

**Tallinn University of Technology**  
**Department of Cybernetics, School of Science**

**Research Report 328/22**

**Annual Report 2021**  
**on Nonlinear Dynamics and Biophysics**

**Jüri Engelbrecht**  
**Tanel Peets**  
**Kert Tamm**

**Tallinn, 2022**

## Contents

1. Introduction
2. Research results
  - Waves in nerve fibres
  - Submitted papers
  - Conferences and abstracts
  - Abstracts submitted
  - Books on general topics
  - General publications
  - General papers submitted
3. Activities
4. Grants and cooperation
5. Varia
6. Conclusions

## 1. Introduction

This Report continues the series of Annual Reports on nonlinear dynamics started in 1999 within the Institute of Cybernetics. After restructuring of the Tallinn University of Technology, the studies on nonlinear waves are carried on in the Department of Cybernetics, the School of Science. What follows, is the description of the results of several researchers in the Laboratory of Solid Mechanics during 2021. The attention is focused on dynamical processes and waves in nerve fibres which means working at the interface of physics, mathematics and physiology.

The most important result is the **publication of a monograph** that reflects the results of research over last years.

## 2. Research results

### Waves in nerve fibres

1. J. Engelbrecht, K. Tamm, T. Peets. Modelling of Complex Signals in Nerves. Springer, Cham, 2021. ISBN 978-3-030-75038-1.

*Abstract.* This book describes fundamental physical principles, together with their mathematical formulations, for modelling the propagation of signals in nerve fibres. Above all, it focuses on the complex electro-mechano-thermal process that produces an ensemble of waves composed of several components, besides the action potential. These components include mechanical waves in the biomembrane and axoplasm, together with the temperature change. Pursuing a step-by-step approach, the content moves from physics and mathematics, to describing the physiological effects, and finally to modelling the coupling effects. The assumptions and hypotheses used for modelling, as well as selected helpful concepts from continuum mechanics, are systematically explained, and the modelling is illustrated using the outcomes of numerical simulation. The book is chiefly intended for researchers and graduate students, providing them with a detailed description of how to model the complex physiological processes in nerve fibres.

2.J.Engelbrecht, K.Tamm, T.Peets. Continuum mechanics and signals in nerves. Proc. Estonian Acad. Sci., 2021, 70, 1, 3-18.

*Abstract.* The review describes how ideas from the fields of physics and mathematics have influenced the studies on signal propagation in nerves, which has classically been related to electrophysiology and chemistry.

3. T.Peets, K.Tamm, J.Engelbrecht. On physical background of nerve pulse propagation: heat and energy. J. Non-Equil. Thermodyn., 2021, vol. 46, 4, 343-353.

Online from May 18, 2021: <https://doi.org/10.1515/jnet-2021-0007>

*Abstract.* Recent studies have revealed the complex structure of nerve signals in axons. Besides the electrical signal, mechanical and thermal effects are also detected in many experimental studies. In this paper, the mathematical models of heat generation are analysed within the framework of a general model derived earlier by the authors. The main mechanisms of heat generation are seemingly Joule heating and endo- and exothermic reactions. The concept of internal variables permits to model the heat relaxation typical to these reactions. The general energy balance of the whole signal is analysed based on physical mechanisms responsible for emerging the components of a signal which constitutes a wave ensemble. The novelty of this study is in describing the energy for all the components of the wave ensemble. Some open questions are listed for further studies.

4.K.Tamm, T.Peets, J. Engelbrecht. Mechanical waves in myelinated axon wall.

arXiv 2112.11116v1 [physics.bio-ph] 21 Dec 2021

*Abstract.* The propagation of an action potential is accompanied by mechanical and thermal effects. Several mathematical models explain the deformation of the unmyelinated axon wall. In this paper, the deformation of the myelinated axon wall is studied. The mathematical model is inspired by the mechanics of microstructured materials. The model involves the improved Heimburg-Jackson equation together with another equation of wave motion that describes the process in the myelin sheath. The dispersion analysis of such a model explains the behaviour of group and phase velocities. In addition, it is shown how dissipative effects may influence the process. Numerical calculations demonstrate the changes in velocities and wave profiles in the myelinated axon wall.

### **Conferences and abstracts**

1. J. Engelbrecht, K.Tamm, T.Peets. Modelling of complex signals in nerves and the analysis of coupling effects. In: 25th International Congress of Theoretical and Applied Mechanics, August 22-27, 2021, Milan. Abstract Book (online edition), 1568-1569. Presentation by ZOOM, Aug. 26, 2021.

2. J. Engelbrecht, K.Tamm, T.Peets. 6<sup>th</sup> Oxford International Neuron and Brain mechanics Workshop, April 19-20, 2021. Participation by ZOOM.

### **Abstracts submitted**

1.T.Peets, K.Tamm, J.Engelbrecht. Mechanical waves in myelinated biomembrane, The 11th European Solid Mechanics Conference ESMC11, Galway, 4-8 July 2022.

2.K.Tamm, T.Peets, J. Engelbrecht. Modelling of mechanical waves in a myelinated axon. Ibid

## Books on general topics

1.J. Engelbrecht. Complexity in Social Systems and Academies. Cambridge Scholars Publishing, Newcastle, 2021. ISBN 978-1- 5275-7309-5.

*Abstract.* This collection of essays highlights the general ideas of the complexity of physical and social systems. The essays reflect the problems related to education, science policy, networks and values. It is stressed that the best advocates for the management of general ideas are academies that unite top scientists and scholars representing all fields of knowledge. That is why in this context, the activities of academies are also described, including a quite fresh view (2020) on current tasks of academies and academia in general. The essays are based on the author's experience during the last couple of decades in promoting science policy in Europe and worldwide. A summary presents the ideas in a nutshell.

2. J.Engelbrecht. Juhuslikud jalutuskäigud teadusmetsas. Postimehe Kirjastus, Tallinn, 2021. ISBN 978-9916-667-26-2 (Random Walks in Science Woods)

*Abstract.* This is a collection of ideas from the author's diary over many years including explanations of metaphors and scientific terms, stories about research and people, ideas from the author's bookcase, a story about serendipity, descriptions of famous animals in science, etc. The role of teachers and colleagues in life is emphasized.

## General publications

1.J.Engelbrecht. Zlatá Praha – útržky vzpomínek. NaVychod. Special: Estonsko, 2021, pp. 27-28. (Czech-Estonian Special Issue: Golden Prague – looking back)

2. J.Järv, J.Engelbrecht. Proceedings of the Estonian Academy of Sciences celebrates volume 70. Proc. Estonian Acad. Sci., 2021, 70, 1, 1-2

3. J.Engelbrecht, K.Tamm, T. Peets. Närviimpulss ja matemaatika. Horisont , No 3, 2021, 48-52 (Nerve pulse and mathematics – a science-popular description)

4. J. Engelbrecht. Loodus ja füüsika. Tähenduse teejuhik, No 8, Aprill 2021, lk 9 (Nature and physics, Special issue of the Daily Postimees)

5. J.Engelbrecht. Academies and knowledge management. Cadmus, 2021, vol.4, No 4, 56-57.

*Abstract.* Science academies have several roles in a contemporary information-rich society. The most important roles are: (i) to promote science and scholarship; (ii) to provide advice and expertise; (iii) to promote scientific understanding. The activities of academies of science are characterized by the basic principles of science itself: Only scientific research based on transparent methodologies, and scientific arguments based on empirical facts and logical analysis bring us closer to the truth, while reflection, imagination, and creativity tell us where and how to explore further.

6. J.Engelbrecht. Ülo Lepik 100. Sirp, 9.juuli, 2021.

7. J.Engelbrecht, R.Kitt. Knowledge generation and interdisciplinarity. Cadmus, vol.4, No 5, 11-22.

*Abstract.* In this paper, it is argued how the present crises in the world are influenced by breaking up the networks created by the communities worldwide. In addition to human-made networks, many networks in Nature also influence life in many aspects. In this context, the

understandings of the behaviour of complex systems, especially in social spheres help to find better solutions for the future. The interdisciplinary studies uniting the knowledge from science, humanities, and social sciences can describe proactively knowledge generation for understanding the complexity of processes in a coordinated and coherent way and applying it for problem-solving.

8. J.Engelbrecht. Saatesõna Toomas Tiiveli raamatule „Elu on sümbioos“, Ilmamaa, Tartu, 2021, 7-9.(Preface to the book by T. Tiivel ”Symbiosis of Life)

9. J.Engelbrecht.Global system dynamics and future. Glasnik (The Montenegrin Academy of Sciences and Arts, Dept. of Social Sciences), 2021, 25, 237-248.

*Abstract.*The future of mankind is dependent on how we understand the world in all its complexity. The emergent behaviour of the world cannot be completely determined from the behaviour of its components at all the levels: individuals, communities, states and alliances. The world is full of many man-made local and global networks which altogether greatly influence our everyday life. COVID-19 pandemic has crushed many networks and we have to analyse the reasons and envisage the ways out of the mess. Before this crisis, the future world activities were described by the UN SDG's, the possible risks analyzed by the WEF Risk Reports and the future developments described by several scenarios starting from the CoR Report in 1972 on the limits of growth. From the COVID-19 crisis on, the natural wish is to reinstate the previous state of all the networks and activities but this is really a short-run idea. The attitude business-as-usual is a dead end. One should think about the long-run activities which need new paradigms not only proposed but also accepted and implemented. In this essay, some of the ideas about the future related to global systems dynamics are analyzed.

### **General papers submitted**

1. J.Engelbrecht. Some Important Keywords on the Road Ahead. In: Workshop „Pathways to a Sustainable Future for Humanity: Ivo Šlaus’ Vision“. Sept 29, 2021

2. J.Engelbrecht. Piirid mitmest vaatenurgast. Akadeemia.

Multiple views on boundaries

*Abstract.* Every description of phenomena should also include the analysis of causality. Only then one could properly understand the description like Isaac Newton did when he formulated the law of gravitation governing the motion of planets. Describing the complex world around us, in general terms, one should distinguish between physical and social systems. Physical systems are governed by thermodynamics that guides or limits the processes, while in social systems values are the leading and guiding factors. Values are subjective and depend on traditions, history, economy, environment, education, etc. That is why boundaries including the borders between the states, or just differences between the language groups or civic communities are complicated and could be characterized primarily as functional, behavioural, and communicational. It is argued that boundaries can be obstacles but also serve as possibilities for exchange not only goods but also of ideas that is especially important in social systems. The boundaries between scientific disciplines could depend beside the specific information also on values like C.P. Snow and J. Kagan have described. However, in the present world interdisciplinarity may help to cross the boundaries between the disciplines for the benefit of growing knowledge. Another essential keyword is complementarity that is an important factor for a society in the process of changing its trends from a technology-driven society to a socially oriented technology. In this process, the education has a decisive role.

### **General conferences**

1. J. Engelbrecht. WAAS@60, A Planetary Moment. 17. February, 2021 (by ZOOM).  
Session: The Role of Academies of Science and Art in Multilateral System – panelist;  
Session: Basic Sciences and Sustainable Development - panelist.
2. J. Engelbrecht. ALLEA Symposium and General Assembly, 5.-6. May, 2021, Helsinki – participant (by ZOOM).
3. J.Engelbrecht XVII Baltic Conference on Intellectual Cooperation “Mathematics for Society”. 28.-29. June, 2021, Tallinn. Session on Mathematical Applications – chairman.
4. J.Engelbrecht. Conference “Pathways to a Sustainable Future for Humanity: Ivo Šlaus’ Vision”, 29. Sept.,2021, Ljubljana (by ZOOM). Session: Global Leadership, a Road Ahead – speaker.
5. J.Engelbrecht. ISC General Assembly, 11.-15. October, 2021, Paris – participant (by ZOOM).
6. J.Engelbrecht. Eesti Kultuuri Koja konverents”Inimene piiril” 9. November, 2021, Tallinn – session ”Tehislik, tehnoloogiline ja loomulik-looduslik” – moderaator.  
(Conference “Humans at borders”, Estonian Culture Society, moderator)

### **3. Activities**

#### **Teaching**

K. Tamm - Courses in Tallinn University of Technology:

BSc level: Fundamentals of Analytical Mechanics and Elasticity (YFX0590),  
Analytical Mechanics (YFX0591)

T.Peets - Courses in Tallinn University of Technology:

BSc level: Writing Academic Papers and Thesis (YFX0540), Mechanics (YFX0552)

MSc level: Mathematical Modelling and Nonlinear Dynamics (YFX1520),  
Seminar of Applied Mechanics (YFX1530)

J.Engelbrecht – lecture ”Mathematics for complex systems”, Tartu University, 4. Nov., 2021.

#### **Reviewing**

J.Engelbrecht: reviews for Journal of Biological Physics, ZAMM

T.Peets: reviews for Fluids, Human Frontier Science Program

K.Tamm: reviews for Journal of the Royal Society Interface; The European Physical Journal B (three reviews)

#### **Membership in Editorial Boards:**

Applied and Computational Mechanics (Czech Republic): J.Engelbrecht

Proc. Estonian Acad Sci.: J.Engelbrecht

Applied Mechanics (Kiev): J.Engelbrecht

J.Theor. and Appl. Mech. (Warsaw): J.Engelbrecht

Trames (Estonia): J.Engelbrecht

Akadeemia (Estonia): J.Engelbrecht

## **Professional organizations**

Euromech: J.Engelbrecht, K.Tamm, T.Peets

ISIMM: J.Engelbrecht

Nordic Association for Computational Mechanics: T.Peets (member of the Executive Committee)

Estonian Academy of Sciences: J.Engelbrecht (Adviser)

WAAS – World Academy of Art and Science: J.Engelbrecht (Fellow, Trustee until Sept., 2021)

Estonian National Committee for Mechanics: T.Peets (secretary), J.Engelbrecht (member)

## **4. Grants and cooperation**

4.1 Estonian grants

K.Tamm, funded by PRG1227 (ETAg)

T.Peets, funded by PRG1227 (ETAg)

J.Engelbrecht (consultant), funded by PRG1227 (ETAg)

## **5. Varia: publications reflecting previous work**

On book J.Engelbrecht, R.Kitt, „Komplekssüsteemid“ (Complex Systems) Postimehe Kirjastus, Tallinn, 2020:

1. Tervik on suurem kui osade summa. Raamatu tutvustus, EKL ajaleht Raamat, no 4, 2020, lk 2.
2. P. Veigel, Tervik on uurem kui osade summa. Apollo raamatuportaal, 10 dets., 2020.
3. Katkend raamatust. Postimehe AK, 16. jaan., 2021.
4. Kuku Raadio nädalaraamat. R.Kitt, M.Strandberg, 29. jaan., 2021.
5. K. Konsa, Komplekssuse konksu otsas siplev kalake. Sirp, 5. veebr., 2021, 24-25.
6. J.Aru, Terviklikkuse toetuseks. Horisont, No 3, 2021, 58-59.
7. M.Vadi, Kirjanduslinn soovitab: Jüri Engelbrecht ja Robert Kitt „Komplekssüsteemid ehk tervik on suurem kui osade summa“. Online 01.06.2021. [www.tartu.ee/et/uudised](http://www.tartu.ee/et/uudised)

On nerve pulse modelling:

1. J.-J. Oidermaa, Eesti teadlaste mudel kergitab närviimpulsside kõõgipolelt saladusloori. Online: Novaator. 3.juuli 2021, kell 11.04. [err.ee](http://err.ee)

On general results:

1. Jüri Engelbrecht teaduse populariseerijana ja liidrina. Eesti Teaduste Akadeemia Sõnas ja pildis, 2020, Eesti TA Tallinn, 2021, 88-89.  
Same in English: Jüri Engelbrecht as a promoter and leader of science. Estonian Academy of Sciences, Yearbook 2020, 82-84.
2. K.Konsa. Kõikehõlmav modelleerimine närviimpulssist teadlase eluni. Sirp no 45, 12 nov. 2021 (vaatluse all kolm raamatut: vt ülal Books, Books in Estonian).

On book J.Engelbrecht „Juhuslikud jalutuskäigud teadusmetsas“ (Random Walks in Science Woods), Postimehe Kirjastus, 2021:

1. Raamatu esitlus Eesti Teaduste Akadeemias (K.Jaaska, T.Tiivel, R.Ubar)
2. Raamatu tutvustus, Postimees Nädal, 23. okt., 2021
3. P. Veigel. Jalutuskäigud teadusmetsas. Raamat, 17. nov. 2021
4. T. Põldmaa soovitus Kuku raadio saates „Ärataja“, 8. nov.2021
5. Apollo raamatuportaal. Postimees on-line, 24.nov.2021
6. E.Bahhovski. Jalutuskäik tekstiga. Postimees AK, 18. dets. 2021, no 628, lk 27.

## 5. Conclusions

An important stage of modelling of nerve signals has been completed by a book on nerve pulse modelling published by Springer in 2021. The research on modification of the model will be continued with the main attention to the modelling of the myelin sheath.

Concerning the previous results:

- papers by J.Engelbrecht have more than 13 000 “reads” in Research Gate;
- the book "Microstructured Materials: Inverse Problems" (Springer, 2011) - has ca 7000 chapter downloads;
- the book "Questions About Elastic Waves"(Springer, 2015) - has ca 7200 chapter downloads;
- the book "Modelling of Complex Signals in Nerves" (Springer, 2021) has ca 1400 chapter downloads,
- the book "Applied Wave Mathematics II" (Springer 2019) has ca 6800 chapter downloads and the chapter "Mathematics of nerve signals" - over 400 downloads.

The recent results are widely known according to SciVal lists on topics by authors over the world (in brackets the place in the list):

- Solitons; Wave Propagation; Microstructured Solids:  
J.Engelbrecht (2), T.Peets (4), K.Tamm (5);  
From previous results the studies on negative group velocity (2014) have gained more interest.
- Action Potentials; Electrophysiology; Phase transition:  
J.Engelbrecht (12), T.Peets (13), K.Tamm (14).

## Address

Department of Cybernetics, School of Science, Tallinn University of Technology  
Akadeemia 21, 12618, Tallinn, Estonia

## E-Mails:

Jüri Engelbrecht: je@ioc.ee

Tanel Peets: tanelp@ioc.ee

Kert Tamm: kert@ioc.ee