible to secondary instabilities and will subsequently break down into turbulence. In the doctoral thesis of Lundell (2003) a sucecsful attempt was made to control the breakdown process by an active control method, where hot-wires mounted at the wall detected low velocity streaks and control was made by localized suction through small holes.

Another way to control boundary layer flows is to use distributed suction over a large surface. This is done in an experiment where the asymptotic suction boundary layer could succesfully be obtained (maybe for the first time in an exepriment). The effect both on wave disturbances and free stream turbulence induced disturbances are investigated and it is shown that suction may have a strong stabilizing effect. Presently the effect of both suction and blowing on a turbulent boundary layer is studied.

The effect of axial rotation on the structure of rotating pipe flow as well as the emanating jet from a rotating pipe is studied in a newly constructed apparatus. The final goal of the study is to investigate the structure in the near wall region of a swirling impinging jet, with focus on the resulting heat transfer.

The development and interaction of wind turbine wakes in wind farms is an important reserach area and may determine how close wind turbines can be placed in a wind farm. The research aims at actively controlling the turbine yaw and thereby avoiding interference between turbines. This may enhance the total power output of the wind farm as well as avoiding turbulence approaching individual turbines which could cause fatigue.

**Numerical Simulation of Flows of Fluids Containing Small Particles.**

*Researcher(s):* Laszlo Fuchs

*Graduate student(s):* Per Olsson

In multiphase flow, the models used to describe the resence of particles in a fluid usually ignore the force interaction among particles and a fluid flow governed by the Navier-Stokes' equations. In order to gain some insight into the physical phenomena in a microflow environment, we study the interaction among fixed and moving solid spheres and the surrounding fluid. Due to the presence of attracting and repelling forces that depend on the geometrical configurations, one can expect an intensive and complex motion of the particles when they are allowed to move freely. Due to this effect simple rheological (isotropic) models are inadequate.

**Boundary layer transition - Theory and DNS**

*Researcher(s):* Dan Henningson

*Graduate student(s):* Luca Brandt

*Sponsor(s):* FOI, VR

This project involves research to determine the maximum growth possible of disturbances evolving according to linear theory, as well as to investigate the importance of this growth when non-linearity comes into play. Several shear flow types have been considered. The results show that non-modal growth, i.e. growth not associated with individual eigenmodes but inherently dependent on their superposition, can cause large transient amplification. This growth is mainly associated with streaky structures in the streamwise direction. Non-linear calculations have shown that when the optimal disturbances from linear theory are used as initial conditions, the threshold amplitudes required for transition to turbulence is lower than for general disturbances. Recent calculations have also shown that these results carry over into the spatial development of disturbances in boundary layers.

Another part of the project involves direct numerical simulations (DNS) of transition to turbulence where these transient growth mechanisms play a major role. This bypass of the traditional Tollmien-Schlichting instability waves is involved in many shear flow transition scenarios. Previously transition associated with localized disturbances have been investigated, and at present the transition in boundary layers starting with a pair of oblique waves is investigated. These waves generate elongated streakss in the streamwise velocity which rapidly grow due to the non-modal mechanism. The secondary instability of these streaks has also been studied, both using DNS and secondary instability theory.

A new direction in the project is to simulate transition in a boundary layer subjected to free-stream turbulence, where the turbulence is initiated close to the leading edge by a random distribution of continuous spectrum modes.

*Publication(s):* (13), (5)

**Active Control of Boundary-Layer Transition**

*Researcher(s):* Dan Henningson, Martin Berggren, Markus Högberg

*Graduate student(s):* Mattias Chevalier, Jérôme Hoepffner

*Sponsor(s):* NGSSC, FOI, VR

Study and design of active control strategies for transition in boundary layer flows is done within this project. The control strategies are designed using the optimal-control approach to control of the Navier-Stokes equations and use the adjoint-equation technique for associated gradient computations. Linear optimal control techniques based on the Riccati equation are also explored, where spatially localized convolution kernals have been obtained for both control and estimation. The strategies are applied to control or delay of bypass transition as well as other flow instabilities. The performance of these control laws is quantified in direct numerical simulations by computing transition thresholds. We have shown that the threshold values can be increased by about 500% for random perturbations. By using a physically motivated modification of the objective function we have shown that the linear controllers are also able to relaminarize a low Reynolds number turbulent flow. A new direction of this research is to calculate and evaluate these controllers and estimators for more complicated boundary layer flows such as Falkner-Skan and Falkner-Skan-Cooke flows.

**Modern stability prediction methods and control.**

*Researcher(s):* Dan Henningson, Martin Berggren

*Graduate student(s):* Ori Levin

*Sponsor(s):* KTH, STEM, FOI

The project concerns a new transition prediction tool which is being developed in cooperation with DLR in Gottingen. The code uses the parabolized stability equations (PSE) and is so far based on the linearized equations. The method uses a wave ansatz with a slowly varying amplitude function and wave number, similar to the WKB method. In addition an auxiliary condition is introduced which ensures uniqueness of the solution so that the traditional WKB expansion can be avoided. This method has proven to be efficient and to produce accurate stability results for complicated glows. It has been carefully checked against existing solutions and will be extended to handle non-linear interactions between wave components.

Applications motivating the development of this method is the hypersonic transition research carried out within the ESA FESTIP program and laminar wing design carried out in the CEC EUROTRANS and ALTTA programs.

Another direction in this research is to use optimization methods to predict the transition location in flows with high free-stream turbulence levels. This is done using adjoint methods, similar to those used in the active control project, and parabolic approximations for the stability problem. A new transition prediction method has been proposed. The later stages of transition induced by high free-stream turbulence levels have been studied using secondary stability analysis.

### Direct numerical simulation of turbulent separation and separation control

*Researcher(s):* Dan Henningson, Martin Skote

*Graduate student(s):* Astrid Herbst

*Sponsor(s):* PSCI, STEM, FOI

Multidisciplinary issues are increasingly affecting performance and complicating the aeronautical design process. There are advanced ideas of use flow control to improve performance, in particular in conditions when inherent sensitivities or instabilities in the flow could be utilized to accomplish large effects by small controls, e.g. flows with substantial regions of separated flow. In addition, correct modeling of turbulence is one of the most crucial areas for design computation of flow around aircraft configurations, including wings and air intakes. Current models are not accurate enough for many common flow cases, especially when they contain zones of separated flow.

Direct numerical simulations (DNS) of turbulent boundary layers with adverse pressure gradients and separation have been performed, including some very larg supercomputer simulations. The data has been used to evaluate models of separated turbulent flow.

A new direction in this project is aimed at control of flow separation in diffusor flows with application to modern engine air intakes. The objective is to obtain a numerical implementation of a complete flow control system for separated flow in a diffusor. This includes DNS/LES flow solvers, modelling of flow sensors and actuators and active flow control algorithms.

*Publication(s):* (4), (3)

### Optimal design of vehicles with low drag.

*Researcher(s):* Dan Henningson

*Graduate student(s):* Jan Pralits

*Sponsor(s):* SSF, IVS

The project aims at developing methodology needed for optimal design of vehicles with low drag. The general objective is to link aerodynamic computational tools with optimization techniques to create a more automated flow design process in order to improve flow efficiency. The sensitivity of the predicted drag, say, on the design parameters chosen can then effectively be determined by the use of so called adjoint methods. The aim is to automatically incorporate a transition prediction method into the design process of low-drag vehicles. This chosen problem should be seen as one interesting example where these optimal design methods can be applied. The techniques developed in the project are general and once mastered could be applied in a number of other design applications.

*Publication(s):* (45), (30), (6)

**Measurement, modelling and simulation of turbulence.**

*Researcher(s):* Arne Johansson, Stefan Wallin

*Graduate student(s):* Björn Lindgren, Johan Gullman-Strand

*Sponsor(s):* KTH, FFA, IVS, VR

The aim of the project is to develop and critically evaluate models for statistical description of turbulent flows. The main methods used within the present project for gaining further knowledge of the physics of turbulence are experimental studies and direct numerical simulations of turbulent flows. The models so far investigated belong to the realm of one-point closures for the turbulent stress tensor and turbulent heat flux vector to be used for computational fluid dynamics. The main emphasis is laid on closures based on the transport equations for the turbulent stresses. Particularly, our efforts have been focused on the modeling problems of flows exhibiting strongly anisotropic turbulence. Especially the modelling of the inter-component transfer terms have been studied and models for the pressure strain-rate have been proposed. New formulations of explicit algebraic Reynolds stress models have been derived and tested with considerable success in a number of test cases including complex cases such as a Mach 5 turbulent boundary layer with shock induced separation. Also formulations of explicit algebraic Reynolds flux models have been derived and tested against experiments and direct numerical simulation of passive scalar transport in a turbulent channel flow. In conjunction with this modelling work also a DNS study of turbulent channel flow with heat transfer has been carried out.

A new versatile tool for testing and calibrating turbulence models in general 2D geometries has been developed to the stage where several different types of models have been tested. Eddy-viscosity based two-equation models and explicit algebraic Reynolds stress models have been used for the computation of asymmetric diffuser flow. The model tester is based on finite element methods with extensive use of highly automated code generation.

*Publication(s):* (27), (32)

**Turbulent boundary layers at high Reynolds numbers and new wind-tunnel design techniques.**

*Researcher(s):* Arne Johansson, Jens Österlund

*Graduate student(s):* Björn Lindgren

*Sponsor(s):* The Göran Gustafsson Foundation, VR

For turbulent boundary layers typical Reynolds numbers are in most applications very high, whereas most laboratory experiments have been carried out at low to moderate Re. In the present project boundary layer measurements have earlier been carried out in the MTL wind tunnel at KTH, on a 7 m long boundary layer plate and with free-stream velocities up to 50 m/s. This gives Reynolds numbers based on momentum loss thickness of up to 20,000 or roughly 20 million based on x, which is realistic for practical applications. Hot-wire anemometry was used with miniaturized probes to measure the velocity components. New results concerning the overlap region of turbulent boundary formed an important part of the doctoral theses of J. Österlund, presented in Dec. 1999. The results contradicted some new proposals of a power-law for the mean velocity in the overlap region, and instead cofirmed a classical log-law, although with new values of the constants involved. It was also concluded that the universal overlap region starts further out from the wall than previously assumed. The results of the boundary layer measurements have been put into a data-base that has been further analyzed concerning the evaluation of new scaling laws that have been derived by use of Lie group symmetry methods. The most striking result is the verification of an exponential law for the velocity defect in the outer reion of the turbulent boundary layer. These results can be found in the doctoral thesis of B. Lindgren (thesis defence in Dec. 2002). This thesis also contains experimental parts related to wind-tunnel design and flow in an asymmetric diffuser.

*Publication(s):* (41)

**Development of 3d LDV measurement techniques with applications to wall bounded shear flows.**

*Researcher(s):* Rolf Karlsson

*Graduate student(s):* Jan Eriksson

*Sponsor(s):* NUTEK, Vattenfall Utveckling AB

The aim of the project is to develop a practically useful methodology for making simultaneous 3D LDV measurements with high spatial and temporal resolution, and to apply this technique to obtain detailed 3D turbulence data in the plane turbulent wall jet. In a longer perspective, such data will be used to improve near-wall Reynolds stress turbulence modelling. The first phase of the project has now been successfully completed, and measurements in an enclosed circular jet with a measuring volume as small as 0.035 mm have been made. The second phase of the project is to supplement an earlier (2D) experimental investigation of the turbulent wall jet with simultaneous 3D measurements of the total velocity vector. In particular, attention will be focussed on the equation for the turbulent kinetic energy and on the limiting behaviour of the Reynolds stresses near the wall. The 3-component LDV measurements of phase 2 have now been concluded, and a thorough analysis of the results is performed. A paper describing the 2-component measurements has been published in Exp. Fluids. This experiment has also been used as a test case at the ERCOFTAC/IAHR Workshop on Refined Flow Modelling, Paris April 1996 and in Delft June 1997. Together with Prof. W.K. George, USA, and a group at Chalmers Univ. of Technology, the work on a similarity theory of the plane wall jet is concluded, and a paper will be submitted.

**Investigation of turbulent flow separation using PIV.**

*Researcher(s):* Barbro Muhammad-Klingmann

*Graduate student(s):* Kristian Angele

*Sponsor(s):* VR

Flow separation occurs as a result of flow deceleration over the surface of bodies such as lifting wings, turbomachinery blading or diffusers. In most cases flow separation causes severe performance reduction, and it is therefore of great interest to predict. The objective of the present project is to provide experimental data for a well-defined test case, which can be used to develop accurate CFD models. Flow separation can be controlled to some extent by introducing longitudinal vortices in the boundary layer. The effect of such vortex generators on the turbulence structure will be studied experimentally.

The experiments are performed on a flat plate mounted vertically the test section of a low speed wind tunnel. The test section wall opposite to the plate can be expanded to an arbitrary shape, so that the pressure distribution can be varied at will. The boundary layer is removed from the expanding surface by means of suction, forcing the flow to decelerate on the flat plate.

The boundary layer development is studied using LDV and PIV. The PIV technique has been tested in both decelerating and non-decelerating boundary layers, and it has been possible to obtain accurate near-wall measurements of both mean and fluctuation velocities - in fact, PIV gives better near resolution for v‘ and u‘v‘ than both hotwire and LDV. But the most interesting use of PIV is maybe the possibility to investigate sublayer streaks. In non-decelerating flow, the sublayer is much thinner than the light sheet, but in decelerating flow the viscous scale increases, making it possible to perform PIV measurements within the sublayer. This becomes all the more interesting in connection with the study vortex generators and their effect on turbulent flow separation.

**Supersonic Flow Separation**

*Researcher(s):* Barbro Muhammad-Klingmann

*Graduate student(s):* Jan Östlund

*Sponsor(s):* VR

A new generation of rocket engine nozzles using Flow Separation Control (FSC) is about to be developed. The idea is to allow flow separation during sea level operation, in order to increase performance during flight. Such nozzles have a high potential to increase payload, which eventually means increased capacity to launch satellites. Within the European space programme, an engine based on this concept is planned to be launched 2005, provided that reliable methods can be developed for simulation of the fluid dynamics and associated side load phenomena. Success in this development will immediately reflect on the future competitiveness of VAC on the space craft market, and strengthen Sweden’s position as a partner in technical co-operation programmes directed by ESA, as well as the evolving technology co-operation with Russia and USA.

The present research is expected to give
(i) validated turbulence models to be applied in CFD codes for computation of supersonic flow fields with separation
(ii) a method for treating the coupling of fluid flow and structural response.

Apart from their immediate aim, the results will also be directly applicable in military aircraft, e g in the design of afterburners in RAM and SCRAMjets, air-breathing engines, and vectored nozzles used to increase aircraft manoeuvring capabilities.

Activities include

- analysis of data from full and subscale tests,
- developing appropriate CFD-methods for studying the observed phenomena, and
- deriving methods for scaling and engineering correlation.

The CFD program includes turbulence modelling of 3-dimensional time-dependent flow with combustion, requiring heavy computation on parallel machines. The project is mainly performed at VAC, and is closely related to test activities and concept studies for future European spacecraft.

### Numerical methods for the flow at multiple blade twin-wire forming of paper

*Researcher(s):* Anders Dahlkild *Graduate student(s):* Claes Holmqvist

*Sponsor(s):* Faxén Laboratory

The fundamental aspects of dewatering between two wires is to a great extent known, but presently not accurately quantified for dewatering over multiple blades in a series. Detailed knowledge of the involved mechanisms, e.g. wave propagation on free wires, facilitates controll of dewatering and straining of the fiber suspension, which in turn can be used for controll of flock distribution and fibre orientation. The latter factors determine the quality of the paper.

### Modelling of concentrated fibre suspensions

*Researcher(s):* Anders Dahlkild, Jari P. Hämäläinen (Metso Paper Inc.), Kenneth Eriksson (Process Flow Ltd OY)

*Graduate student(s):* David Hammarström (Process Flow Ltd OY)

*Sponsor(s):* TEKES, Metso Paper, Faxén Laboratory

Handling of high consistency fibre suspensions has become increasingly important in the paper making process industry. The objective of the present project is to improve the techniques for computational simulation of flow of high consistency fibre suspensions. Different methods/models will be tested and refined, such as non-Newtonian rheological models and multi-phase models. Computational results will be validated against experimental data as far as they are or become available for these complex flows.

### Cold Gas Quenching

*Researcher(s):* Fritz Bark, Noam Lior, Arthur Rizzi

*Graduate student(s):* Roland Wiberg, Olivier Macchion

*Sponsor(s):* Faxén Laboratoriet

Previous researchs have shown that cold gas flow nonhomogeneities create distortions of the metal parts during quenching. This project aims at defining which parts of a furnace should be optimized in order to minimize those disortions.

### Luminiscence in compressed gases and sonoluminescence

*Researcher(s):* Martin Lesser, Henrik Alfredsson, Hanno Essén, Nicholas Apazidis, Nils Tillmark

*Sponsor(s):* TFR

The project involves both theoretical and experimental investigations to determine the causes and nature of luminescence in gases. A main purpose is to characterize what occurs in extreme bubble collapse in a liquid, especially that driven by high frequency acoustic radiation. It is also of interest to examine extreme mechanisms that can drive the emission of radiation to higher frequencies and amplitudes. The main approach is to use shock focusing in various forms to achieve this end.

### Active control of flow separation in an asymmetric plane diffuser

*Researcher(s):* Arne Johansson

*Graduate student(s):* Olle Törnblom, Björn Lindgren

*Sponsor(s):* STEM, VR

Measurements of the three velocity components and their fluctuations have been carried out in the spanwise symmetry plane of a plane asymmetric diffuser. A data-base with the experimental data have been created and it has been extensively used both to characterize the flow in the diffuser, with special attention to the separated region, and to evaluate turbulence model predictions.

The main measurement techniques used are Laser Doppler Velocimetry for the spanwise velocity and its fluctuation and Particle Image Velocimetry for the other two velocity components and their fluctuations. Along with these measurements static wall pressure measurements have been performed to characterize the pressure loss in the diffuser both with separating flow and with attached flow. The attached flow is obtained by use of vortex generators bringing in high momentum fluid into the separated near-wall region and thereby preventing the flow separation.

The work has been documented in three papers focusing on the flow characteristics, comparison with model predictions and a description of the experimental procedure respectively. The two first papers have been included in a doctoral thesis (Björn Lindgren) and all three in a licentiate thesis (Olle Törnblom). The work has also been presented at two conferences (Southampton and Lisbon 2002) and will be presented at TSFP3 in Sendai 2003.

The future focus on this work will be to complement the data-base with further near wall measurements and to implement separation preventing control other than the vortex generator method described above. This addition to the data-base will further improve the possibilities to perform important model prediction comparisons.

*Publication(s):* (38)

**Control of oscillatory thermocapillary convection**

*Researcher(s):* Henrik Alfredsson, Gustav Amberg

*Graduate student(s):* Junichiro Shiomi

*Sponsor(s):* VR

In many solidification processes in materials technology, thermocapillary convection in the liquid metal is crucial for the properties of the finished product. Examples of such processes are all the various techniques for crystal growth, and welding where the flow in the weld pool determines the penetration of the liquid pool (i.e. 'weldability'). Often it is technically important to avoid oscillatory flow, and thus it is important to understand the stability characteristics of thermocapillary convection in general. In the project, experimental techniques have been developed that allow us to study onset of oscillatory thermocapillary convection in detail. Quantitative velocity measurements have been carried out using PIV. A first study has been carried out where active control has been introduced in the experiment and it is found that oscillations can be at least partially suppressed.

In the new phase of the project that is proposed here, the possibility to stabilize thermocapillary convection will be explored further. The design of sensors and heaters must be improved to obtain complete suppression of modes with a higher spatial wavelength. The control schemes must be developed to be effective in highly nonlinear regimes.

**Diffuse interface methods for computations in materials science**

*Researcher(s):* Gustav Amberg

*Graduate student(s):* Irina Loginova

*Sponsor(s):* VR

The structure of materials is changed by phase transformations during synthesis and processing.

Many phase transformations involve diffusion and/or heat transfer and the rate of such a phase transformation may often be evaluated quite precisely by solving a diffusion problem. The growth or dissolution of a secondary particle in a parent phase is a classical problem. When there are several diffusing species the problem becomes quite complicated. The phase diagram becomes multidimensional and thus the operating compositions at the moving phase interface cannot be read directly from the phase diagram. At present such multicomponent systems have only been solved by assuming very simple geometries, e.g. spheres, plates, etc. A drawback is that the shape of a growing particle is not predicted by the calculation.

Diffuse interface methods have been used increasingly to study the dynamics of phase boundaries over the last ten years. In this approach a new field variable, the order parameter, is used to track the phase boundary. A value of 0 or 1 designates the two phases, and transition regions are identified with the phase boundary. Over the last ten years a number of phase field simulations of thermal solidification have appeared in the litterature. However, until now no simulations for truly multi-component transformations in two or three dimensions have been reported. It is proposed to develop diffuse interface methods that can treat multicomponent phase change. The numerical methods that have been used so far must be improved significantly in order to do such simulations efficienty.

### Numerical simulation of weld pools

*Researcher(s):* Gustav Amberg

*Graduate student(s):* Minh Do-Quang

*Sponsor(s):* PSCI

In the project proposed here, the possibility of simulating reasonably complete mathematical models is to be exploited. These simulations are characterized by complex physical phenomena such as surface tension driven convection, electromagnetic forces, heat and mass transfer, solidification and melting, etc. The surface tension must be modelled realistically, including the solution of convective diffusion equations restricted to the melt - gas interface, for surface concentrations of surface active substances. The Reynolds numbers that are encountered are such that the melt flow is between a rapid laminar flow with thin boundary layers, up to transitional unsteady or even turbulent flow. There are also different timescales in this problem, since the timescale for the melt flow is much shorter than the timescale for melting/solidification. These simulations would typically be either time dependent axisymmetric or steady three-dimensional. The main effort in this project will be to improve the modelling to make predictions of weldability for realistic steels. The aim is to make this sufficiently reliable to be used as a tool for predicting welding properties of new materials. The knowledge that is generated should eventually be made available to industry as improved expert systems or small simulations that can be done online. Apart from development of the physical models, a significant development of the numerical techniques must be carried out in order to deal with the somewhat nonstandard mathematical models in an efficient way. There will be a close coupling between simulations made at KTH and corresponding experiments at AvestaSheffield.

**High level modelling for high-lift aerodynamics**

*Researcher(s):* Arne Johansson, Stefan Wallin

*Graduate student(s):* Olof Grundestam

*Sponsor(s):* EU

This project is part of a research program (HiAer ) funded by EU, with partners also in Finland, Germany, England, Italy and France. It is aimed at one of the big challenges for future generations of European transportation aircraft, namely the development of new and unconventional high-lift devices leading to substantial improvements in both cruise efficiency and landing and take-off performance. The goal of HiAer is to contribute to lowering the industrial cost and risk in design of new high lift systems by improving the flow modelling state-of-the-art CFD tools, and (in the part that concerns this project) to develop new turbulence models and with the aid of these demonstrate accurate prediction of 3D high lift flows. The turbulence modelling work is focussed around explicit algebraic Reynolds stress modelling (EARSM), which is a rational approximation of a full differential Reynolds stress model (DRSM) at a two-equation level. The development work will be directed into four different strongly interacting routes:

- Effect of strong streamline curvature will be considered by rational extensions of terms from the DRSM.
- The choice of basic 'length-scale determining' equation in EARSM will be studied and optimised by the use of rational constraints. The near-wall treatment is closely connected to this work. Adaptive 'wall-function' kind of boundary conditions, for optimal grid-point distribution in 3D cases where resolution is critical, will also be considered.
- The choice of basic quasi-linear pressure-strain rate model will be optimised and a reduced functional basis in 3D mean flow will be searched for.
- Finally, a strongly non-linear, realisable DRSM will be tested and possibilities to include such ideas at the EARSM level will be investigated.

*Publication(s):* (25)

**Development of an electro-dialysis cell for continuous removal of nitrate from ground water.**

*Researcher(s):* Anders Dahlkild, Göran Lindbergh, Anna Velin, Mårten Behm

*Graduate student(s):* Carl-Ola Danielsson

*Sponsor(s):* Faxén Laboratoriet

In this project, a specific water filtration device an electrodialysis-type cell that incorporates grafted non-wovens as ion exchange textile is developed. The equipment is to be used for waste treatment and is to be suitable for treating effluents that already have low concentration impurities, but need to be purified further to a ppb level. The objectives are to design equipment that has large surface area for the ion exchange material per unit volume of cell, to develop mathematical models for the velocity, pressure field and the current-potential distribution inside the designed cell, and to construct and validate the equipment in the field of effluent treatment.

**Two-phase modelling of dilute fibre suspensions.**

*Researcher(s):* Anders Dahlkild, Jari Hämäläinen

*Graduate student(s):* Marko Hyensjö

*Sponsor(s):* Faxén Laboratoriet

It is known from experiments that flocs of fibre networks may form or disrupt in certain flows. In the project we try to increase the knowledge how the flocs are formed and disrupted from theoretical considerations. The properties of the final paper are to a large extent influenced by the way the fibre suspension is treated and dewatered in the so called forming unit. An important part of the forming unit is the head box which ejects the suspension into the dewatering stage of the process in form of a wide jet. Two critical components of the headbox is the turbulence generator, which acts to disperse the fibres uniformly in the water, i.e. without flocs, and the following converging channel which produces the thin jet of fibre suspension that will become the final paper sheet. In the converging channel, after the turbulence generator, there is a tendency of the reformation of flocs which will appear as a non-uniformity of the produced paper sheet . For paper manufacturing the increased knowledge of how these two components work and interact is of fundamental importance, and the project therefore focuses on this. The goal is to refine existent fibre flocculation models and to develop a computational tool that can be validated against experiments and predict the flocculation process in a headbox. The work is expected to result in a doctoral degree.

**"3D Nozzle": Compressible Flow with Shock, Transition, Turbulence and Unsteadiness**

*Researcher(s):* Henrik Alfredsson, Nils Tillmark

*Graduate student(s):* Timmy Sigfrids

*Sponsor(s):* STEM

The object of the project is to enhance the fundamental physical understanding of compressible flow with shock, transition, turbulence and unsteadiness. The application of the basic research is aimed towards prediction models, which can be used towards solving industry-relevant problems of various types. The project involves several elements in a 3D viscous compressible flow environment:

- Overall flow measurements in a nozzle at sub- and transonic speeds.
- Detailed boundary layer measurements.

- Applying modern measurement techniques (hot-wire, LDV, PIV) to compressible viscous flow.
- Development of a new measuring technique towards time-dependent pressures.
- Implementation, development and test of advanced transition/turbulence models into a general purpose Navier-Stokes solver from an overall perspective.

The highly complex flow conditions found in most energy-conversion components will be significantly simplified for the purpose of the research study, while retaining most of the fundamental and essential flow features present in such components. Experiments will be performed on a nozzle test facility, in which two- and three-dimensional bumps are inserted. These models will represent several complex flow phenomena appearing in energy-converting components. The test section allows also for a time-dependent variation of the flow. The modular design of the test facility will provide testing possibilities of new sensor technology in compressible flow. Modern techniques as pressure sensitive paint and shear stress sensitive liquid crystals will also be tried out to be able to map the pressure distribution at the model surface. Numerical predictions will be performed on the model object using Reynolds-averaged Navier-Stokes codes. The comparison between experimental and numerical results will serve as an aid for the development of basic models related to boundary layer transition and separation in a complex compressible flow environment. The research project will include four graduate students, each with a distinct responsibility and research task. Collaboration between fundamental and applied research groups, as well as between research groups at different universities in Sweden, will greatly improve the progress of the research and be a fruitful experience for all graduate students involved in the project. The experimental parts will take place at KTH. The significant industrial perspective of the underlying physical phenomena will further enhance the students' experience. Four interdisciplinary TeknL. theses are expected to result from the project.

**Nonlinear interactions between internal gravity waves**

*Researcher(s):* Erik Lindborg

*Sponsor(s):* VR

The project will study the dynamics of a strongly stratified fluid, with special emphasis on nonlinear interactions between internal gravity waves. Theoretical and numerical investigations will be combined with statistical analyses based on data from MOZAIC data base, consisting of wind, temperature and ozon records from a large number of commercial air flights.

**Higher-order finite difference methods for DNS/LES in complex geometries**

*Researcher(s):* Arne Johansson, Dan Henningson, Bertil Gustafsson, Per Lötstedt, Jonas Nilsson

*Graduate student(s):* Arnim Brüger

*Sponsor(s):* NGSSC, IVS, VR

The aim of this project is to perform direct numerical simulations (DNS) of turb ulent flow phenomena in complex geometries. A so far unique discretisation method of the incompressible Navier-Stokes equations will be used. It is based on higher-order difference methods which allow for the use of curvilinear, staggered meshes. The compact higher-order stencils make it more efficient and less memory demanding than the standard second-order methods routinely used today.

The final goal is to simulate turbulence phenomena on a wing profile geometry. This is an important step towards realistic applications of a DNS method. Another important issue is to simulate turbulent flow separation in an asymmetric diffuser, a case where ongoing experiments is performed at the department of Mechanics.

In a further step the DNS code will form a basis for inclusion of large eddy simulation (LES) models. The research will build on the compact higher-order finite difference methods developed in an ongoing cooperation project between the department of Mechanics, KTH and TDB, Uppsala University.

*Publication(s):* (50)

**Shock enhancement of sonoluminescence**

*Researcher(s):* Martin Lesser, Hanno Essén, Nicholas Apazidis, Nils Tillmark

*Sponsor(s):* VR

The main objective of this project is to investigate experimentally and theoretically the possibility of enhancement of bubble collapse and sonoluminescence by action of strong, highly symmetrical and stable polygonal shocks. Generation and stable behavior of this type of converging shocks has been investigated experimentaly and theoretically by the members of the group. The experimental study will be conducted by means of a new type of a shock tube.

*Publication(s):* (19)

**Simulation and modeling of turbulent flow and combustion**

*Researcher(s):* Geert Brethouwer

*Sponsor(s):* The Göran Gustafsson Foundation, VR

The aim of the project is to study the effect of rotation and buoyancy on turbulent shear flows and turbulent mixing using DNS and to proceed the modeling work of the KTH-mechanics group. The aim is in particular to extend the recently developed Reynolds stress models and scalar flux model with the description of the effects of rotation and buoyancy on turbulence and turbulent mixing so that the models are applicable for a wider range of problems.

**Simulation and modelling of turbulent flow and combustion**

*Researcher(s):* Arne Johansson, Geert Brethouwer

*Graduate student(s):* Daniel Ahlman

*Sponsor(s):* STEM (CECOST)

Walls have a significant influence on the combustion process in many practical applications like car engines and gas turbines. One of the important reasons is that the walls are in general much colder than the burning mixture. The heat transfer to the wall leads then to a relative low temperature of the fuel-oxidizer mixture near the wall. Due to the relative low temperature the combustion rate in the near wall region is slower than in the rest of combustion chamber and it is even possible that the fuel is not completely consumed which leads to pollution. The goal of this project is to study combustion in the near wall region by means of highly accurate direct numerical simulations (DNS). The system that will be simulated is combustion in a compressible turbulent channel flow with cold walls. In this channel a simple reaction takes place between a partly premixed fuel and oxidizer. In addition to the simulation work a model for turbulent combustion will be developed. The recently developed EARSM (explicit algebraic Reynolds-stress model) and EASFM (explicit algebraic scalar flux model) will be extended so that they can take into account the density variations in a non-isothermic turbulent flow. In a later stage the EARSM and EASFM will be combined with a model to describe the reaction of the fuel and the oxidizer. The developed turbulent combustion models will be validated with the DNS data. The project is part of the STEM-financed CECOST program.

### 6.4 Education didactics

#### Distance Education and Flexible Learning

*Researcher(s):* Richard Hsieh, Göran Karlsson

*Sponsor(s):* The Distance Consortium

Development of a national distance course for distance teachers. Period of development was Jan. 10 - Sept. 15, 1998 followed by the 5 credit point courses given 1998/1999 and 1999/2000. Cooperating universities: KTH, University of Lund, University of Uppsala, University of Umeå, University of Växjö.

#### Distance Teacher Education and PBL.

*Researcher(s):* Göran Karlsson

*Sponsor(s):* Fees from participants organisations

This 5 point credit course was originally developed through private investments outside KTH and from 1998 integrated into KTH continuing education scheme; it is given once or twice every academic year in cooperation with University of Karlstad and Centronics AB, Uppsala. In total 11 courses have been given.

#### National Training Center for Educational Management

*Researcher(s):* Göran Karlsson

Creation of National Training Center for Educational Management to meet the needs of educational professionals functioning in senior management roles in national and provincial governments, universities and other higher education institutions, colleges and schools, by assisting them to develop their understanding and skills in respect of current educational management law, theory and practice and to prepare them for leadership roles at national and international levels.

# 7 Research activities

## 7.1 Doctoral theses defended 2002

**Gunnar Tibert**

*Thesis title:* Deployable Tensegrity Structures for Space Applications

*Date:* April 15 , 2002
*Faculty opponent:* Professor Robert Skelton, University of California, San Diego
*Evaluation Commitee:* Dr. Zhong You, University of Oxford, Professor Emeritus Alf Samuelsson, CTH, MSc Thorwald Larsson, Rymdstyrelsen
*Main Advisor:* Professor Anders Eriksson

**Jean-Marc Battini**

*Thesis title:* Co-rotational beam elements in instability problems

*Date:* January 18 , 2002
*Faculty opponent:* Professor Eduard Riks, Delft University of Technology, Netherlands
*Evaluation Commitee:* Professor Jean-Louis Batoz, InSIC, France, Dr. Reijo Kouhia, Helsinki University of Technology, Dr. Adam Zdunek, FOI
*Main Advisor:* Professor Anders Eriksson

**Petri Piiroinen**

*Thesis title:* Recurrent Dynamics of Nonsmooth Systems with Application to Human Gait

*Date:* November 29 , 2002
*Faculty opponent:* Professor Gabor Stepan, Department of Applied Mechanics, Budapest University of Technology and Economics, Hungary
*Evaluation Commitee:* Professor Michael Benedicks, Institutionen för Matematik, KTH, Professor Viktor Berbyuk, Dept of machine and Vehicle Systems, Chalmers, Dr Tom Wadden, Objecta Systems AB, Stockholm, Sweden
*Main Advisor:* Guest researcher Harry Dankowicz

**Björn Lindgren**

*Thesis title:* Flow facility design and experimental studies of wall-bounded turbulent shear-flows

*Date:* December 17 , 2002
*Faculty opponent:* Prof. Hassan Nagib, IIT, Chicago
*Evaluation Commitee:* Professor Lennart Löfdahl, CTH, Doctor Rolf Karlsson, Vattenfall Utveckling AB, PhD Per Elofsson, Volvo Car Corp.
*Main Advisor:* Professor Arne Johansson

## 7.2 Licentiate theses presented 2002

**Nulifer Ipek**

*Thesis title:* Modeling of electrolytic pickling
*Date:* March 6 , 2002
*External examiner:* MSc Göran Lindbergh, KTH, Mekanik, Faxén Laboratory
*Main Advisor:* Professor Fritz Bark

**Aleksandar Filipovski**

*Thesis title:* Co-rotational shell element for elasto-plastic, quasi-static problems
*Date:* June 7 , 2002
*External examiner:* Ass. Prof. Reijo Kouhia, Helsinki, Finland
*Main Advisor:* Professor Anders Eriksson

**Jan Östlund**

*Thesis title:* Flow processes in rocket engine nozzles with focus on flow separation and side loads
*Date:* June 13 , 2002
*External examiner:* Dr. Ardeshir Hanifi, , FFA/FOI
*Main Advisor:* Dr Barbro Muhammad Klingmann

**Johan Gullman-Strand**

*Thesis title:* Turbulence modeling using automated code generation applied to asymmetric diffuser flow
*Date:* June 14 , 2002
*External examiner:* Professor Lars Davidson, Chalmers
*Main Advisor:* Professor Arne Johansson
*Co-advisor:* Professor Gustav Amberg

**Richard Holm**

*Thesis title:* On the Fluid Mechanics of Partial Dewatering during Roll Forming in Paper Making
*Date:* June 14 , 2002
*External examiner:* Prof. A. Talamelli, Univ. of Bologna
*Main Advisor:* Professor Henrik Alfredsson

**Arnim Brüger**

*Thesis title:* Higher order methods suitable for direct numerical simulation of flows in complex geometries.
*Date:* June 14 , 2002
*External examiner:* Dr Jakob Yström, NADA, KTH
*Advisors:* Professor Dan Henningson and Professor Arne Johansson

**Mattias Chevalier**

*Thesis title:* Adjoint Based Control and Optimization of Aerodynamic Flows
*Date:* June 5 , 2002
*External examiner:* Dr. Per Weinerfelt, SAAB Aerospace, Future Products, Linköping
*Main Advisor:* Professor Dan Henningson

**Claes Holmqvist**

*Thesis title:* Modelling of the Pressure Distributions in Twin-Wire Blade Formers
*Date:* October 16 , 2002
*External examiner:* Professor Staffan Toll, Chalmers University of Technology
*Main Advisor:* Dr Anders Dahlkild

**Anders Ahlström**

*Thesis title:* Simulating Dynamical Behaviour of Wind Power Structures
*Date:* October 24 , 2002
*External examiner:* Prof. Lars Bergdahl, CTH, Water Environment Transport
*Main Advisor:* Professor Anders Eriksson

## 7.3 Publications 2002

### 7.3.1 Papers published in archival journals and books

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[2] Dankowicz, H., Piiroinen, P T, Nordmark, A., 2002, Low-velocity Impacts of Quasi-periodic Oscillations, *Chaos, Solitons & Fractals*, **14**, 2

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[29] Talamelli, A. Fornaciari, N., Westin, J. & Alfredsson, P.H., 2002, Experimental Investigation of streaky structures in a relaminarizing boundary layers, *Journal of Turbulence*, **3**, 1-13.

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[58] Lindgren, B., Johansson, A.V., 2002, Evaluation of the flow quality in the MTL wind-tunnel, *Technical report*, KTH/MEK/TR–KTH/MEK/TR–KTH/MEK/TR–02/13–SE–SE-

[59] Ipek, N., 2002, Modeling of Electrolytic Pickling, *Licentiate thesis*, KTH/MEK/TR–02/03–SE

### 7.4 Seminars

*March 5* Kazuo Aoki, University of Kyoto
Dynamics of Rarefied Gas Flows: Asymptotic and Numerical Analyses of the Boltzmann Equation

*March 6* Nulifer Ipek, KTH, Mekanik, Faxén Laboratory
Modeling of Electrolytic Pickling

*March 7* Hans Jakob Kaltenbach, TU, Berlin
Flow separation and separation control

*March 11* Mikhail Dzugutov, Nada, KTH
What is liquid? A view from molecular dynamics

*March 21* Gustaf Mårtensson, FaxénLaboratoriet, KTH
Turbulence in rapidly rotating systems

*March 28* Sergej Zilintikevich, Uppsala University
Geophysical boundary layers: classical theory and recent developments

*April 12* Oleg Rudenko, Moscow
Nonlinear Acoustics and Medicine

*April 16* Michael Vynnycky, KTH, Mekanik
Fuel cells: an application of practical asymptotics

*April 18* Björn Lindgren & Arne Johansson, KTH, Mekanik
Evaluation of new scaling laws for turbulent boundary layers using the KTH data-base

*April 25* Jens Fransson, KTH, Mekanik
Flow around a porous cylinder subjected to uniform suction or blowing

*May 2* Junichiro Shiomi, KTH, Mekanik
Control of oscillatory thermocapillary convection in a half-zone model

*May 16* Laszlo Fuchs, KTH, Mekanik
Some fluid dynamical aspects of drug administration by inhalation

*May 23* Minh Do-Quang, KTH, Mechanics
Parallel solvers in femlego: Application in 3-D welding pool simulation

*May 30* Erik Lindborg, KTH, Mekanik
Strongly stratified turbulence: A special type of motion

*June 5* Mattias Chevalier, KTH, Mekanik
Adjoint Based Control and Optimization of Aerodynamic Flows

*June 6* Martin Lesser, KTH, Mekanik
Luminescence in Fluids

*June 7* Aleksandar Filipovski, KTH, Mekanik
Co-rotational shell element for elasto-plastic, quasi-static problems

*June 13* Jan Östlund, KTH, Mekanik
Flow processes in rocket engine nozzles with focus on flow separation and side loads

*June 14* Johan Gullman-Strand, KTH, Mekanik
Turbulence modeling using automated code generation applied to asymmetric diffuser flow

*June 14* Arnim Brüger, KTH, Mekanik
Higher order methods suitable for direct numerical simulation of flows in complex geometries

*June 14* Richard Holm, KTH, Mekanik, Faxén Laboratory
On the fluid mechanics of partial dewatering during roll forming in paper making

*June 20* Davide Cardano, Politecnico of Turin, Italy
Experimental analysis of the turbulence development inside a two-dimensional contraction

*August 13* Leonhard Kleiser, ETH, Zürich
Simulation of Particle-Driven Gravity Currents

*October 16* Claes Holmqvist, KTH, Mekanik, Faxén Laboratory
Modelling of the Pressure Distributions in Twin-Wire Blade Formers

*October 17* Fredrik Lundell, KTH, Mekanik
Opposition control of free-stream turbulence induced transition

*October 24* Anders Ahlström, KTH, Mekanik
Simulating Dynamical Behaviour of Wind Power Structures

*October 31* Nicholas Apazidis, KTH, Mekanik
Focusing of strong shocks in an elliptic reflector

*November 14* Erland Källén, MISU
Global climate change and regional effects in the Nordic area

*November 19* Martin Lesser, KTH, Mekanik
Sophia-Mathematica, A new implementation of Sophia in the Mathematica Computer Algebra System

*November 21* Dan Henningson, KTH, Mekanik
Optimal control and estimation applied to three-dimensional boundary layers

*November 26* Jan Östlund, KTH, Mekanik
Presentation of Conventional Rocket Nozzle Design / K53, Teknikringen 28

*November 28* Michael Vynnycky, KTH, Mekanik
The asymptotics of dewatering

*November 29* Petri Piiroinen, Mekanik, KTH
Recurrent Dynamics of Nonsmooth Systems with Application to Human Gait

*November 29* Erik Stålberg, KTH, Mekanik
A preconditioning method for a compressible Navier-Stokes code

*December 3* Karl Borg, KTH, Mekanik
Force on a spinning sphere moving in a rarefied gas

*December 5* Shuya Yoshioka, KTH

Scaling law for the reattachment control of back-step turbulent flow

*December 12* Henrik Alfredsson, KTH, Mekanik
Experimental Fluid Dynamics Research - fruitful exchange with computations

*December 16* Hassan Nagib, IIT, Chicago
Measurements and Asymptotic Analysis of High Reynolds Number Flows in Channels and Pipes

*December 17* Björn Lindgren, KTH, Mekanik
Flow facility design and experimental studies of wall-bounded turbulent shear-flows

# 8 FaxénLaboratoriet

A short description of FaxénLaboratoriet (web address: http://www2.mech.kth.se/ faxenlab) is given below for 2002. The text in this section is an extract (with some modifications) of the operational plan for FaxénLaboratoriet for the period 2001-3. The Department of Mechanics is the host institute for FaxénLaboratoriet.

## 8.1 Introduction

FaxénLaboratoriet, below referred to as FLA, is a VINNOVA Competence Centre with the goal of making research results and methods in experimental, numerical and theoretical fluid mechanics practically useful for the participating industrial partners. It also has a goal to broaden the multidisciplinary knowledge base of fluid mechanics in industrial process technology by means of a research program leading to Licentiate and Doctoral degrees. The costs of this centre are shared equally between KTH, VINNOVA, and the following industrial partners:

ABB Group Services Center AB/CRC

ABB Power Technology Products AB

ABB Process Industries AB

Albany International AB

Alfa Laval Tumba AB

Borealis AB

Eka Chemicals AB

Ipsen International GmbH

Linde Gas AG

Metso Paper Inc.

M-real

Outokumpu Copper Partner AB

Process Flow Ltd Oy

SAPA AB

SCA Packaging Research

Stora Enso Research

Vattenfall Utveckling AB

The following contribute financially as non-signatory partners:
University of Tokyo
Institut National Polytéchnique de Grenoble
University of Pennsylvania
MISTRA (Stiftelsen för Miljöstrategisk Forskning)

Staff from the following departments of KTH are involved in the activities of FaxénLaboratoriet:

- Alfvénlaboratoriet
- Dept. of Chemical Engineering & Technology
- Dept. of Materials Processing
- Dept. of Mechanics (host department of FaxénLaboratoriet)
- Dept. of Pulp and Paper Chemistry & Technology
- Dept. of Solid Mechanics

The inter-disciplinary character of the work at FLA is well illustrated by the names of these departments.

## 8.2 Management and organisation of the Centre

Major decisions about the activities of FLA are made by its Board. The present members of this are:
Lars Hanarp (Albany Nordiskafilt AB)
Fredrik Herlitz (Eka Chemicals AB)
Torsten Holm (Linde Gas AG)
Rolf Karlsson (Vattenfall Utveckling AB (Chairman))
Arne Johansson (Dept. of Mechanics, KTH),
Anders Wigsten (Stora Enso Research)
Carl Zotterman (Metso Paper, Inc)

The operative leadership at FLA consists of the following:
Professor Fritz Bark, Dept. of Mechanics, KTH – Director
Dr. Anders Dahlkild, Dept. of Mechanics, KTH - Deputy Director
Dr. Michael Vynnycky, Dept. of Mechanics, KTH - Scientific Coordinator

Ingunn Wester, Dept. of Mechanics, KTH - Administrative Head

The research efforts of FaxénLaboratoriet are aimed at three main areas:

Electrochemical Processes
Materials Processing
Paper Technology

## 8.3 Research performed at FaxénLaboratoriet

Relevant publications are listed in section 7.3. FaxénLaboratoriet arranged a number of seminars, listed in section 7.4.

### 8.3.1 Electrochemical Processes

*Industrial partners:* ABB Group Services Center AB/CRC, Eka Chemicals AB, Vattenfall Utveckling AB.

*Other parties:* Institut Polytéchnique de Grenoble, University of Pennsylvania.
*Graduate students:* Erik Birgersson, Carl-Ola Danielsson, Jan Eriksson, Nulifer Ipek, Linda Nylén, Ulrike Windecker.
*Supervisors:* Fritz Bark, Mårten Behm, Anders Dahlkild, Göran Lindbergh, Noam Lior, Michael Vynnycky, Anna Welin, Said Zahrai.

General description:
Electrolysis takes place in baths of electrolyte in so-called electrolysers, in which a number of electrodes are immersed, either connected in series or in parallel. Due to the reactions at the electrodes the concentration field varies in space, with the result that the electrolytes weight (per unit volume) will be locally either less or more than the average weight in the bath. Consequently the electrolyte is set in motion by the force of gravity. This motion is nearly always turbulent. Furthermore, in e.g. the production of sodium chlorate, hydrogen gas is generated at the cathode and in the zinc electro-winning process, oxygen gas is evolved also at the anode. Due to drag force between the bubbles and the electrolyte, the upward motion of the bubbles of gas causes turbulent circulation of the electrolyte in the reactor.

Many problems which are closely related to the fluid mechanical phenomena mentioned above are highly relevant for optimisation of the design of electrolysers. For instance, the exchange of mass at the electrodes should be maximized, which requires a rapid supply of undepleted electrolyte. However, high velocities result in short residence times in the electrolysers, which leads to a lot of electrolyte passing through the electrolyser without being fully used. The development of gas bubbles at the electrodes is often exploited to drive the electrolyte through the electrolyser, but at the same time a large volume fraction of bubbles increases the electrical resistance of the electrolyte, which increases the Ohmic loss of energy. Today, the consumption of energy is perhaps the most critical problem in the electrochemical process industry.

Projects:

I:1 Investigation of electrode kinetics at rotating electrodes

I:2 Pickling of steel

I:3 Forced convection
I:4 Development of an electrodialysis cell
I:5 Flow in solid polymer fuel cells

### 8.3.2 Materials Processing

*Industrial partners:* ABB Group Services Center AB/CRC, ABB Power Technology Products AB, ABB Process Industries AB, Alfa Laval Tumba AB, Borealis AB, Ipsen International GmbH, Linde Gas AG, Outokumpu Copper Partner AB, SAPA AB.
*Other parties:* University of Pennsylvania, University of Tokyo
*Graduate students:* Jerome Ferrari, Jenny Kron, Mats Larsson, Gustaf Mårtensson, Lorent Olasz, Roland Wiberg.
*Supervisors:* Fritz Bark, Hasse Fredriksson, Peter Gudmundsson, Torbjörn Hellsten, Bo Häggblad, Jin Li, Hans Moberg, Arne Johansson, Noam Lior, Galina Shugai, Michael Vynnycky, Said Zahrai.

General description:
In the continuous casting of metals, the molten material or melt is supplied continuously through a cooling annulus, the mould. Solidification first takes place at the rim of the melt, forming a shell in contact with the mould. The solidification continues outside the mould, gradually building up a thicker shell until the whole cross section is solid metal. The quality of the steel and structure of the metal surface depends to a great extent on the flow of the melt in the mould. Due to the turbulent motion caused by the violent filling process, slag material at the upper surface of the melt is easily mixed into the melt, contaminating the final product with small inclusions. One way of reducing this contamination is to use a so-called electromagnetic brake, by which a magnetic field is used to dampen the turbulent motion. The surface structure of the final product is dependent on the flow in the neighbourhood of the contact line at the mould between molten and solidified material. The poorly understood interplay between the solidification process, surface tension, gravity and forces induced by the flow is now being investigated.

In the mechanical engineering industry heat treatment is a central process in the manufacture of high-performance components such as bearings, gears and sledge-hammers. These products obtain their mechanical properties as a result of the phase changes which take place during cooling (quenching or hardening) after heat treatment. The activities of the Centre concerning hardening of steel will be carried out in collaboration with the Swedish Institute for Metals Research at which theoretical and experimental research is being carried out under the supervision of the Technical Council of the Swedish Mechanical Engineering Industry. Also the Brinell Centre for Metallurgical Research will participate in these efforts. In FaxénLaboratoriet, realistic computational methods will be developed for the heat transfer between component and cooling gas. These methods will complement the existing simulation models for the transport of heat, the phase changes and the mechanical response, i.e. rest stresses and deformation, within the component. The resulting computational model will constitute both a unique and a powerful tool for controlling hardening processes.

Projects:

II:1 Modelling of thermal stresses in the continuous casting of copper and aluminium alloys
II:2 Quenching of steel
II:3 Turbulence at small Rossby numbers
II:4 Numerical modelling of liquid metal flow with a free surface
II:5 Modelling of the XLPE-Cable manufacturing process

### 8.3.3 Paper Technology

*Industrial partners:* Albany Nordiskafilt AB, Metso Paper, Inc, M-Real, Process Flow Ltd Oy, SCA Packaging Research AB, Stora Enso Research AB.

*Graduate students:* Roger Bergström, Monica Fällman, Richard Holm, David Hammarström, Claes Holmqvist, Marko Hyensjö, Jordan Ko, Krister Åkesson.
*Supervisors:* Henrik Alfredsson, Anders Dahlkild, Jari Hämäläinen, Bo Norman, Daniel Söderbergh, Hannes Vomhoff, Said Zahrai.

General description:
In a paper-making machine a suspension of cellulose fibres is turned into a wet mat of fibre by squirting out most of the water. In traditional forming, most of the water is squirted out of the suspension on a moving horizontal filtering net, a so-called 'wire'. The suspension is transferred to the wire by the means of a thin but broad jet from a 'head box'. The water is then sucked out of the suspension through the wire. However, there are a number of drawbacks in this method. Hydrodynamic instabilities in the interface between the suspension and the air above it will limit the speed at which the process can take place. Furthermore, one-sided de-watering makes the structure of the surface of the paper different on its two sides, which is most inconvenient in he case of for instance printing paper.

These disadvantages can be eliminated to a great extent in modern twin-wire machines. In these the jet from the head box is directed into the space between two almost parallel wires, which are kept close together and at high tension. The pair of wires is then passed over one or more rollers or blades which makes the separation between the streamlines increase due to the centrifugal force. This leads to an increase in the pressure, which drives the water out of the suspension. This method works reasonably well in actual operation, but the understanding of its basic mechanics is far from complete. A better understanding will almost certainly lead to considerable improvements in the method. Basically the quality of the final product, measured by homogeneity and the iso-tropy of the fibres, is determined by the flow in the head box and the flow on and between the wires.

Projects:
III:1 Forming between twin wires
III:2 Initial roll forming
III:3 Flow of concentrated pulp suspensions

III:4 Modelling of dilute fibre suspensions

III:5 Numerical modelling of fibre fractionation in hydrocyclones

## 8.4 Financial status

The total cash (in MSEK) contributions for 2002 from the three major parties amounted to:

| | |
|---|---|
| KTH | 2.4 |
| Industry | 3.0 |
| VINNOVA | 6.0 |
| Other | 1.1 |
| Total | 12.5 |

In addition to this, there are also in-kind contributions, totalling roughly 6.5 MSEK (according to budget), from industry and KTH.

## 8.5 Miscellaneous

*The year 2002 at FaxénLaboratoriet: a sample of events*

January 23: FLA Board Meeting at KTH
February 6: Lic.Eng. defence, Jérome Ferrari
February 20: FLA Board Meeting at KTH
March 6: Lic.Eng. defence, Nulifer Ipek
April 19: FLA Board Meeting at KTH
June 14: Lic. Eng. defence, Richard Holm
June 17: FLA Board Meeting at KTH
September 26-27: FLA Annual Meeting at KTH
September 27: FLA Board Meeting at KTH
October 16: Lic. Eng. defence, Claes Holmqvist
December 16: FLA Board Meeting at KTH