

Colloquium Final Report

N. 630 – Nonlinear Elasticity: Modelling of multi-physics and applications

Dates and location: **25/03/2024 - 28/03/2024, Edinburgh, UK**

Chairperson **Yibin Fu**

Co-Chairperson **Michel Destrade**

Conference fees

- Early-bird registration (payment in GBP with exchange rate 1€=0,87 GBP) **250.0 €**
- Early-bird registration online participation (payment in GBP with exchange rate 1€=0,87 GBP) **120.0 €**
- Late registration (payment in GBP with exchange rate 1€=0,87 GBP) **350.0 €**
- Late registration online participation (payment in GBP with exchange rate 1€=0,87 GBP) **200.0 €**

What other funding was obtained? **The Institute of Mathematics and its Applications (IMA), £904 London Mathematical Society (LMS), £3,000 International Centre for Mathematical Sciences (ICMS), £24,000**

What were the participants offered? **All plenary speakers were offered free accommodation and had their flights paid**

All other speakers were offered free accommodation

A number of people without funding had their registration fees waived

A number of non-speakers were also offered free accommodation

Number of members of Euromech (reduced registration fee) **34**

Number of non-members of Euromech (full registration fee) **25**

Applicants (members)

- David Abrahams
- Arya Amiri
- Valentina Balbi
- John Ball
- Martine Ben Amar
- Davide Bigoni
- Federico Bosi
- Laurence Brassart
- Roger Bustamante

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- Alfio Grillo
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- Gerhard Holzapfel
- Mikhail Itskov
- Lihua Jin
- Karima Khusnutdinova
- Robin Knops
- MINGCHAO LIU
- Yang Liu
- Chiara Lonati
- Oscar Lopez-Pamies
- Xiaoyu Luo
- Andreas Menzel
- Ray Ogden
- Souhayl Sadik
- Prashant Saxena
- Kostas Soldatos
- Konstantin Volokh
- Yuxin Xie

Applicants (non members)

- Afshin Anssari-Benam
- Ciprian Coman
- Xiqiao Feng
- Mokarram Hossain
- Mahmood Jabareen
- Dongfeng Li
- Xudong Liang
- Andrey Melnikov
- Patrizio Neff
- Nhung Nguyen
- Andrea Nobili
- Raimondo Penta
- Michel Potier-Ferry
- Shaoxing Qu
- Giuseppe Saccomandi
- Yasemin Sengul Tezel
- Matteo Taffetani
- Luigi Vergori
- Joh Willis
- Rui Xiao
- Fan Xu
- Quan Zhang
- Yapu Zhao
- Zheng Zhong
- Pingping Zhu

Scientific Report

Nonlinear Elasticity has a long and distinguished history in modelling the mechanics of soft materials. Originally developed to capture the behaviour of rubber and polymers, it is currently experiencing a strong revival due to newly found applications in, for instance, the high-tech industry and healthcare. It is continuously being expanded to describe new materials and new multi-physics fields such as electromagnetic forces in dielectric elastomers, surface tension, residual stress, swelling and growth in hydrogels and biological soft tissues, etc. Novel problems are being attempted and understood with the development of advanced numerical, experimental, and theoretical techniques.

A leading light in this field has been provided for more than fifty years by Professor Ray Ogden FRS, who turned 80 on 19 September 2023. This Euromech Colloquium celebrated his achievements and used the occasion to review the state of the art and explore future directions of research for nonlinear elasticity.

The Colloquium received generous support from the Institute of Mathematics and its Applications (IMA), London Mathematical Society (LMS), and the International Centre for Mathematical Sciences (ICMS), in addition to Euromech.

The Colloquium was held over a three-and-a-half-day period. The ICMS provided an excellent venue for the event, with the hotels within walking distance, and very good facilities for discussions (e.g. black and white boards everywhere, a big coffee and lunch area, and a separate seminar room for breakout meetings). The technical and logistic support was first-rate, and the online talks were included seamlessly with top sound and video quality.

A hybrid mode was used to accommodate those who could not travel to Edinburgh easily. There were 58 in-person participants and another 60 people registered online. There were 41 talks (two of them online) and four posters. The Colloquium covered four main topics: biomechanics, buckling and instability, modelling and analysis of smart soft materials, and new insights into classical topics. These main topics were well covered and represented by the three keynote lectures: The development of a building block for a structural artery model by Gerhard Holzapfel (Technical University of Graz, Austria), Non-equilibrium stimuli-responsive soft materials, Lihua Jin (University of California, Los Angeles, USA), and The magnetoelastic behaviour of elastomers filled with ferrofluid inclusions: Theory and numerical implementation, Oscar Lopez-Pamies (University of Illinois, Urbana-Champaign, USA).

Talks concerned with biomechanics addressed the issues of structural artery modelling, biochemomechanical coupling theory of lymph nodes, bone remodelling, tissue growth, and modelling of aortic aneurysms. Buckling and instability have always been important topics of nonlinearity. Problems addressed this time included instability of prestressed lattice structures, creasing, buckling of hydrogel beams with Mullins effect taken into account, localized necking due to residual stress or surface tension, effects of curvature on wrinkling, wrinkling of graded bilayers, asymptotic numerical method for computing bifurcation, discrete model for snapping analysis of axisymmetric shells, and wrinkling in spinning discs. Smart soft materials include liquid crystal elastomers, hydrogels, polymer networks, magnetoelastic materials and electroelastic materials. Their constitutive modelling, and the analysis of structures made of such materials under the stimuli of multi-fields, pose many challenges, and represent an important area of active research within nonlinearity in recent years. Twelve of the talks were devoted to various aspects of this topic, e.g. constitutive modelling and analysis of double-network hydro-gels and elastomers filled with ferrofluids inclusions, design of phase transforming metamaterials with magnetic interactions, analysis of soft

dielectric composites with high phase contrast, tunable wave manipulation in hard-magnetic soft elastic metamaterials, theory for magnetoelastic thin shells, etc.

In addition to addressing modern challenges, we also had a good number of talks devoted to classical topics of nonlinear elasticity, to provide fresh new insights. Problems addressed included new formulations of nonlinear viscoelasticity, a new modelling strategy for rubber materials and their fracture, constitutive requirements that ensure non-occurrence of stress softening, Hertz contact, fibre-reinforced membranes with activated fibres, multiscale modelling of nearly incompressible polymer composites, Poynting effect, Love hypothesis, Cosserat model of elastic solids reinforced by curved and twisted fibres, circumferential shear, and solitary waves. Finally, we also had a talk giving the audience a taste of what machine learning can do in constitutive modelling; this is likely to become an increasingly important aspect of future research.

In conclusion, the Colloquium served brilliantly its original purpose of reviewing the state of the art and identifying new research directions in nonlinear elasticity. The feedback from the questionnaire conducted at the end of the meeting was overwhelmingly positive. We thank Euromech, IMA, LMS, and ICMS for the financial support and ICMS for letting us use their beautiful venue and excellent facilities.

Number of participants from each country

| COUNTRY | PARTICIPANTS |
|----------------|---------------------|
| United Kingdom | 22 |
| United States | 4 |
| France | 2 |
| Ireland | 3 |
| Kazakhstan | 1 |
| Germany | 3 |
| Italy | 7 |
| Israel | 2 |
| Denmark | 1 |
| Canada | 1 |
| China | 11 |
| Chile | 1 |
| Austria | 1 |
| TOTAL | 59 |

Please send this report in electronic form to the Secretary General of EUROMECH, within one month after your Colloquium.