Institute of Cybernetics at Tallinn Technical University
Chair of Geometry, Tartu University
Estonian Marine Institute
Centre of Biomedical Engineering of Tallinn Technical University

CENS

Centre for Nonlinear Studies

Annual Report

2001

Tallinn, Estonia

CENS
Institute of Cybernetics at Tallinn TU
Akadeemia tee 21
Tallinn 12618, Estonia
Phone: (+372) 620 4150
Fax: (+372) 620 4151
Prof. J.Engelbrecht, je@ioc.ee
Prof. H.Aben, aben @ioc.ee
Prof. M.Rahula (Tartu), rahula@math.ut.ee
Prof. H.Hinrikus, hiie@bmt.cb.ttu.ee
Dr. T.Soomere, soomere@anet.ee

Internet: http://cens.ioc.ee

Contents

Abstract

The studies of solitary waves in microstructured solids has revealed several nonlinear phenomena like control of amplitudes in a harmonic force field, the existence of trains of negative and positive solitons, the existence of regularities in patterns of trajectories of intracting solitons (A.Salupere, J.Engelbrecht, O.Ilison, L.Ilison, M.Kukk). The methods for acoustodiagnostics of inhomogeneous materials and prestressed solids have been derived and qualitative changes in signals determined (A.Ravasoo, A.Braunbrück). The mechanism of the stress-induced phase-transition front propagation is explained and numerically studied (A.Berezovski). New types of equations of magnetophotoelasticity are derived (H.Aben, L.Ainola) and a special method constructed for a phase-stepping polariscope (J.Anton). Piano hammers were tested experimentally and analysed theoretically (A.Stulov).

The deformation of the left ventricle is modelled with energy transfer in heart cells taken into account (M.Vendelin), M.Lemba). The scaling exponents for the heart-rate variability are found (J.Kalda, M.Säkki). The complex analysis of certain ECG parameters is carried out (T.Lipping, J.Lass, H.Hinrikus).

The inverse problem of 2D surface solitons is solved and the mechanism of amplification of 2D interaction solitons explained (P.Peterson). The mechanism of energy exchange between different modes of surface waves is explained (T.Soomere). The wind and wave regimes in the Baltic Proper and off northwest Saaremaa are studied (T.Soomere).

Random self-affine fractal surfaces are studied (J.Kalda). Lie-Cartan methods and fiber bundles are used for analysing several nonlinear dynamical systems (V.Abramov).

Keywords: nonlinear dynamics, microstructured solids, solitons, acoustodiagnostics, photoelasticity; cardiac contraction, cell energetics, signal processing, water waves, resonant wave-wave interaction, differential equations.

Sisukord

Lühikokkuvõte

Mikrostruktuuriga materjalides levivate üksiklainete analüüsis on selgitatud rida mittelineaarseid efekte nagu amplituudide korrigeerimise võimalus harmoonilise jõuvälja abil, negatiivse ja positiivse amplituudiga solitonide jada tekkemehhanism ning solitonide trajektooride regulaarne muster (A.Salupere, J.Engelbrecht, O.Ilison, L.Ilison, M.Kukk). On arendatud mittehomogeensete materjalide ja eelpingestatud tahkiste akustodiagnostika meetodeid ja tuvastatud signaalide kvalitatiivsed erinevused (A.Ravasoo, A.Barunbrück). On selgitatud pingeväljast tingitud faasi-frondi levi mehhanism mäluga materjalides ja arendatud termodünaamiliselt korrektset numbrilist meetodit (A.Berezovski). On tuletatud uut tüüpi magnetofotoelastsuse võrrandid (H. Aben, L.Ainola) ja esitatud meetod faasisammuga polariskoobi juhtimiseks (J.Anton). On testitud klaverihaamreid ja määratud teoreetiliselt nende omadusi (A.Stulov).

On esitatud matemaatiline mudel südame vasaku vatsakese deformatsioonide seostamiseks südamelihase rakkudes toimuvate ainevahetusprotsessidega (M.Vendelin, M.Lemba). Südamerütmi variaabelsuse analüüsis on leitud skaleerivad eksponendid (J.Kalda, M.Säkki). On läbi viidud kompleksne EKG parameetrite analüüs (T.Lipping, J.Lass, H.Hinrikus).

On lahendatud kahemõõtmeliste pinnasolitonide pöördülesanne ja antud seletus interaktsioonisolitonide võimendumisele (P.Peterson). On tuvastatud energiavahetuse mehhanism pinnalainete erinevate moodide vahel, on analüüsitud tuule- ja lainetusreziime Läänemeres ja Saaremaa looderannikul (T.Soomere).

On uuritud juhuslikke fraktaalseid enese-afiinseid pindu (J.Kalda). On analüüsitud fraktaalseid dünaamilisi süsteeme Lie-Cartani meetodil (V.Abramov).

Võtmesõnad:
mittelineaarne dünaamika, mikrostruktuuriga materjalid, solitonid, akustodiagnostika, fotoelastsus, südamelihase kontraktsioon, rakuenergeetika, signaalitöötlus, pinnalained, interaktsioon, diferentsiaalvõrrandid.

1. Introduction

This Report is the third Annual Report of CENS following CENS 1999 and CENS 2000. Traditionally it covers all the activities of CENS. There is however an important part included – a foresight programme. In 2001, the Ministry of Education of Estonia has started a new Programme on Centres of Excellence in Research. CENS has applied to be included into this Programme and the international evaluation has rated the activities of CENS as "excellent". Due to very limited funding, only a few "outstanding" got the addititional funding through the Programme. Nevertheless, CENS is included into the list of Centres with the growing support of its regular funding. All this will be analysed below.

Section 2 gives a short overview on structures of CENS based on the materials of the recent evaluation. The most important part of this Report is Section 3 where the abstracts of all the studies are presented. The funding is described in Section 4 and Section 5 gives an overview on all the formal activities, such like published papers, conferences, lecture courses, etc. Section 6 is the second focal point of this Report. It describes the research plans for the future, summarizes the evaluation results and formulates the prospects based on the evaluation and trends of science policy in Estonia and Europe.

2. Centre for Nonlinear Studies CENS

2.1 General

The structure of CENS in 2001 includes the following research groups:

- Wave propagation (IoC at TTU);
- Fractality and biophysics (IoC at TTU);
- Optical nonlinearity (IoC at TTU);
- Waves in fluids (Estonian Marine Institute);
- Geometric approach (Chair of Geometry, Tartu University);
- Nonlinear signal processing (Centre of Biomedical Engineering of TTU).

There have been several joint meetings of the CENS as a whole. The most important joint activity was the preparation to the international evaluation, carried out within the Estonian Programme of Centres of Excellence in Research. The evaluation itself took place in November, 2001. The research programmes of groups, CENS as a whole and the results of the evaluation are analysed in Section 6.

The International Advisory Board (IAB) of CENS is the following

Prof.	Josef Ballmann (RWTH Aachen);
Prof.	Bengt Lundberg (Uppsala University);
Prof.	Gérard A. Maugin (University of Paris 6);
Prof.	H. Keith Moffat (Cambridge University);
Prof.	Valdur Saks (University of Grenoble);
Dr.	Andras Szekeres (Budapest Technical University);
Prof.	Dick van Campen (Eindhoven University of Technology);
Prof.	Brenny van Groesen (Twente University).

Three IAB members (V.Saks, A.Szekeres, B. van Groesen) have visited CENS, others have sent their written opinions or results and research plans of CENS.

2.2 Strategy of CENS

The first strategic aim is to be at the frontier of science. This is possible only by intensive co-operation and information change. Indirectly, contacts with leading centres and international meetings, etc. serve this purpose. Directly, the advice from the International Advisory Board is essential. As a result, publications in leading journals witness that CENS follows this aim steadily.

The second strategic aim is to be the central point in Estonia and react to the needs of the society. This is the mission of CENS. That is why contacts with industry and hospitals/cardiology centres and the Ministry of Environmental Affairs (marine sciences) are so important. That is why some of the publications are directed to Estonian society (but still in English) and some instruments (see below) used for disseminating knowledge nationally.

2.3 Instruments of CENS

Networking

Internationally, the most important is the co-operation through grants and formal agreements. At present, formal agreements of co-operation exist with the following centres: University of Paris 6, Technical University Denmark, Eindhoven Technological University, Helsinki University of Technology, Torino University, Wroclaw University, Budapest Technical University, Hong Kong City University. This co-operation network is planned to be enlarged. Informal co-operation is with: Uppsala University, RWTH Aachen, Twente University, University of Kaunas, University of Tromsø, University of Salerno, University of Grenoble, etc.

The networking through ESF programme NATEMIS (Nonlinear Acoustic Techniques for Micro-scale Damage Diagnostics) involves 8 centres throughout Europe. Close relations with International Union of Theoretical and Applied Mechanics (IUTAM) and European Mechanics Society (Euromech) gives the direct access to the information on hot problems. IUTAM Bureau members (H.K.Moffat, D.van Campen) are in the IAB of CENS, J.Engelbrecht is the IUTAM Bureau member and the convener of the Advisory Board of the Euromech. H.Aben is the member of the European Permanent Committee on Experimental Mechanics.

Nationally, CENS is the seat of the Estonian National Committee for Mechanics (ENCM), the IUTAM adhering organization. ENCM also co-ordinates the Estonian National Programme on Mechanics, runs Estonian Days of Mechanics (every three years) and special lectures.

Meetings

Internationally, CENS keeps tracks on several series of meetings run by the international community. These are the following.
IUTAM meetings;
Euromech Meetings;
Nordic- Baltic Conferences on Biomedical Engineering (invited + contributions);
Nordic Seminars on Computational Mechanics (invited lectures from fellows, and contributions from students);
Fenno-Ugric Days of Mechanics (started in 1995);
General Assembly of European Geophysical Society;
International Conferences on Experimental Mechanics;
International Conferences on Glass;
Nationally, Estonian Days of Mechanics are run by CENS.

Shorter one-day meetings and seminars are organized regularly, for example "Chaos and Order" in the Estonian Academy of Sciences, Oct. 1999.

Teaching

Internationally, the fellows have been invited to give lecture courses. The former ones included courses in Budapest Technical University, RWTH Aachen, Helsinki University of Technology, CISM in Udine (lecture materials published by Springer in 1994). The most recent ones include:

H.Aben	"Hybrid and tomographic method in experimental mechanics", Bari, Italy, 2000.
H.Aben	"Glass Stress Summer School", Tallinn, Estonia, 2000.
J.Engelbrecht	"Nonlinear evolution equations", PhD course, Messina, Italy, 2000.
J.Engelbrecht	"Nonlinear Dynamics", PhD course, Turin, Italy, 2000.

Nationally, BSc, MSc, PhD courses are run in Tallinn Technical University and Tartu University (see Application). Weekly seminars, although not in official curricula, are actually also a part of education process. It must be stressed that CENS is a research unit with no obligatory teaching. However, postgraduate studies are a "must" for CENS.

Publications

Internationally, the papers are published in international journals corresponding to the profile of studies. CENS also keeps the track of IUTAM publications (reviewed Symposia Proceedings in Kluwer series) which are considered very important in the mechanics community over all the world. J.Engelbrecht, H.Aben and M.Rahula have published monographs (McGraw Hills, Kluwer, Springer, Pitman, Longman, World Scientific). Several special issues of journals have been edited as guest-editors (the latest Wave Motion, 2001, 34, N 1, Elsevier by J.Engelbrecht with G.A.Maugin and A.Samsonov). Publication in international journals is a top priority of CENS.

Nationally, the publication is a mission. We use strictly reviewed and indexed Proceedings of the Estonian Academy of Sciences, series Physics-Mathematics and Engineering, concentrating on special issues (all certainly in English). These journals are now in the system of EBSCO. Latest issues:
Physics-Mathematics, 1997, 46, 1/2 - nonlinear dynamics;
Physics-Mathematics, 1999, 48, 3/4 - nonlinear dynamics;
Engineering, 2001, 7, 2 - marine sciences.

The latest monographs in Estonian (oriented to students) are "The Book of Chaos" by Ü.Lepik and J.Engelbrecht and "The Beauty and Charm of Mathematics" by M.Rahula. We value very much the joint publications with our partners in industry and hospitals. The overviews on our activities are published by M.Kutser (Proc. Estonian Acad. Sci. Eng. 1999, 5, 2, 168-178; 2000, 6, 3, 230-251). We feel our mission also in popularization of science. Essays by J.Kalda and J.Engelbrecht have reflected several aspects of science and mechanics in particular (magazines Akadeemia, Horisont). A view from young scientists (M.Vendelin, O.Kongas, M.Lemba) has been published in a special issue "Young Researchers" (Academy Publ., 2000). Public lectures and demonstrations have been organized (J.Engelbrecht, H.Aben, A.Salupere, A.Stulov). In all this our ideology is: to bring philosophy of science into research, to point out new and intriguing knowledge, to inform public about that.

3. Main results 2001

3.1 Institute of Cybernetics, Tallinn Technical University.

3.1.1 Dynamics of microstructured materials and solitons.

Solitary waves in periodically forced dispersive media. Wave propagation in dispersive media (media with microstructure) with periodic forcing is studied. The simplest mathematical model for such a process is the KdV-type nonlinear evolution equation, which has a sine-term in the r.h.s. This equation is integrated numerically under periodic boundary and harmonic initial conditions making use the pseudospectral method. As a result, it is shown that the force field can be divided into four categories - weak, moderate, strong and dominant - depending on the character of the solution. In the case of weak, moderate or strong force fields soliton type solutions are found to emerge. Compared to the conservative case (modelled by the KdV equation) the character of the solution is essentially different. In the conservative case a train of symmetric solitons having proportionally decreasing amplitudes forms from the harmonic input. In the forced case some emerging solitons can be suppressed and some amplified depending on the strength of the force field. In the case of the strong force field the number of emerging solitons is higher than that in the KdV case. All emerged solitons are asymmetric and they can be amplified to three different levels. Solitons amplified to the same level have equal amplitudes. In the case of the dominant force field the solution is not of solitonic character, i.e., here the force field is dominating over nonlinear and dispersive properties of the media. The value of the dispersion parameter determines the minimum and the maximum number of emerging solitons — the weaker the dispersion the higher the number of solitons. For fixed value of the dispersion parameter the maximum number of solitons is determined by the field parameter — the lower the value of the field parameter the more solitons can emerge. If both, the dispersion parameter and field parameter, have fixed values then the value of the force parameter determines the total number of emerging solitons as well as the number of solitons in a certain level (A.Salupere, M.Kukk).

Solitary waves in materials with higher order dispersion
The wave propagation in microstuctured media with different nonlinear properties is studied. Two Korteweg - de Vries type evolution equations with quartic and quadratic nonlinearity and both the third- and the fifth-order dispersion, FKdV and KdV435 respectively, are used as model equations. The third order dispersion parameter d and that of the fifth order b have opposite sign, which guarantees the pure normal dispersion (like in the KdV case). Both model equations are integrated numerically by the pseudospectral method with respect to time variable under harmonic initial conditions and periodic boundary conditions. Solution types, behaviour of the extrema and periodicity are examined and described in the case of both model equations. In both cases the character of the solution is solitonic – the type of solution for the KdV435 equation is a train of negative solitons but for the FKdV equation a train of positive solitons. In both cases periodic behaviour of spectral quantities can be detected for strong(er) dispersion.

Wave propagation in dilatant granular materials is modelled by a hierarchical Korteweg-de Vries type equation. The dispersion analysis for the model equation is carried out and normal and anomal dispersion domains in the 3D material paremeters space are found (A.Salupere, O.Ilison, L.Ilison).

Long time behaviour of KdV solitons – weak dispersion limit
The emergence and interaction of KdV solitons generated by harmonic initial conditions are studied in the long run (hundreds of recurrence time t_R). In the long run this process is characterized not so much by regular soliton trains but rather by soliton ensembles. It has been shown explicitly that under indicated initial conditions the width of emerging solitons are mostly larger than the distance between maxima of wave profiles. Consequently, visible are the ensembles formed by several simultaneously interacting solitons including also hidden (virtual) solitons. The conditions for emerging such ensembles are studied over the wide range of amplitude ratios for typical dispersion parameters. After the initial train of solitons has emerged, the further process is characterised by propagation of soliton ensembles and in numerical simulations the local maxima of wave profiles can be traced. The geometrical patterns of trajectories of those maxima are analysed. In the short run arc-like patterns are formed but in the long run regular rhombus-like patterns are detected. The backbones of those rhombi are balanced trajectories which correspond to interacting solitons whose phase-shifts to the right are balanced by phase-shifts to the left. Consequently, over long time and space intervals these trajectories can be approximated by straight lines. A rhombus in the $x - t$ plane has the space periodicity 2π dictated by the initial excitation and time periodicity t_P which is related to the recurrence time t_R and is dictated by balanced trajectories. Such a pattern is a steady feature of regularity in the soliton emergence process that usually is taken to be shadowed by the loss of the recurrence in the strict sense. Based on that analysis, it is possible to cast more light to the recurrence and periodicity in the long run (A.Salupere, J.Engelbrecht, P.Peterson).

Surface solitons
When looking down on a disturbed surface of water that is under influence of gravity, complicated wave patterns, formed by the crests of waves, are observed. In this study the question "Can we predict the amplitudes of waves and a subsequent evolution of surface from the information obtained from a single photographic snapshot of the wave pattern?" is addressed. This, the so-called inverse problem of wave crests, arises in many practical applications, e.g. when estimating sea conditions from a aerophoto, or when generating deterministic wave fields to test ship models, or when measuring surface elevation without causing any artificial effects.

To ensure an affirmative answer, in this study surface waves are modelled by 2D multi-soliton interactions of KdV type models (in Hirota sense). This approach is supported by observation that soliton phenomenon is rather robust in (the theory of) water waves. As a result of the study, an algorithmic method is established for constructing interaction patterns for an arbitrary number of solitons. This method is based on the novel decomposition of soliton solutions into a superposition of solitons and interaction solitons. Uniqueness of the solution to the inverse problem is proved for two KP soliton interactions. Also sensitivity to initial data is studied. All new concepts are demonstrated for three and five soliton interactions. The analysis is applied for unidirectional wave propagation models, in particular, in the case of KdV-Sawada-Kotera model. It is concluded that the classical KdV model is too narrow to demonstrate all aspects of solitons interaction, which is not the case for the KdV-Sawada-Kotera model. PhD thesis of P. Peterson is prepared based on the results above (P.Peterson).

3.1.2 Biomechanics and biophysics

Mathematical modelling of intracellular energy fluxes

The oxidative phosphorylation has been recently studied in chemically skinned cardiac fibers. It turns out that the affinity of those fibers to adenosine diphosphate (ADP) is an order of magnitude lower that of isolated mitochondria. The prevailing hypothesis to explain this difference is that during the isolation of mitochondria, the permeability of their outer membranes is considerably increased. This year we tested the alternative hypothesis that the low affinity of the fibers to ADP is caused by the restricted diffusion into the fiber. We performed the experiments to compare and evaluate the two competing hypotheses and we refuted the prevailing one.

Recently, for the first time, the dynamic response of oxidative phosphorylation to the stepwise changes in workload has been assessed at various levels of inhibition of the creatine kinase (CK). This year we composed a model and simulated these experiments. We demonstrated that while the energy buffering is controlled by the cytosolic CK isoform, the transfer of the energy in the form of phosphocreatine is controlled by the mitochondrial CK isoform. We proposed that comparing the dynamics described above for species having different activities of mitochondrial isoform (such as rabbits compared to rats) may allow to estimate the diffusion barrier between the ATP producing and consuming sites in the cardiac muscle (O.Kongas).

Mechanical contraction of the heart muscle.

The mechanical performance of the ventricle depends on both the properties of the actomyosin complex and fiber orientation within the left ventricular wall. It has been shown theoretically (Bovendeerd et al, J Biomech, 27: 941–951, 1994), that the distribution of stress and strain in the left ventricular wall is highly sensitive to the changes in the fiber orientation within the wall. Taking into account such sensitivity, the fiber orientation has to be regulated carefully in the ventricles by adaptation processes. We investigated the influence of fiber orientation on the ejection fraction and the heterogeneity of the distributions of fiber stress, fiber strain and ATP consumption.

A finite element model was used with active properties described by the Huxley-type cross-bridge model. The model computes the deformation of the ventricle, local strains, passive and active stress, and ATP consumption in the ventricular wall. The governing equations were discretized using the finite element method in conjunction with Galerkin's method. The fiber orientation was quantified by two angles: the helix fiber angle, describing the crossover of fibers between base and apex of the heart, and the transverse angle, describing the crossover of fibers between inner and outer layers of the cardiac wall. According to our simulations, the variances of the sarcomere length, developed stress and ATP consumption during a beat have very similar dependencies on transmural course of the helix fiber angle. The optimal transverse angle value is also similar if the variance of the sarcomere length or developed stress is minimized. The dependence of sarcomere length, developed stress and ATP consumption variances on the helix fiber angle distribution is not simple: the variances have several minima at different helix fiber angle distributions. However, we identified only one region in the studied design space with high ejection fraction of the left ventricle and relatively homogeneous distributions of sarcomere strain, developed stress and ATP consumption within the ventricular wall. This region corresponds to the physiological distribution of the helix fiber angle in the LV wall. From our analysis we concluded that if the fiber orientation is regulated by strain or stress distribution the adaptation process should be stable and lead to the ventricles with high ejection fraction provided the difference between actual and optimal fiber orientation is relatively small.

In our simulations, a linear PVA–ATP consumption relationship was obtained. Since we used the cross-bridge model which reproduced linear SSA–ATP consumption relationship, the measured PVA–ATP relationship can be predicted theoretically from the SSA–ATP relationship. The computed ATP consumption distribution was similar to the distribution of oxygen consumption estimated from PCr-to-ATP ratio measurements by NMR. According to the measurements, PCr-to-ATP ratio is slightly higher in the epicardial layer than in the endocardial layer and, with a midwall layer value between these two. From the available PCr-to-ATP ratio measurements, one can conclude that oxygen consumption in epicardial layers is lower than in endocardial layers. According to our simulations, the highest ATP consumption rate is between the midwall and endocardial layers and the smallest ATP consumption in sub-epicardial layer.

From our analysis of the model solution we concluded: (a) the variances of sarcomere strain and developed stress are minimized by almost the same fiber orientation, which is close to the measured one; (b) there exists a local minimum of the sarcomere strain and stress variances in the region that corresponds to a high ejection fraction of the left ventricle. From this result it can be concluded that, if the orientation of the muscle fibers in the left ventricle is regulated by the adaptation process to minimize the heterogeneity of the strain or stress distribution in the left ventricular wall, the resulting design of the left ventricle will lead to a good left ventricle performance as a pump (M.Vendelin, M.Lemba).

Fractality

Inverse 6-vertex model and 4-vertex (4V) models have been formulated. These models are suited for the numerical analysis of random self-affine surfaces. In particular, 4V-model has a very high numerical efficiency. Evidences are given that the inverse 6-vertex and 4V models belong to the same universality class. 4V-model has been used to calculate the fractal dimension of a single isoline as a function of the roughness exponent of random self-affine surfaces. New scaling exponent of random self-affine surfaces has been introduced, the fractal dimension of the set of "oceanic coastlines". It is shown that for negative roughness exponents, this fractal dimension is equivalent to the fractal dimension of (correlated) percolation clusters. Computer code has been prepared to calculate this exponent as a function of the roughness exponent.

The algorithm of gradient-limited surfaces has been modified. The elevation line does not follow a randomly chosen aim line, but instead, is a random walk. The results of numerical analysis indicate that this model belongs to the same universality class as body-centered solid-on-solid model (J.Kalda).

Heart rate variability

The heart rate variability database has been extended to include the records of more than 400 patients. Surrogate data analysis has been used to show that the correlation dimension of the sequence of normal-to-normal (NN) intervals does not measure the dimensionality of the underlying non-linear attractor, but instead, is a certain scaling exponent. This scaling exponent depends mostly on the level of short-time variability, and how this variability depends on the mean heart rate.

The rank-length distribution law of the low-variability periods has been used to construct three new non-linear measures of heart rate variability. These quantities characterize the complex structure of HRV signal, where the low- and high variability periods are deeply intertwined, aspect which is not covered by the other methods of heart rate variability analysis (such as fractional Brownian motion based multifractal analysis). These quantities discriminate efficiently between the seven studied patient groups, with p-values up to 0.01% (J.Kalda, M.Säkki).

3.1.3 Nonlinear wave theory

Acoustodiagnostics of inhomogeneous and prestressed solids.
The simultaneous nonlinear propagation, reflection and interaction of two longitudinal waves in inhomogeneous materials is studied in detail. The wave propagation is described on the basis of the derived analytical solutions (i) in the nonlinear elastic material with weakly inhomogeneous physical properties and (ii) in the nonlinear elastic material undergoing inhomogeneous predeformation.

In the first case, the influence of the physical inhomogeneity of the material described by the different functions on the wave motion is analysed in detail. The main attention is paid to the nonlinear phenomena that accompany two waves simultaneous propagation (evolution of harmonics, nonlinear interaction, etc.). The effects of three parameters that characterize a nonlinear elastic material (density, linear elasticity, nonlinear elasticity) on the evolution of the wave profile is clarified in one-dimensional formulation. The essential regularity is discovered - by quadratic nonlinear formulation the separate influence of the weak variation of the properties of the physically nonlinear elastic material on the distortion of the profile of the longitudinal wave with small but finite amplitude is additive. This regularity makes it possible to pose algorithms for separate nondestructive evaluation of weak inhomogeneity in different physical properties of the material.

In both cases, numerous numerical experiments are implemented with the view to clarify the influence of the inhomogeneity caused by the variation of the physical properties of the material or by the external affects (inhomogeneous predeformation) to the simultaneous propagation, reflection and interaction of two longitudinal waves in nonlinear elastic material. The basic conclusion of the analysis of the obtained results is that by quadratic nonlinear formulation inhomogeneity, independently from its kind evokes modulation in nonlinear effects of sine wave propagation. The absence of the modulation characterizes homogeneous physical properties of the material but does not characterize the existence of homogeneous predeformation in the material. So it has been shown that it is possible to solve several qualitative and quantitative problems of nondestructive evaluation for inhomogeneous materials on the basis of two wave simultaneous propagation data (A.Ravasoo, A.Braunbrück).

Thermodynamic model for phase-transition front propagation.
It is shown that the developed model captures the experimentally observed particle velocity difference appearing during the impact-induced phase transformation. A thermodynamic model for impact-induced martensitic phase transitions is developed on the basis of thermodynamics of discrete systems and material formulation of continuum mechanics.

The extensive study of the problem of moving phase boundaries shows that the velocity of a moving phase boundary cannot be determined in the framework of continuum mechanics without any additional hypothesis. What continuum mechanics is able to determine is the so-called *driving force* $f_{\mathcal{S}}$ acting on the phase boundary. The propagation of a phase boundary is thus expected to be described by a *kinetic relation* between the driving traction $f_{\mathcal{S}}$ and the rate V_N, at which the transformation proceeds:

$$V_N = \phi(f_{\mathcal{S}}),$$

where the constitutive function ϕ provides a continuum-level characterization of the micro-mechanisms underlying the transformation process.

Whether impact causes a phase transition depends on the magnitude of the impact velocity v_0. *The criterion for the nucleation* of a austenite-to-martensite phase transition is assumed to be the attainment of a critical value f_* of driving traction $f_\mathcal{S}$ at the phase boundary. It is assumed that f_* is a materially determined constant.

It is found that the kinetic relation and the nucleation criterion together single out a unique solution from among the infinitely many solutions that satisfy the jump conditions at discontinuities.

The proposed model does not use any explicit expression for the kinetic relation for the phase transition front propagation. All the needed information is extracted from the thermodynamic consistency conditions for adjacent discrete elements. So-called *contact quantities* are introduced for the description of non-equilibrium states of the discrete elements representing continuous body. The values of contact quantities for adjacent elements are connected by means of so-called *thermodynamic consistency conditions*. Such conditions should be distinct for the homogeneous and heterogeneous case.

The values of contact quantities can be determined (at least approximately) within the composite wave-propagation algorithm that was successfully applied for the thermoelastic wave propagation in inhomogeneous media including the case of rapidly varying properties.

A thermodynamic criterion of the initiation of the phase transition process follows from the simultaneous satisfaction of both homogeneous and heterogeneous thermodynamic consistency conditions at the phase boundary. A critical value of the driving force is determined that corresponds to the initiation of the phase transition process (A.Berezovski).

Piano hammers - theoretical and experimental studies

Piano hammer studies are based on the hysteretic (hereditary) model of piano hammer and upon the huge number of experimental data. The experimental testing of piano hammers has been carried out using a piano hammer testing device. This arrangement permits to register the force and compression histories during the hammer-string interaction with a rather high accuracy and, using the hereditary hammer model, to find the hammer parameters by numerical simulation of the dynamic experiments.

The several hundreds of piano hammers produced by various manufacturers, e.g. Schneider, Renner, Abel etc. were tested and compared. It is experimentally shown that the piano hammers possess history-dependent properties, or in other words, are made of a material with memory. The hammers from various manufacturers differ from each other mainly by their stiffness.

The good agreement of the experiment with the theory is verified for the various types of hammers and for a broad range of hammer velocities. The dependence of the slope of the force-compression characteristics of the hereditary hammer on the rate of loading is demonstrated.

It is established that the hammer parameters strongly depend on the diameter of the string. The qualitative estimation of the air humidity influence on the stability of the hammer parameters is given. The quantitative and qualitative influence of the piano hammer mechanical treatment (hand tuning) on the hammer parameters was investigated. The regular dependencies of the piano hammer parameters on the key number were obtained. For the Abel's set of piano hammers the continuous dependencies of the hammer parameters on the key number are presented.

The simulated flexible string vibration spectra excited by different piano hammers are calculated and the comparison of hammers in a frequency - domain is carried out (A.Stulov).

General wave theory and numerical algorithms.
An unified description of thermoelastic waves and martensitic phase-transition fronts is developed on the basis of thermodynamic consistency conditions.

The propagation of waves and phase-transition fronts in thermoelastic media is governed by the same field equations and equations of state (at least in the integral formulation). However, if these equations are quite enough for the description of thermoelastic waves, it is not the case for the phase-transition fronts. Certain additional conditions are requested in the presence of moving discontinuities for separating a unique solution among the whole set of possible ones satisfying given initial and boundary conditions. Following the balance of pseudomomentum, we can determine the driving force acting on the interface between phases. However, a kinetic relation between the driving force and the velocity of the phase boundary is still needed. Moreover, the initiation (or nucleation) criterion also should be specified. In spite of these differences, the thermoelastic wave and phase-transition front propagation can be considered under one umbrella, namely, from the point of view of thermodynamic consistency.

The thermodynamic consistency manifests itself only at the discrete level of description (e.g., in numerical approximation). It simply means that the thermodynamic state of any discrete element (grid cell) of the computational domain should be consistent with the corresponding state of its sub-elements (sub-cells) if we try to refine the mesh. As it is shown, this consistency is achieved only by taking into account the energy of interaction between the sub-elements.

The crucial hypothesis is the connection between the interaction energy and so-called contact quantities which describe the non-equilibrium states of discrete systems. The contact quantities are very similar to well-known numerical fluxes commonly used in the finite-volume numerical methods. These quantities can be calculated by means of thermodynamic consistency conditions which are different for processes with and without entropy production. The latter consideration dictates us the rule of application of the consistency conditions: one is used in the bulk (for thermoelastic waves) and another at the phase boundary (where the entropy is produced).

Computations of test problems for two-dimensional thermoelastic waves in media with rapidly-varying properties (e.g. in functionally graded materials) are performed. The comparison with the experimental investigations of the impact-induced martensitic phase transformation is also obtained in the one-dimensional case (A.Berezovski).

Software development
A program "FPIG – Fortran to Python Interface Generator" (http://cens.ioc.ee/projects/f2py2e/) is developed. Its purpose is to scan Fortran 77/90/95 codes and produce interface modules for Python language (http://www.python.org/) which allows users to call (computationally highly efficient) Fortran routines from (a very high level and flexible) Python language, and vice-versa (P.Peterson).

3.1.4 Optical nonlinearity and photoelasticity

Methods of the stress field tomography
New types of the magnetophotoelasticity equations have been derived. These equa-

tions do not have singularity at the point of entrance of light into the specimen. The integral Wertheim law has been generalized for the case when stresses are in equilibrium through the thickness of the specimen and rotation of the plane of polarization due to the Faraday effect is present. Closed form solution of the inverse problem of magnetophotoelasticity for three particular stress distributions, important by residual stress analysis in glass, have been found (L.Ainola, H.Aben).

A mathematical model of a six-step phase-stepping polariscope has been constructed using MathCad 2001. The model permits one to estimate the measurement errors which depend on the variation of the intensity of light, on the nonlinearity of the CCD camera, on the erroneous positions of the polaroids and quarter-wave plates, etc. With this model the correctness of the inversed phase-stepping method has been proved. The model permits quicker and more precise calibration of the polariscope (J.Anton).

Problems related to the application of the generalized sum rule in cases when the stress distribution deviates from the axisymmetric one have been investigated. In this case, by measurement of the residual stress in a certain meridional section, the average value of the axial stress is different from zero. That contradicts to the assumptions which have been used by deriving the generalized sum rule. With numerical experiments it has been shown that by calculating the radial and circumferential stress the average axial stress should be taken equal to zero (A.Errapart).

3.2 Tartu University

3.2.1 Geometric approach to nonlinear problems

Conception of a universal exponential law in jetspaces of maps elaborated in Tartu has been applied in such areas as the theory of differential equations and dynamical systems. The results were presented at the international meetings in Kaunas (April, 2001), Klaipeda (July, 2001) and Messina (November, 2001).

We have shown how the operator of a group of linear transformations can be associated to a linear vector field. In connection with this correspondence several tensor representations of a group of linear transformations have been studied. For example, we have studied the representations of the group GL(2,R) in the space of symmetric (p,0)-forms. In this case we also showed the connection between Veronese maps and operators of Hilbert. This connection allows us to give an interpretation of the operators of Hilbert by means of Lie vector fields. We have studied the representations of the group GL(n,R) in the space of symmetric vector-valued (p,1)-forms in connection with classification of polynomial dynamic systems. This approach is based on the K.Sibirski-D. Boularas theory.

We have developed an approach to the theory of non-linear dynamical systems based on the notion of connection in fiber bundle and on the notion of translation of fiber. Contemporary interpretation of classical tensor analysis based on vector bundles and tangent bundles is offered and possible applications in quantum field theory are described (V.Abramov ao).

Interaction between flows on quadrics and corresponding bifurcations are studied.

3.3 Estonian Marine Institute

3.3.1 Waves in fluids

Theory of kinetic equations (resonant wave-wave interactions).

It is shown that in the framework of multi-modal kinetic equations (describing resonant energy exchange between different wave classes) energy exhange rate depends on two different types of coefficients - interaction coefficients and coupling coefficients.

As an example of multi-modal kinetic equations describing evolution of different wave systems with comparable frequencies, the kinetic equation describing slow evolution of the energy spectrum of baroclinic Rossby waves in three-layer model ocean is derived. Explicit analytical expressions for the coupling coefficients describing energy exchange intensity between different modes are obtained and their main properties are established. It is demonstrated that several types of interactions vanish in the case of simple realistic vertical structures of the ocean and that, at least, a four-layer model is necessary in order to involve all possible interaction types. As in the two-layer case, the kinetic equation possesses a fully barotropic solution. Motion systems consisting of a superposition of the barotropic and the first baroclinic mode always transfer energy to the second barotropic mode. If energy initially is concentrated in the baroclinic modes, the barotropic mode will necessarily be generated (T.Soomere).

Anisotropy of wind and wave regimes in the Baltic Proper.
It is shown that directional distribution of moderate and strong winds in the Baltic Sea area is strongly anisotropic. The dominating wind direction is southwest and a secondary peak corresponds to north winds. Northwest storms are relatively infrequent and north-east storms are extremely rare. The primary properties of the anisotropy such as prevailing winds, frequency of their occurrence, directional distribution of mean and maximum wind speed coincide on both sides of the Baltic Proper. The specific wind regime penetrates neither into mainland nor into the Gulf of Finland or the Gulf of Riga.

It is shown that Vilsandi wind data well represent both scalar and directional properties of wind regime in the Baltic Proper. Angular distribution of wind speed in extreme wind events (based on the Weibull distribution) has the specific two-peaked shape with maxima corresponding to southwest and north winds, and a deep minimum for eastearly winds. Extensive periods in which wind direction is uniform over large areas frequently occur in the Baltic Proper. Both wind speed and direction may change essentially during such events, but the changes may occur synchronously in radically separated sites (T.Soomere).

Typical and extreme wave fields off northwest Saaremaa Island.
Properties of saturated wave field in the neighbourhood of possible sites of the Saaremaa deep harbour during typical ($\sim 15\ m/s$) and extreme storms ($\sim 25\ m/s$) are analysed on the basis of wave model WAM forced by steady winds, and directional distribution of winds. The toughest wave regime is at Undva (Uudepanga Bay, probability of occurrence of waves exceeding 3 m is 1 %) and the mildest at Vaigu (0.13 %). Wave regime at Suuriku-Kuriku is slightly better than at Undva (probability of critical wave heights 0.6 %). Directional distribution of wave heights in typical and extreme storms is highly anisotropic. The highest waves correspond to NNW storms. Remarkable wave height anomalies may occur in the neighbourhood of the harbour sites. The anomalies emerge only during very strong storms and may serve as a major navigation danger (T.Soomere).

Sensor calibration theory.
A new application of signal processing on the basis of Kalman filtering is constructed for surveillance systems. A new computational method known as the Fast Kalman Filtering provides effective statistical means for calibrating the whole system in real-time. Accuracy estimations based on the theory of Minimum Norm Quadratic Unbiased Estimation have been constructed in order to avoid any divergence of the filtering. The method can be easily generalized to any system of surveillance of extreme events e.g.

extreme water level or wave heights (K.Rannat).

Modelling of absorption spectra.
The parameters of an exponential model for describing the absorption spectra of coloured dissolved organic matter (CDOM) in lakes with diverse water quality were analysed. The expediency of some other models for the approximation of these spectra is estimated. An attempt to describe these spectra by means of hyperexponential functions $\sim exp(-\alpha\lambda^{\eta})$ shows that approximations with $\eta < 1$ generally lead to better fit than the traditional exponential approximation $\eta = 1$ or the Gaussian approximation $\eta = 2$. (L.Sipelgas, H.Arst, A.Erm, P.Oja, T.Soomere).

3.4 Biomedical Engineering Centre, Tallinn Technical University

3.4.1 Biosignals interpretation: analyses of ECG T-wave morphology.

In order to reveal the possible correlation between the level of myocardial electrical instability assessed at Holter monitoring and certain ECG parameters characterizing ventricular repolarization 24-hours ECG recordings were analyzed in 91 patients divided into four groups according to the maximal Lown grade ventricular arrhythmia.

The following parameters were calculated: RT-interval (RT) duration and variability, RT apex interval (RTa) duration and variability, areas of the first and second half of T-wave (S1, S2) and maximal rise and fall slopes of T-wave (k1, k2). An original signal processing algorithm for ECG was developed for that purpose.

The results of our study demonstrate that certain T-wave morphology parameters, such as areas S1, S2 and slopes k1, k2 possess significant prognostic capabilities for predicting potentially life-threatening arrhythmias at Holter monitoring. The area of the falling phase of T-wave (S2) seems to be the most sensitive parameter in this set. The only insignificant difference for S1 was recorded between groups 4A and 4B, but nevertheless the strong tendency of S1 decrease at higher arrhythmias grades was revealed.

The utilization of the study results - non-invasive analysis of temporal ventricular repolarization heterogeneity and certain aspects of T-wave morphology - provides an important tool for sudden death risk stratification and assessment of antiarrhythmic drug treatment benefits/drawbacks in patients with CAD.

Thus, the results of our study demonstrate that several parameters characterizing ventricular repolarization phase on surface ECG appear to have strong correlation with the level of myocardial electrical instability assessed at Holter monitoring. The determination of the clinical significance of these parameters requires further investigations.

Main result: Complex analysis of certain T-wave parameters, as well as RT interval variability can be a useful tool for identification of patients at increased risk of sudden cardiac death (T.Lipping, J.Lass, H.Hinrikus).

4. Funding

4.1 Basic funding through the Ministry of Education

1. Project 0320200s98. Nonlinear dynamics and stress analysis. Supervisor: J.Engelbrecht.
2. Project 0200793s98. Dynamics of turbulent processes and nonlinear waves. Supervisor: T.Soomere.
3. Project 0140238s98. Interpretation of bioelectromagnetic signals. Supervisor: H.Hinrikus (partly related).

4.2 Estonian grants:

1. ETF 3595. "Photoelastic methods for nondestructive measurement of stress fields".
2. ETF 3739. "Fractal model of oxygen consumption and contraction in cardiac muscles".
3. ETF 4068. "Interaction of solitary waves".
4. ETF 4151. "Scale invariance and intermittency in heart rate variability".
5. ETF 4504. "Propagation of phase-transition fronts in solids".
6. ETF 4704. "*In silico* studies of heart ischemia".
7. ETF 4706. "Inverse problems for description of properties and states of inhomogeneous materials".
8. ETF 4708. "Investigation of piano hammers".
9. ETF 4272. "Algorithms for discrimination of life-threatening heart arrhythmia".
10. ETF 4281. "Application of method for optical coherent photodetection in carediovascular diagnostics".
11. ETF 4025. "Analytical and numerical study of surface wave anomalies in the Baltic Sea".
12. ETF 4515. "Exterior calculus of higher order, generalized cohomologies and their applications to higher spin gauge fields".
13. ETF 4420 "Mappings and singularities in geometry and applications".

4.3 International grants

1. NATO Collaborative Linkage Grant "Thermomechanics of progress and stability of phase interfaces (crystals, alloys)", partners University of Paris 6, Technical University Berlin.
2. ESF Programme NATEMIS. "Nonlinear Acoustic Technique for Micro-Scale Damage Diagnostics", partners from many European centres in Italy, The Netherlands, Czech Republic, etc.

3. EC Marie Curie Postdoctoral Fellowship to O.Kongas on "Building Working Muscle Cells in the Computer: Biocomplexity and Metabolism" in Free University of Amsterdam.

4. Dynamo (Dynamic Adaptive Modelling of the Human Body) project, Ragnar Granit Institute, Tampere University of Technology.

4.4 Contracts

1. Philips Electronics Nederland B.V.: contract for supplying automatic polariscope AP-02 SM. Supervisor: H.Aben.

2. Estonian Centre of Environmental Investments: contract for studies of influence of high craft speed ships' wake on coastal dynamics. Supervisor: T.Soomere.

5. Publicity of Results

5.1.1 Research Reports

1.	Mech 223/01	A.Salupere, P.Peterson and J.Engelbrecht. Long time behaviour of soliton ensembles.
2.	Mech 224/01	A.Berezovski, G.A.Maugin. On the thermomechanics of moving boundaries.
3.	Mech 225/01	A.Berezovski, Maugin, T.Ugam. Impact-induced martensitic phase transformations.
4.	Mech 226/01	J.Engelbrecht, A.Ravasoo, A.Salupere. Nonlinear waves in solids and the inverse problems.
5.	Mech 227/01	P.Peterson. Construction and decomposition of multi-soliton solutions of KdV type equations.
6.	Mech 228/01	P.Peterson. Construction of multi-soliton interaction patterns of KdV type equations.
7.	Mech 229/01	P.Peterson. Construction and decomposition of multi-soliton solutions of KdV type equations.
8.	Mech 230/01	M.Kukk, A.Salupere. Solitonic structures in periodically forced dispersive media.
9.	Mech 231/01	A.Braunbürck, A.Ravasoo. NDE of inhomogeneous nonlinear elastic material by ultrasound nonlinear interaction data.
10.	Mech 232/01	A.Ravasoo. NDE based on the analysis of ultrasonic waves nonlinear interaction in inhomogeneously predeformed material.
11.	Mech 233/01	A.Ravasoo. Wave profile distortion and NDT of inhomogeneously predeformed material.
12.	Mech 234/01	A.Stulov. Piano testing device: The force sensor problem.
13.	Mech 235/01	A.Stulov. Experimental testing of piano hammers: features and parameters.
14.	Mech 236/01	M.Säkki, J.Kalda, M.Vainu, M.Laan. Diagnostic performance of the nonlinear measures of heart rate variability.
15.	Mech 237/01	M.Säkki, J.Kalda, M.Vainu, M.Laan. What does the correlation dimension of the human heart rate measure?
16.	Mech 238/01	J.Kalda. Gradient-limited surfaces.
17.	Mech 239/01	O.Ilison. Soliton formation in dispersive media with lower and higher order nonlinearity.

5.1.2 Lecture Notes

1. Mech 01/01 A.Berezovski. Thermomechanics of Moving Phase Boundaries.

5.2 Publications

Books, proceedings and thesis

1. G.A.Maugin, J.Engelbrecht, A.Samsonov (eds). Special issue on Nonlinear Waves in Solids: Analytical and Numerical Aspects. Wave Motion, 2001, 34, 1.
2. A.Guran, G.Maugin, J.Engelbrecht, M.Werby (eds). Acoustic Interaction with Submerged Elastic Structures, Part II: Propagation, Ocean Acoustics and Scattering Singapore et al. World Scientific, 2001, 367 pp.
3. P.Peterson. Multi-soliton interactions and the inverse problem of wave crests. PhD thesis, TTU, 2001. ISBN: 9985-59-233-X.
4. M.Vendelin. Cardiac mechanoenergetics in silico. PhD thesis, TTU, 2001. ISBN: 9985–59–231–X.

Papers (refereed)

1. A.Berezovski, G.A.Maugin. Simulation of thermoelastic wave propagation by means of a composite wave-propagation algorithm. J. Comp. Physics, 2001, 168, 1, 249-264.
2. G.A.Maugin, A.Berezovski. Simulation of two-dimensional thermoelastic waves and fronts. In: Thermal Stresses 2001 (Proc. 4th International Congress on Thermal Stresses, June 8 - 11, Osaka, Japan), Eds. Y.Tanigawa, R.B.Hetnarsky and N.Noda. Osaka, 2001, 39-42.
3. A.Ravasoo, B.Lundberg. Nonlinear interaction of longitudinal waves in an inhomogeneously predeformed elastic medium. Wave Motion, 2001, 34, 2, 225-237.
4. J.Kalda. Description of random Gaussian surfaces by a four-vertex model. Phys. Rev. E, 2001, 64, 020101(R), 4 p.
5. A.Stulov, A. Mägi. Piano hammer: Theory and experiment. In: Musical sounds from past millennia. (Proc. of the International Symposium on Musical Acoustics. ISMA 2001, September 10 - 14, 2001, Perugia, Italia), Edited by D. Bonsi, D. Gonzalez, D. Stanzial, The Musical and Architectural Acoustics Laboratory FSSG-CNR, c/o Fondaz. Cini, Venezia, Italia, 2001, Vol.1, 215-220.
6. P.Peterson, E.van Groesen. Sensitivity of the inverse wave crest problem. Wave Motion, 2001, 34(4), 391 - 399.
7. P.Peterson, J.R.R.A. Martins, and J.J.Alonso. Fortran to Python Interface Generator with an Application to Aerospace Engineering. In: Proceedings of the 9th International Python Conference. Long Beach, California, 2001, (also on CD-ROM).

8. A.Ravasoo, J.Janno. Nondestructive characterization of materials with variable properties. Acta Mechanica, 2001, 151, 3-4, 217-233.

9. A.Braunbrück, A.Ravasoo. NDE of inhomogeneous nonlinear elastic material by ultrasound nonlinear interaction data. Proc. 31th Annual International Conference on Non-Destructive Testing Defektoskopie 2001, November 20 - 22, 2001, Prague, Czech Republic, 77-84.

10. J.Engelbrecht, A.Salupere, J.Kalda, and G.A. Maugin. Discrete spectral analysis for solitary waves. In: A.Guran, G.A.Maugin, J.Engelbrecht, and M.Werby, (eds). Acoustic Interactions with Submerged Elastic Structures. Part II: Propagation, Ocean Acoustics and Scattering, v.5. Series on Stability, Vibration and Control of Systems, Series B, World Scientific, Singapore et al., 2001, 1-40.

11. A.Salupere, J.Engelbrecht, and G.A.Maugin. Solitonic structures in KdV-based higher-order systems. Wave Motion, 2001, 34, 51-61.

12. T.Soomere. New insight into classical equilibrium solutions of kinetic equations. Journal of Nonlinear Science, 2001, 11, 4, 305-320.

13. P.Miidla, K.Rannat, J.Heinloo. Numerical stability in a model of layered structure of thermohaline fields. Proc. Estonian Acad. Sci. Phys. Math., 2001, 50, 1, 49-62.

14. T.Soomere, S.Keevallik. Anisotropy of moderate and strong winds in the Baltic Proper, Proc. Estonian Acad. Sci. Eng., 2001, 7, 1, 35-49.

15. T.Soomere. Wave regimes and anomalies off north-western Saaremaa Island, Proc. Estonian Acad. Sci. Eng., 2001, 7, 2, 157-173.

16. T.Soomere. Extreme wind speeds and spatially uniform wind events in the Baltic Proper, Proc. Estonian Acad. Sci. Eng., 2001, 7, 3, 195-211.

17. J.Elken, J.Kask, T.Kõuts, U.Liiv, R.Perens, T.Soomere. Hydrodynamical and geological investigations of possible deep harbour sites in north-western Saaremaa Island: Overview and conclusions, Proc. Estonian Acad. Sci. Eng., 2001, 7, 2, 85-98.

18. J.Lass, J.Kaik, K.Meigas, H.Hinrikus, and A. Blinowska. Evaluation of the quality of rate adaption algorithms for cardiac pacing, Europace 2001, 3, 221-228.

19. K.Meigas, R.Kattai, and J.Lass. Optimising of signal processing parameters in cardiovascular diagnostics. IFMBE Proceedings Medicon 2001, IX Mediterranean Conf. on Med. and Biol. Eng. and Comp., June 2001, Pula, Croatia. 328-331.

20. Ü.Olli, D.Karai, J.Lass, J.Kaik, and M.Vainu. Analysis of T-wave morphology for discrimination of life threatening arrhythmias - preliminary study. IFMBE Proceedings Medicon 2001, IX Mediterranean Conf. on Med. and Biol. Eng. and Comp., June 2001, Pula, Croatia, 344-347.

21. J.Lass, J.Kaik, D.Karai, and M.Vainu. Ventricular repolarization evaluation from surface ECG for identification of the patients with increased myocardial electrical instability, IEEE EMBS 23td Annual Int. Conf., Okt. 25 - 28, 2001, Istanbul, Turkey, CDROM, 4 p.

22. H.Aben. Simplified interpretation of an integrated photoelastic fringe pattern. Exp. Techn., 2001, 25, 6, 45-47.

23. H.Aben, L.Ainola. Optical tomography of the laser's Gaussian electric field. Optics & Laser Technol., 2001, 33, 29-30.

24. H.Aben, L.Ainola, J.Anton, and A.Errapart. Dètermination des contraintes dans les prèforms optiques a saut d'indice. Colloque "Photomècanique 2001", Poitiers, GAMAC, 2001, 71-78.

25. H.Aben, J.Anton, and A.Errapart. Residual stress measurement in axisymmetric glass articles. Proc. Int. Cong. on Glass, Edinburgh, 2001, 2, 242-243.

26. L.Ainola, H.Aben. Transform equations in polarization optics of inhomogeneous birefringent media. J. Opt. Soc. Am. A, 2001, 18, 9, 2164-2170.

27. M.Rahula. Dynamic systems and their inference to the environment. Year book of Estonian Mathematical Society, Tartu, 2001, 117-137 (in Estonian).

28. J.Kalda, M.Säkki, M.Vainu, and M.Laan. What does the correlation dimension of the human heart rate measure? E-print physics/0112031, 2001.

29. J.Kalda, M.Säkki, M.Vainu, and M.Laan. Zipf's law in human heartbeat dynamics. E-print physics/0110075, 2001.

Abstracts

1. A.Berezovski. Simulation of stress-induced phase-transition front propagation in thermoelastic media. Book of Abstracts, Finno-Ugric International Conference of Mechanics with Beda Symposium, Rackeve, Hungary, 27 May -2 June, 2001.

2. A.Berezovski, J.Engelbrecht, and G.A.Maugin. A thermodynamic approach to modeling of stress-induced phase-transition front propagation in solids. In: IUTAM Symposium on "Mechanics of Martensitic Phase Transformation in Solids", June 11 - 15, 2001, Hong Kong. Book of Abstracts, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, p.5.

3. G.A.Maugin, A.Berezovski. Simulation of two-dimensional thermoelastic waves and fronts. The 4th International Congress of Thermal Stresses "Thermal Stresses 2001", June 8 - 11, 2001, Osaka, Japan. Book of Abstracts, Osaka Prefecture University.

4. A.Berezovski, G.A.Maugin. Thermodynamics of discrete systems and martensitic phase transition simulation. The 6th Meeting on Current Ideas in Mechanics, Thermodynamics and Related Fields, Sept. 3 - 6, 2001, Berlin. Book of Abstracts, Technische Universitat Berlin, p. 2-3.

5. A.Berezovski. Thermomechanical modeling of martensitic phase-transition front propagation. The First SIAM-EMS Conference "Applied Mathematics in our Changing World", Sept. 2 - 6, 2001, Berlin. Collection of Abstracts, Konrad-Zuse-Zentrum fur Informationtechnik Berlin, p. 55-56.

6. A.Ravasoo. Nonlinear waves interaction and NDT. Finno-Ugric International Conference of Mechanics with Beda Symposium, 27 May - 2 June, 2001. Abstract, Savoyai Palace, Rackeve, Hungary, p. 52.

7. A.Ravasoo. Nonlinear distortion of ultrasonic wave profile and NDT. Program and Abstracts of the 6th International Workshop on Nonlinear Elasticity in Materials. June 18 - 22, 2001, Leuven, Belgium, p. 45.

8. A.Ravasoo. NDE based on the analysis of ultrasonic waves nonlinear interaction in inhomogeneously predeformed material. Abstract, IVth International Workshop Advances in Signal Processing for Non Destructive Evaluation of Materials. Aug. 7 - 10, 2001, Universite Laval, Quebec city, Canada, p. 64.

9. J.Engelbrecht, A.Ravasoo, and A.Salupere. Nonlinear waves in solids and inverse problems. Abstract, IUTAM Symposium on Computational Mechanics of Solid Materials at Large Strains, University of Stuttgart, Aug. 20 - 24, 2001, Germany, p. 34.

10. P.Peterson, E.van Groesen. Wave interaction patterns and prediction of wave parameters. In: Symposium on Mathematical Support for Hydrodynamic Laboratories (LabMath), Institut Teknologi Bandung, Indonesia, Sept. 9 - 11, 2001.

11. J.Engelbrecht, A.Salupere, and P.Peterson. Soliton ensembles and the periodicity in their interaction patterns. In: Seminar and Workshop on Nonlinear Lattice Structure and Dynamics, Dresden, Germany, Sept. 4 - 9, 2001, p.4.

12. J.Kalda. A simple model of geologic landscapes. STATPHYS 21 Conference, Cancún, Mexico. Book of Abstracts, July 15 - 20, 2001, p. 233.

13. A.Salupere, J.Engelbrecht, and P.Peterson. On the long-time behavior of soliton ensembles. Abstract Book, Second IMACS Conference on Nonlinear Evolution Equations and Wave Phenomena: Computation and Theory. Athens, USA, April 9 - 12, 2001.

14. A.Salupere, M.Kukk. On solitonic structures in nonconservative dispersive media. Abstract Book, Finno-Ugric International Conference on Mechanics - Fudom 2001, May 27 - June 2, Rackeve/Budapest, Hungary, 2001.

15. M.Lemba, M.Vendelin. Actomyosin complex the energy profiles: estimation of profiles by analysing the performance of the cardiac muscle in silics. XXX European Muscle Conference, Pavia, Italia, Sept. 8 - 13, 2001, p. 135.

16. T Soomere, S.Keevallik. Anisotropy of moderate and strong winds in the Baltic Proper, Geophys. Res. Abstract, 3, 2001 (CD).

17. T.Soomere. Classical equilibrium solutions of kinetic equations. Geophys. Res. Abstract, 3, 2001 (CD).

18. T.Soomere. Anisotropy of wind and wave regimes in the Baltic Proper. In: Baltic Sea Science Congress 2001, Stockholm Marine Research Centre, Stockholm University, 2001, 128.

19. M.Rahula. Dynamical systems and translation of tensor fields. Matematika ir matematinis modeliavimas - 2001, Konferencijos pranešimu medžiaga, Kaunas, Technologija, 2001, 16 (in Russian).

20. D.Tseluiko. Monge-Ampère operators and equations. Matematika ir matematinis modeliavimas - 2001, Konferencijos pranešimu medžiaga, Kaunas, Technologija, 2001, 16 (in Russian).

Essays

1. J.Engelbrecht. Science, creative activities, needs. Proceedings of the Parliament of Estonia, 2001, N 3, 103-109 (in Estonian).

2. J.Engelbrecht. Science without borders. Eurobridge, 2001, 1, 7-12 (in Estonian).

3. J.Engelbrecht. Science in turn of a new century. In: M.Veiderma (ed), Thinking of Estonia. Academic Council of the State President 1994 - 2001, Academy Publishers, Tallinn, 2001, 81-95 (in Estonian).

4. J.Engelbrecht. Science and society - faculties close or apart. In: R.Vihalemm (ed), Estonian Studies in the History and Philosophy of Science (219 Boston Studies in the Philosophy of Science), Kluwer, Dordrecht et al., 2001, 77-88.

5. J.Engelbrecht. Science and sciences in changing time. In: The reform of Science in Estonia - plusses and minuses. Estonian Acad. Sci., Tallinn, 2001, 11-23 (in Estonian).

Submitted papers

1. A.Berezovski, G.A.Maugin. Application of wave-propagation algorithm to 2D thermoelastic wave propagation in inhomogeneous media. In: E.F.Toro (Ed.) Godunov Methods: Theory and Applications, Kluwer, Dordrecht, 2001, (accepted).

2. A.Berezovski, J.Engelbrecht, and G.A.Maugin. A thermodynamic approach to modeling of stress-induced phase-transition front propagation in solids. In: Proceedings of the IUTAM Symposium on "Mechanics of Martensitic Phase Transformation in Solids", June 11 - 15, 2001, Hong Kong, Kluwer, (accepted).

3. A.Berezovski, G.A.Maugin. Thermoelastic wave and front propagation, (accepted to J. Thermal Stresses).

4. W.Muschik, A.Berezovski. Thermodynamic interaction between two discrete systems in non-equilibrium, (submitted to J. Non-Equilib. Thermodyn.)

5. A.Berezovski, G.A.Maugin. Thermodynamics of discrete systems and martensitic phase transition simulation, (submitted to Technische Mechanik).

6. A.Ravasoo. Wave profile distortion and NDT of inhomogeneously predeformed material. Proc. Euromech 419 Colloquium, Oct. 3 - 6, 2001, Prague, Czech Republic, (accepted).

7. A.Ravasoo. NDE based on the analysis of ultrasonic waves nonlinear interaction in inhomogeneously predeformed material. Proc. IVth International Workshop Advances in Signal Processing for Non Destructive Evaluation of Materials. Aug. 7 - 10, 2001, Universite Laval, Quebec City, Canada, (accepted).

8. J.Engelbrecht, A.Ravasoo, and A.Salupere. Nonlinear waves in solids and inverse problems. Proc. IUTAM Symposium on Computational Mechanics of Solid Materials at Large Strains, University of Stuttgart, Aug. 20 - 24, 2001, Germany, (accepted).

9. J.Kalda, M.Säkki, M.Vainu, and M.Laan. Zipf's law in human heartbeat dynamics. Phys. Rev. Lett. Phys. Rev. Lett., (submitted).

10. M.Säkki, J.Kalda, M.Vainu, and M.Laan. On the nonlinear measures of the heart rate variability of children, to appear in: "Euroattractor 2001", ed. W.Klonowski, (accepted).

11. P.Peterson. Construction of multi-soliton interaction patterns of KdV type equations. Physica D, (accepted).

12. P.Peterson. Construction and decomposition of multi-soliton solutions of KdV type equations. Nonlinearity, (submitted).

13. A.Salupere, J.Engelbrecht, and P.Peterson. On the long-time behaviour of soliton ensembles. Mathematics and Computers in Simulation, (submitted).

14. M.Vendelin, P.H.M.Bovendeerd, J.Engelbrecht, and T.Arts. Ventricular fibers are oriented for high ejection fraction and uniform distribution of strain and stress, (submitted Am. J. Physiol.).

15. O.Kongas , J.H.G.M. van Beek. Creatine kinase in energy metabolic signaling in muscle. In: Proc. 2nd Int. Conf. Systems Biology, Pasadena, 2001, (submitted).

16. O.Kongas et al. High apparent Km of oxidative phosphorylation for ADP in skinned fibers: where does it stem from, (submitted to Amer. J. Physiol.).

17. P.Peterson, E. van Groesen. Wave interaction patterns and prediction of wave parameters, (submitted to Applied Ocean Research).

18. J.Engelbrecht, M.Vendelin. Microstructure described by hierarchical internal variables. Rendicorti Matem. Univ. Torino, (accepted).

19. T.Soomere. Anisotropy of wind and wave regimes in the Baltic Proper. J. of Sea Research, (submitted).

20. T.Soomere. Kinetic equation for Rossby waves in three-layer ocean. J. of Nonlinear Science, (submitted).

21. L.Sipelgas, K.Kallio, H.Arst, A.Erm, P.Oja, and T.Soomere. Optical properties of dissolved organic matter in Finnish and Estonian lakes. Lakes and Reservoirs, (accepted).

22. J.Lass, J.Kaik, D.Karai, M.Vainu, and H.Hinrikus. Discrimination of the patients with increased myocardial electrical instability by ventricular repolarization parameters assessed from 24-hours Holter monitoring, Pace, (submitted).

23. H.Aben, J.Anton, and A.Errapart. Residual stress measurement in axisymmetric glass articles. Glass Technology, (submitted).

24. H.Aben, J.Anton, and A.Errapart. Measurement of tempering stresses in axisymmetric glass articles. Proc. 2nd International Colloquium on modelling of Glass Forming and Tempering. Valenciennes, 2002, (submitted).

25. L.Ainola, H.Aben. On the direct and inverse problems of magnetophotoelasticity. J. Opt. Soc. Am. A., (submitted).

26. M.Rahula, D.Tseluiko. Interaction of flows on the quartics. XLII Conference of Lithuanian Mathematical Society, Klaipeda, June, 2001, (accepted).

27. D.Tseluiko. On classification of hyperbolic Monge-Ampère equations on 2-dimensional manifolds. Rendiconti del Seminario Matematico di Messina, 2002, (submitted).

5.3 Conferences

1. Finno-Ugric International Conference on Mechanics - FUDoM 2001, Rackeve, Hungary, May 27 - June 2, 2001.
   J.Engelbrecht, M.Vendelin. Scaled microstructure and internal variables.
   A.Berezovski. Simulation of stress-induced phase transition front propagation in thermoelastic media.
   A.Salupere, M.Kukk. On solitonic structures in nonconservative dispersive media.
   A.Ravasoo. Nonlinear waves interaction and NDT.
   M.Kutser. CENS - a flexible structure for joint activities.

2. IUTAM Symposium on "Mechanics of Martensitic Phase Transformation in Solids", Hong Kong, June 11 - 15, 2001.
   A.Berezovski, J.Engelbrecht, G.A.Maugin. A thermodynamic approach to modeling of stress-induced phase-transition front propagation in solids.

3. IUTAM Symposium on Computational Mechanics of Solid Materials at Large Strains, Stuttgart, Aug. 20 - 24, 2001.
   J.Engelbrecht, A.Ravasoo, A.Salupere. Nonlinear waves in solids and inverse problems.

4. Seminar and Workshop on Nonlinear Lattice Structure and Dynamics, Max Planck Institute for the Physics of Complex Systems, Dresden, Sept. 4 - 9, 2001.
   J.Engelbrecht, A.Salupere, P.Peterson. Soliton ensembles and the periodicity in their interaction patterns.

5. Second IMACS Conference on Nonlinear Evolution Equations and Wave Phenomena: Computation and Theory, Athens, USA, Apr. 9 - 12, 2001.
   A.Salupere, J.Engelbrecht, and P.Peterson. On the long-time behavior of soliton ensembles.

6. The 6th Meeting on Current Ideas in Mechanics, Thermodynamics and Related Fields, Berlin, Sept. 3 - 6, 2001.
   A.Berezovski, G.A.Maugin. Thermodynamics of discrete systems and martensitic phase transition simulation.

7. The First SIAM-EMS Conference "Applied Mathematics in our Changing World", Berlin, Sept. 2 - 6, 2001.
   A.Berezovski. Thermomechanical modeling of martensitic phase-transition front propagation.

8. IVth International Workshop on Advances in Signal Processing for Non Destructive Evaluation of Materials. Universite Laval, Quebec City, Canada, Aug. 7 - 10, 2001.
   A.Ravasoo. NDE based on the analysis of ultrasonic waves nonlinear interaction in inhomogeneously predeformed material.

9. 31th Annual International Conference on Non-Destructive Testing Defektoskopie. Prague, Czech Republic, Nov. 20 - 22, 2001.
   A.Braunbrück, A.Ravasoo. NDE of inhomogeneous nonlinear elastic material by ultrasound nonlinear interaction data.

10. 6th International Workshop on Nonlinear Elasticity in Materials. Leuven, Belgium, June 18 - 22, 2001.
   A.Ravasoo. Nonlinear distortion of ultrasonic wave profile and NDT.

11. IUPAP conference STATPHYS 21, Cancun, Mexico, Juli 15 - 20, 2001.
   J.Kalda. A simple model of geologic landscapes.

12. European Interdisciplinary School on Nonlinear Dynamics for System and Signal Analysis Euroattractor 2001, Warsaw, June 19 - 28, 2001.
   M.Säkki, J.Kalda, M.Vainu, M.Laan. On the nature of the correlation dimension of the heart rate.

13. International Symposium on Musical Acoustics, ISMA, Perugia, Italia, Sept. 10 - 14, 2001.
   A.Stulov, A.Mägi. Piano hammer: theory and experiment.

14. The integrated heart: Cardiac structure and function. In Queenstown, New Zealand, Aug. 19 - 21, 2001.
   M.Vendelin, P.H.M.Bovendeerd, J.Engelbrecht, D.H. van Campen, and T. Arts. Distribution of strain, stress and energy consumption as a function of cardiac fiber orientation.

15. The XXXIVth International Congress of Physiological Sciences "From Molecule to Malady", Christchurch, New Zealand, Aug. 27 - 31, 2001.
   M.Vendelin, J.Engelbrecht, E.Seppet, and V.Saks. Intracellular energetic units in cardiac muscle cell: *in silico* study.

16. Symposium on Mathematical Support for Hydrodynamic Laboratories (LabMath), Institut Teknologi Bandung, Indonesia, Sept. 9 - 11, 2001.
   P.Peterson and E. van Groesen. Wave interaction patterns and prediction of wave parameters.

17. XXX European Muscle Conference, Sept. 8-13, 2001, Pavia, Italia.
   M.Lemba, M.Vendelin. Actomyosin complex free energy profiles: estimation of properties by analysing the performance of the cardiac muscle *in silico.*

18. 26th General Assembly of the European Geophysical Society, Nice, April, 2001.
   T.Soomere, S.Keevallik. Anisotropy of moderate and strong winds in the Baltic Proper.

19. 26th General Assembly of the European Geophysical Society, Nice, April, 2001.
   T.Soomere. Classical equilibrium solutions of kinetic equations.

20. Baltic Sea Science Congress, Stockholm, November, 2001.
   T.Soomere. Anisotropy of wind and wave regimes in the Baltic Proper.

21. Colloque "Photomècanique 2001", Poitiers, GAMAC, Apr. 24 - 26, 2001.
   H.Aben, L.Ainola, J.Anton, A.Errapart. Dètermination des contraintes dans les prèforms optiques a saut d'indice.

22. Congress on Glass, Edinburgh, Sept. 26 - 29, 2001.
    H.Aben, J.Anton, A.Errapart. Residual stress measurement in axisymmetric glass articles.

23. 18th Danubia-Adria Symposium on Experimental Methods in Solid Mechanics, Steyr, 2001.
    A.Errapart. Complete axisymmetric residual stress measurement in glass.

5.4 Seminars outside the home Institute

1. J.Engelbrecht, Internal variables and contraction of cardiac muscles (co-author M.Vendelin). Helsinki University of Technology, Otaniemi, January, 2001.

2. J.Engelbrecht, Formation of soliton ensembles (co-authors: A.Salupere, P.Peterson), City University, Hong Kong, June, 2001.

3. J.Engelbrecht, Periodicity in soliton formation (co-authors: A.Salupere, P.Peterson), University of Paris 6, Oct., 2001.

4. A.Salupere, Solitons in a force field (co-author M.Kukk), University of Paris 6, Oct., 2001.

5. A.Ravasoo, Simple nonlinear methods for nondestructive material characterization. European Science Foundation programme "NATEMIS" Workshop, Bruges, Belgium, 23 March, 2001.

6. A.Ravasoo, Modulation of nonlinear effects of wave propagation and material inhomogeneity. European Science Foundation programme "NATEMIS" Workshop, Prague, Czech Republic, 23 Nov., 2001.

7. J.Kalda, Statistical topography of random surfaces. Tallinn Pedagogical University, 16 Aug., 2001.

8. J.Kalda, Nonlinearity and scale independence in heart rate variability. Estonian Society of Biomedical Engineering and Biophysics variability. Estonian Society of Biomedical Engineering and Biophysics. Tallinn, 27 Sept., 2001.

9. T.Soomere, Hydrodynamical patterns in the Baltic Sea. Estonian Academy of Sciences, Tallinn, 23 May, 2001 (in Estonian).

10. T.Soomere, Wind and wave regimes off northwest Saaremaa. Dept. of Meteorology, Uppsala University, 4 May, 2001.

11. T.Soomere, Waves and patterns in large salty pools. Institute of Cybernetics, Roosta , 11 Okt., 2001.

12. T.Soomere, Ocean as the climate buffer and pump. Estonian Academy of Sciences. Tallinn, 26 Okt., 2001.

5.5 Supportive grants (travel, etc.)

1. FUDOM - Academy Exchange Scheme, - local expences (J.Engelbrecht, A.Berezovski, M.Kutser, A.Ravasoo, A.Salupere).

2. City University, Hong Kong - intensive week for research, local expences (J.Engelbrecht).
3. Hong Kong University of Science and Technology - participation at IUTAM Symposium (J.Engelbrecht).
4. Stuttgart University - participation at IUTAM Symposium (J.Engelbrecht).
5. Max Planck Institute for Complex Systems, Dresden - participation at Workshop Nonlinear Lattice Structure and Dynamics (J.Engelbrecht).
6. NATO grant - intensive week for research in Paris 6 (J.Engelbrecht, A.Salupere).
7. EU grant - for attending a Newton Institute EuroConference "Surface Water Waves in Cambridge (P.Peterson).
8. LabMath, ITB Indonesia - for participation at Symposium (P.Peterson).
9. NATO Grant PST.CLG.976009, - two weeks research in Paris 6 (A.Berezovski).
10. NATO Grant PST.CLG.976009 - two weeks research at Berlin Technical University (A.Berezovski).
11. EU grant - for participation at First SIAM-EMS Conference "Applied Mathematics in our Changing World" (A.Berezovski).
12. Tallinn Piano Factory grant - for participation at Symposium on Musical Acoustics (A.Stulov).
13. IUPAP - for participation at STATPHYS21 (J.Kalda).
14. NATEMIS ESF grant - for one month research in the Institute of Thermomechanics of the Czech Acad. Sci (A.Braunbrück).
15. NATEMIS ESF grant - for participation at the 6th International Workshop on Nonlinear Elasticity and Materials (A.Ravasoo).
16. PhD grant - for participation at XXXIV Int. Conf. of Physiological Sciences (M.Vendelin).
17. EC grant for participation in Summer School Euroattractor 2001 (M.Säkki).
18. Visby fellowship to cover living expences in Uppsala (K.Kasemets).

5.6 International cooperation

Cooperation within the European Science Foundation Programme "Nonlinear Acoustic Techniques for Micro-Scale Damage Diagnostics" (NATEMIS), partners in Italy, Czech Republic, Germany, Belgium et al.

NATO Collaborative Linkage Grant "Thermomechanics of progress and stability of phase interfaces (crystals, alloys)", partners University of Paris 6, Technical University Berlin, Institute of Cybernetics.

Within collaborative agreements:

Institute of Cybernetics:
- Laboratory for Mechanics of Materials of Helsinki University of Technology.
- Laboratory of Theoretical and Applied Mechanics of Helsinki University of Technology.
- Department of Mathematics of City University Hong Kong.
- HAS-TUB Research Group for Continuum Mechanics, Hungarian Academy of Sciences.
- Stevin Centre for Computational and Experimental Engineering Science, Eindhoven, University of Technology.
- Department of Mathematical Modelling, Technical University of Denmark.
- Department of Mathematics, University of Turin.
- Laboratoire de Modelisation en Mecanique, Universite Pierre at Marie Curie, Paris.

Estonian Marine Institute:
- Dept. of Meteorology, Uppsala University.
- Finnish Marine Research Institute.
- GKSS, Geesthacht, Germany.

5.7 Research programmes (national)

1. Nonlinear Dynamics (part of the Estonian Programme on Mechanics).
2. Physiological signal processing (part of the Estonian Programme on Biomedical Engineering).

5.8 Teaching activities

1. A.Salupere – courses in TTU:
   - Dynamics
   - Statics
   - Continuum Mechanics
   - Seminars and Special Seminars for BSc, MSc and PhD students.
2. T.Lipping, J.Lass – Signal Processing, TTU, Spring 2001.
3. J.Lass, T.Lipping – Physiological signal processing, TTU, Autumn, 2001.
4. J.Engelbrecht – Mathematical modelling, TTU, Spring 2001.
5. J.Kalda – Training of the Estonian and Finnish teams for the 32nd International Physics Olympiad.

5.9 Longer visits of fellows

1. Olav Kongas – post-doc position at Amsterdam Free University.
2. Tarmo Lipping – post-doc position at Dartmouth University, Hanover, USA.
3. Andres Braunbrück – one month research in the Institute of Thermomechanics of the Czech Acad. Sci.

4. Arkadi Berezovski – two one-week research visits to:
   - University Paris 6
   - Technical University Berlin.

5.10 Visiting scholars

1. Dr. Andras Szekeres, Budapest Technical University, "Selected topics of thermo-hygro-mechanics".
2. Prof. Pier Paolo Delsanto, Politecnico di Torino, "Nonclassical nonlinear effects in the propagation of ultrasonic waves".
3. Dr. Robert Stepien, Institute of Biocybernetics and Biomedicine Technique of Polish Acd. Sci. "Nonlinear quantifiers of EEG-signal complexity".
4. Prof. Brenny van Groesen, University of Twente, "Non-classical Helmholtz problems in device optics".
5. Prof. Raimo Sepponen, Helsinki University of Technology, "Telemedicine for Cardiology".
6. Prof. K.Kahma, Finnish Marine Research Institute, "Modelling of wind waves in the northern part of the Baltic Sea".
7. Dr. Peter Beda, Budapest Technical University "Nonlinearity and gradient dependance in constitutive modeling".
8. Prof. Philip de Fever, Leuven University. Lecture course on differential geometry.

5.11 Theses

Institute of Cybernetics:

Promoted:

1. P.Peterson. Multi-soliton interactions and the inverse problem of wave crests. PhD thesis, TTU, 2001, (supervisors: J.Engelbrecht, B.van Campen).
2. M.Vendelin. Cardiac mechanoenergetics in silico. PhD thesis, TTU, 2001, (supervisors: J.Engelbrecht, P.H.M.Bovendeerd, V.Saks).
3. A.Braunbrück. Nonlinear interaction of longitudinal waves in inhomogeneous elastic material. TTU, MSc, 2001, (supervisor A.Ravasoo).
4. M.Säkki. On the fractality of the human heart rate dynamics. TTU, MSc, 2001, (supervisor J.Kalda).
5. O.Ilison. Soliton formation in dispersive media with lower and higher order nonlinearity. TTU, MSc, 2001, (supervisor A.Salupere).
6. L.Ilison. Waves in granular materials and dispersion analysis. TTU, BSc, 2001, (supervisor A. Salupere).
7. M.Lemba. Actomyosin complex free energy profiles influence to the performance of the cardiac muscle. BSc, (supervisor M.Vendelin).
8. A.Koitmäe. Improvement of the description of the activation mechanism in the model of cardiac muscle. BSc, (supervisor M.Vendelin).

In progress:

1. PhD: O.Ilison, M.Säkki, R.Kitt, J.Anton, A.Braunbrück.
2. MSc: L.Ilison, M.Kukk, M.Lemba.

Tartu University:

Promoted: D.Tseluiko. Monge-Ampére operators in the structure, MSc (supervisor M.Rahula).

In progress: D.Tseluiko - PhD.

Estonian Marine Institute:

In progress: K.Kasemets - PhD.

Centre of Biomedical Engineering:

Promoted:

1. T.Lipping. Processing EEG during anesthesia and cardiac surgery with non-linear order statistics based methods. Tampere University of Technology, February 2001, PhD.
2. Ü.Olli. Analyses of cardiac arrhytmias at Holter monitoring. TTU, BSc.
3. M.Parts. EEG recording and processing for detection of low-level stressor TTU, BSc.

5.12 Distinctions

1. P.Peterson. Young Scientist Publication Award. Institute of Cybernetics.
2. O.Ilison. Estonian Academy of Sciences student award.
3. D.Karai. National student award.
4. M.Parts. National student award.

5.13 Exhibitions, fairs

1. Laser Device for Cardiovascular Diagnostics, Intellektika, Tartu, February 2001.

5.14 Conferences and seminars

Seminars (over academic terms):
- cell energetics;
- thermodynamics;
- solitons;
- thermomechanics of moving phase boundaries.

6. Summary

6.1 General remarks.

The year 2001 has been rather successful with many results, theses, etc. The list of submitted papers and that of papers under preparation are both long. The year 2001 meant also the consolidation of research plans activated by the Estonian Programme for Centres of Excellence in Research. Below these research plans are briefly presented (see 6.2).

The infrastructure has been improved through all the grants - the Computing Centre consists now of 25 Athlons and 4 Alphas.

The links with society have been improving – Tallinn Piano Factory, the ministry of Environmental Affairs, Tallinn Diagnostic Centre a.o. are excellent partners using the results of the research.

6.2 Research plans.

Nonlinear waves

General perspectives: Analysis of effects of microstructure and phase transition on wave propagation, more attention to meso- and nano-mechanics with dispersive effects, solitons, their interaction and behaviour in force fields.

Work plan: Modelling of soliton ensembles in microstructured solids, analysis of dispersive properties of wave hierarchies); verification of a thermodynamic model for stress-induced phase-transition front propagation, linear case; analysis of nonlinear and dispersive effects for NDT of inhomogeneous solids; analysis of piano hammers produced by various manufacturers, determination of material parameters; modelling of surface waves with corrected dispersion properties.

Modelling of solitary waves in hierarchically microstructured materials without and with forcing; analysis of stress-induced phase-transition on front propagation, nonlinear 2D case; analysis of governing parameters for inverse problems of NDT in materials with microinhomogeneities; piano scaling on the basis of measured characteristics; derivation of 2D correct equations for surface waves and prediction of deterministic extreme waves.

Analysis of interaction of solitary waves in microstructured materials and analysis of solitons in molecular crystals; description of macroscopic manifestations of martensitic structures; derivation of algorithms for characterization of NDT in materials with microhomogeneities with special attention to micro-scale damage; analysis of piano string excitation by different hammers; experiments with extreme surface waves.

Framework: Structurally, a group for studies in nonlinear surface waves is expected to be formed (P.Peterson). Master classes will be organized (G.A. Maugin - phase transition, K.Santaoja -thermomechanics, etc.). European Science Foundation programme NATEMIS means a strong network supporting this group. An Euromech Colloquium on Nonlinear Waves in Microstructured Solids (N 436) will bring this community to Tallinn in 2002. The co-operation with Tallinn Piano Factory is going on. PhD and MSc studies are related to several ongoing projects, study scripts will be prepared.

Fractality and biophysics

General perspectives: Intention to elaborate a more defined Physiome project with Estonian (Tartu University and National Institute of Chemical Physics and Biophysics) and international partners for in silico modelling of cell energetics. More applications of fractal theory and lattice modelling in interdisciplinary areas. Attention to practical applications for diagnostic purposes.

Work plan: Analysis of the prognostic and diagnostic relevance of the measures based on the multiscaling Zipf 's law for heart rate variability; analysis of the stress, deformation , and energy consumption heterogeneity in the ventricular wall using in silico modelling; analysis of modes of high-energy phosphoryl groups transfer in cardiac muscle depending on the substrate and on the activities of creatine kinase; analysis of statistical topography of rough surfaces.

Analysis of surrogate date for explaining the correlation dimension of normal heart rhythm on the basis of underlying nonlinear dynamics; derivation of a mathematical model for replicating the processes at the onset of acute ischemia, analysis of the measured PCr, Pi and ATP concentration dependencies on the workload in ischemic hearts; simulation of the convective diffusion by turbulent velocity field using super-correlated percolation model.

Analysis of the forward- and backward burst dynamics in the flooding process of the random self-affine surfaces; construction of the lattice model for the evolution of the natural languages reproducing the Zipf's law; analysis of the ischemic heart by mathematical simulation for establishing conditions for cardioprotection against acute ischemia.

Framework: Results are based on intensive international co-operation and networking which is planned to be even more enlarged. This means also a need for upgrading computing facilities. Co-operation with Tallinn Diagnostic Centre, hospitals, Tartu University and the Biomedical Engineering Centre at TTU support the team. Master classes (D.van Campen - biomechanics, V.Saks - cell energetics) are planned. A workshop of cell energetics is in the preparation. PhD and MSc studies are supported constantly that form a part of projects. In long run a special group on biophysics/biomechanics will be formed.

Nonlinear integrated photoelasticity

General perspectives: Development of nonlinear theory of integrated photoelasticity and its algorithms for solving inverse problem without restricting assumptions. Recent progress is based on the earlier fundamental results of the same group during three decades.

Work plan: Exact formulation of the nonlinear inverse problem of integrated photoelasticity (IP); influence of bending of the light rays in 3D models.

Application of genetic algorithms for nonlinear inverse problems of IP; inverse problem of magnetophotoelasticity; construction of the automatic polariscope.

Investigation of neural networks for solving the inverse problems of IP; construction of the automatic polariscope.

Framework: Besides fundamental research in the field of optical stress field tomography and application of the results for residual stress measurement in glass industry, in 2003 - 2005 the laboratory will widen its scope to other optical methods of experimental mechanics. The aim is combined application of different contemporary optical methods for solving complicated stress analysis problems.

Waves in fluids

General perspectives: The group will concentrate on general wave theory, with applications in wind wave forecast and wave generation anomalies in the Baltic Sea area. Problems related to topographic wave anomalies as well as specific properties of wave evolution in an strongly stratified medium and on sheared currents will be studied in detail. An extensive field campaign, combined with numerical wave simulation, is planned in order to clarify details of soliton-like ship wash created by high speed craft ships in Gulf of Tallinn.

Work plan: Wind wave anomalies in the Baltic Sea; interaction of wind waves with multilayer vertical structure of the basin; numerical wave modelling fore the central area of the Baltic Sea; analysis and interpretation of laboratory experiments with two-dimensional turbulence and geophysical flows, dispersion in a two-layer experiment.

Generalization of kinetic description to wave systems with an arbitrary number of vertical modes; creation of a new wave atlas for the central area of Baltic Sea; continuing numerical wave modelling.

General wave theory in multi-modal systems; wind waves on sheared flows and shallow water; modelling of surface waves induced by high-speed craft traffic, anomalies of surface wave fields.

Framework: Recently, the group has been invited to participate in the follow-up of the European Radar Ocean Sensing (EuroROSE) project (that was organized to demonstrate the monitoring and short-term prediction capabilities of wind, waves and currents in synergy between radar remote sensing and numerical modelling). EuroROSE follow-up plan intends to create an operational forecasting system of wind, waves and current fields in the entire Baltic Sea. Ship wash generated by vessels moving faster than phase speed of surface waves in shallow water propagates as a solitary wave packet and may cause serious inconveniencies at a distance of several kilometers from the ship lane. A special contract work is expected to analyse this situation in Gulf of Tallinn. Cooperation with Uppsala University and Coriolis Laboratory in Grenoble will continue. Some projects (ship wash) are planned together with another CENS group - Nonlinear waves.

Geometric approach

General perspectives: Construction of an exterior calculus with $d3 = 0$ on braided line, quantum plane and free associative algebra with n generators. The generalized cohomologies are studied. The set of first order differentials is extended by adding to it the higher order differentials of local co-ordinates of a manifold and this extension allows to construct a generalized exterior calculus. The tensorial behaviour of the higher order differentials is restored with the help of a connection and its higher order analogies. Developing of a new method for studying non-linear processes: dynamical system considered as the flow of a vector field in the space-time acts on tensor fields; this is useful to describe by means of a Lie derivative. An entire classification of 2-semiparallel surfaces in general case will be given.

Work plan: Developing the Lie invariant methods for studying linear and non-linear dynamical systems on manifolds; analysis of the symmetries of equations of mathematical physics and operators like Monge-Ampère; analysis of the singularities of mappings (catastrophes) in the light of novel exponential law.

Extension of the invariant Lie-Cartan methods to the investigation of general tensor fields in dynamic flows, with applications in theoretical physics; analysis of the Veronese mappings and corresponding embeddings of dynamics from ones spaces to anothers; drawing up the investigations of symplectic and other structures in jet bundle concerned the arising of differential operators on manifolds.

Generalization of the results for monograph "Lie-Cartan Calculus and Applications"; investigation on the moving Cartan frame in connection with Lie fields in infinite jet bundles, generalization of idea of dynamics and their invariants on manifolds.

Framework: Networking with the University of Paris 6 and University of Tromsøis to be enlarged. Special attention will be paid to joint seminars with Tallinn groups of CENS (geometric and applied aspects of dynamics on manifolds). Master classes on contemporary theories of differential operators and equations will be organized (V.Lychagin, Z.Navickas, A.Vinogradov). The studies of this group bring CENS closer to exact mathematical basis of dynamics.

Nonlinear signal processing

General perspectives: Application of nonlinear methods (fractal analysis, order statistics based methods) to the detection of various diseases and abnormal patient states from physiological signal like ECG and EEG. The main interest is focused on detecting states leading to sudden cardiac death from the ECG signals as well as ischemic and hypoxic states of the brain from EEG signals. The methods are compared to traditional linear methods and the ability of the methods to detect the abnormal states is evaluated.

Work plan: Comparison of the effectiveness of linear and nonlinear (order statistics based and fractal analysis) methods in the analyses of different parameters derived from the ECG;

Estimation and validation of the prognostic and diagnostic reliability of selected indicators based on nonlinear analysis of the ECG signal;

Nonlinear statistics and dynamics based methods in analyses of the EEG signals - estimation of the diagnostic reliability.

Framework: Biological processes are very complex by nature. They are often modeled as random processes, however, the development of nonlinear dynamics has revealed that there are often certain laws conducting those quasiperiodic, random-like processes. Also, models can be created to generate data similar to those, measured from physiological processes. Applying the methods of nonlinear dynamics to physiological signals like ECG and EEG not only gives us new possibility to detect changes in these parameters but also, through modelling, gives insight into the mechanism generating these processes. Close cooperation with the group Fractality and biophysics and with cardiology groups/hospitals.

6.3 Evaluation

CENS was evaluated in Nov., 2001 by a team from Finland: Prof. J.Timonen and Prof. R.Nieminen. The evaluators have very seriously analysed all the activities of CENS, meeting most of the staff. The overall result was "excellent" with the SWOT summary as follows:

Strengths

We were quite impressed by the overall concept of the Centre and its efforts to bring coherence to the various research efforts around nonlinear phenomena. There is a sincere, clearly voiced strive towards a multidisciplinary, internationally recognised unit. Proper attention is also paid to the importance of raising a new generation of scientists and of making research careers attractive for young scientists. The Centre recognises the importance of international contacts, networking and mobility, as well as the importance of applications of nonlinear methods in industry and society at large.

Weaknesses

In our opinion, the Centre would benefit from better focussing the research effort by streamlining its activities. The future plans are scattered and try to cover a wide area of problems, but reflect a certain lack of ambition, including the omission of new methodological developments. The Centre must continue to pay serious attention to the recruitment of students and young scientists. We also encourage it to improve contacts and collaborations between the research teams themselves and towards applications outside the Centre.

Opportunities

The Centre is newly formed and in the process of molding itself. This provides an opportunity define new visions and goals for the future. Continuing the organizational restructuring would help in actually achieving these goals.

Threats

An obvious threat is the lack cohesion in the Centre which would dilute any possible synergy effects. This in turn would contribute negatively to the success of student and researcher recruitment.

We thank very much the evaluators who have looked to our problems with deep professionality and openness.

The ideas above have been analysed at the annual Christmas seminar of CENS in December. The main point raised by the evaluators is the focussing. We fully agree with the problem but bring up our motivation from the smallness of the country. CENS is the only research unit in Estonia that covers the fields of our activities. We see clearly focussing around four directions:

- wave dynamics in the mesoscale of materials;
- biomechanics and biosignals;
- dynamics of surface waves;
- methods of mathematical physics.

In our research, nonlinearity is a deep notion that needs developing special methods in order to understand physical phenomena and use this knowledge. We certainly use all the possibilities to co-operate internationally and nationally.

6.4 Final remarks

In materials given to the evaluators, we have summed up the role of CENS in the following way:

Mechanics in the contemporary world is neither only conservation laws nor Navier-Stokes equations, nor pure applications. Mechanics is interwoven with many fields and phenomena, deeply in physics, deeply in biophysics, deeply in mathematics, etc. New materials, fractality, biophysical processes, loss of predictability, coherent structures and many more give new insight to old understandings. The order to keep pace, one should move together with the frontier of science. This is the main aim of CENS not forgetting its mission in Estonia. CENS as a small research unit cannot be active on the large scale but we are a part of a network - creating a whole by parts. Our part is clearly determined by activities listed above.

Breakthroughs are expected in nonlinear dynamics of microstructured solids and phase transition fronts, cell energetics, acoustodiagnostics, nonlinear surface waves theory, optical stress field tomography, nonlinear ECG and EEG signal processing, Lie-Cartan methods. To our knowledge, these studies are at the frontier of science.

Papers in preparation

1. A.Salupere, P.Peterson, J.Engelbrecht. Long-time behaviour of soliton ensembles. Part I: Emergence of ensembles. Chaos, Solitons & Fractals.
2. A.Salupere, P.Peterson, J.Engelbrecht. Long-time behaviour of soliton ensembles. Part II: Periodical patterns of trajectories. Chaos, Solitons & Fractals.
3. J.Engelbrecht, M.Vendelin. Huxley type crossbridge model for stress analysis in the left ventricle. Biomechanics and Modelling in Mechanobiology.
4. T.Sillat, J.Engelbrecht. Waves in hierarchically structured materials. European J. of Mechanics, A/Solids.
5. J.Engelbrecht. Mode distribution and Farey tree in emergence of KdV solitons. Physics Letters A.
6. M.Säkki, J.Kalda, M.Vainu, M.Laan. What does the correlation dimension of the human heart rate measure? Phys. Rev. E.
7. M.Säkki, J.Kalda, M.Vainu, M.Laan. Diagnostic performance of the nonlinear measures of heart rate variability. Med. Biol. Eng. Comp.
8. J.Kalda. Gradient-limited surfaces. Phys. Rev. E.
9. J.Kalda. Oceanic coastlines and percolation clusters: fractal dimension and super-universality. Rhys. Rev. E.
10. J.Kalda. 1 + 1 dimensional percolation problem. Rhys. Rev. E.
11. J.Kalda. Zipf's law for subclasses of words. Rhys. Rev. E.
12. A.Braunbrück and A.Ravasoo. NDE of inhomogeneous nonlinear elastic material by ultrasound nonlinear interaction data. Proc. 31th Annual International Conference on Non-Destructive Testing Defektoskopie 2001, November 20 - 22, 2001, Prague, Czech Republic.
13. A.Ravasoo. Qualitative and quantitative ultrasonic NDE of inhomogeneous plane strain in elastic material. NDT & E International.
14. A.Ravasoo and A.Braunbrück. A. Material inhomogeneity and modulation of nonlinear effects of wave propagation. Wave Motion.
15. A.Ravasoo. Continuous constitutive equation for microcracked nonlinear material. Physica D: Nonlinear Phenomena.
16. A.Ravasoo. Nonlinear waves in microcracked materials. Wave Motion.
17. A.Berezovski and G.A.Maugin. Dynamics of impact-induced phase transition fronts. Journal de Physique IV.
18. A.Berezovski and G.A.Maugin. Simulation of impact-induced martensitic phase-transition front propagation in thermoelastic solids. Proceedings of IUTAM Symposium on Dynamics of Advanced Materials and Smart Structures, May 20 - 24, 2002, Yonezawa, Japan.

19. A.Berezovski, J.Engelbrecht and G.A. Maugin. Computation of moving phase boundaries in solids. Computational Mechanics.

20. A.Berezovski, J.Engelbrecht and G.A. Maugin. Numerical simulation of two-dimensional wave propagation in functionally graded materials. Eur. J. Mech. Solids.

21. A.Salupere, M.Kukk. Periodically forced solitons in dispersive media. Wave Motion.

22. A.Salupere, O.Ilison. Soliton formation in media higher order dispersion. Physica D.

23. A.Salupere. On the KdV soliton ensembles – velocities and the zero level of soliton train.

24. A.Stulov. Experimental and computational studies of the piano hammer I: Piano hammer testing device. JASA.

25. A.Stulov. Experimental and computational studies of the piano hammer II: Experimental testing and numerical determination of the piano hammer parameters. JASA.

26. A.Stulov. Piano string excitation I: hereditary hammer. JASA.

27. A.Stulov. Piano string excitation II: string support. JASA.