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Marching bifurcations

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ABSTRACT

This paper dedicated to my late mum and dad (Ludwika and Karol Wiercigroch), presents a light-hearted account of important events in my academic career, which have influenced my development and contributed to my achievements. It meant to be published on the occasion of my round birthday, which celebration was delayed by COVID-19 pandemic and some other factors. Predominantly, it is based on a booklet I wrote in 2013 on the occasion of bestowing on me a title *a doctor honoris causa* by the Technical University of Lodz (LUT) of my native Poland. The main focus of this piece is the friendship and interactions with my academic colleagues around the world and in particular with Professor Tomasz Kapitaniak of the LUT. In mathematics, a bifurcation is a qualitative change in a solution, wherein a march is not only a synonym of a periodic excitation but also the passing time. In this context, a bifurcation being a qualitative change has a major influence on the global solution. This definition resonates well a much wider context and this paper attempts to provide some examples.

1. Bifurcations in life: A short and biased research autobiography

In the language of mathematics a bifurcation is a qualitative (structural) or topological change of the solution. Bifurcations can be divided as sub and supercritical. The former are more dangerous and can lead to catastrophic effects not only in the language of mathematics. From the stability point of view, we can distinguish among others the following standard types of bifurcations: saddle-node, period doubling, pitchfork and Hopf . A rather unusual type is a grazing bifurcation, which occurs in impacting oscillators, which I and my group have been thoroughly investigating for many years and have managed to get some new insights introducing so-called grazing induced bifurcations ((e.g. [23,29–31,37,40,45,48,55]).

Marching Bifurcations is a light-hearted account of important events in my career and life, which influenced my development and contributed to my achievements. I was born on 14 July 1960 in Rajcza in working class family and was the second son of my late parents, Ludwika and Karol Wiercigroch. From the earlier years, I have shown a significant interest and talent in mathematical and physical sciences. I was very interested in chemistry taking parts in the primary school Olympiads and carried out many chemical experiments, often dangerous, but luckily without any lasting consequences. In this period, I was also a keen altar boy being significantly influenced by the charismatic cardinal of Krakow, the late pope, John Paul II (Karol Wojtyla) and my local priest, Reverend Stanislaw Bajer.

As a high school I chose the Technical High School in Żywiec, the best high school in mathematical and physical sciences in terms of spatiotemporal location. This choice allowed me to deepen the knowledge in hard sciences, specifically in mathematics and mechanics, having at the same time a good practical grounding. Time spent in Żywiec had also a beneficial effect on the development of my shy personality at that time. A vastly positive influence in these formative years had my Head Teacher and an acknowledged expert in design, late Mr Eugeniusz Wrzeszcz. I graduated from the high school not only with flying colours, but as the best graduate I was given a free entry to any Polish university. The second free entry came from being a laureate of the National Competition for the Best Technical Projects, which was held in 1980 in the capital Warsaw.

The choice of my degree programme and university can be described as the first important bifurcation of the subcritical type. In that time two people had made a very strong influence on my future activities, namely, the Reverend Franciszek Pieczka and Mr Piotr Wiercigroch. The Reverend Pieczka led a seminary workshop aimed to deepen the Christian faith and to recruit new adepts to the Krakow Seminary. Mr Piotr Wiercigroch, my God father, a distinguished inventor and engineer with some 30 patents, was a strong supporter of the Warsaw Military Academy of Technology.

First, I considered the Theological Seminary of Krakow Archdiocese and the Warsaw Military Academy of Technology, but after the visits to both institutions, I quickly decided to subcritically bifurcate to the Applied Mathematics and Theoretical Physics Faculty of the Silesian

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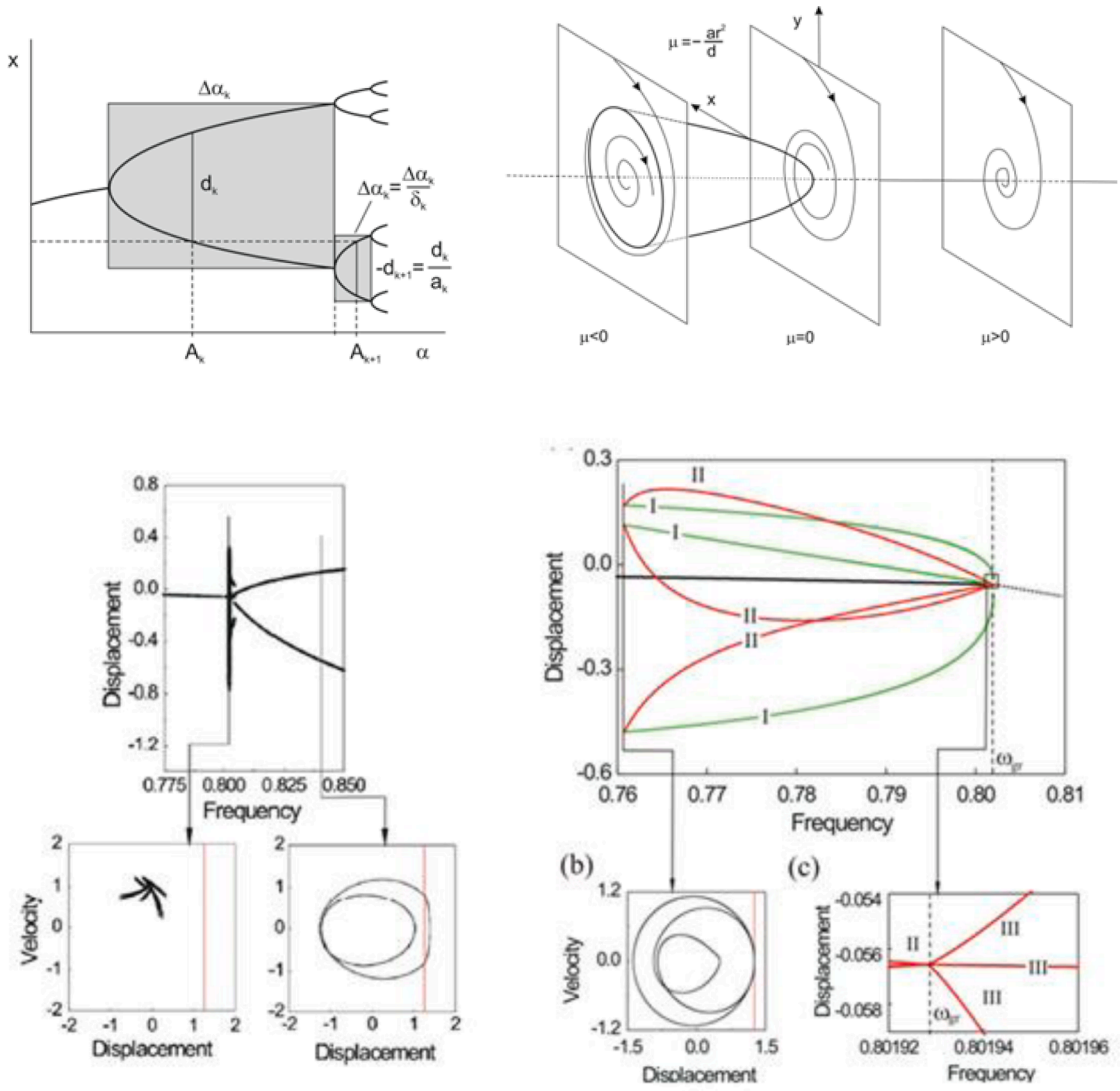

Fig. 1. The upper panels shows examples of typical bifurcations of period doubling (left) and Hopf type (right). The lower panels depict grazing induced bifurcations investigated thoroughly by my research group, where on the left and right hand sides the modelling and experimental results are shown (e.g. [29–31]).

Fig. 2. The first two from the left photographs were taken in 1972 when I was in the primary school, when my church in Rajcza was celebrating a millennium of Cracovian diocese. On the very left is my school ID photograph; on the right is a photograph of the millennium celebration mass during which I was serving. The ID photograph on the right was taken during the final year in the high school.

University of Technology. The Warsaw Military Academy of Technology was very persistent and keen to get me enrolled, which I managed to escape. The next bifurcation was saddle-node type to a stable solution, the Mechanical-Technological Faculty of the same University, from which I graduated in 1985 with the first class (see the right panel of Fig. 3). My specialization was machine tools and other technological machinery. Just after my graduation I was offered an assistantship in the Machine Tools Department led by a late Professor Tadeusz Tyrlik.

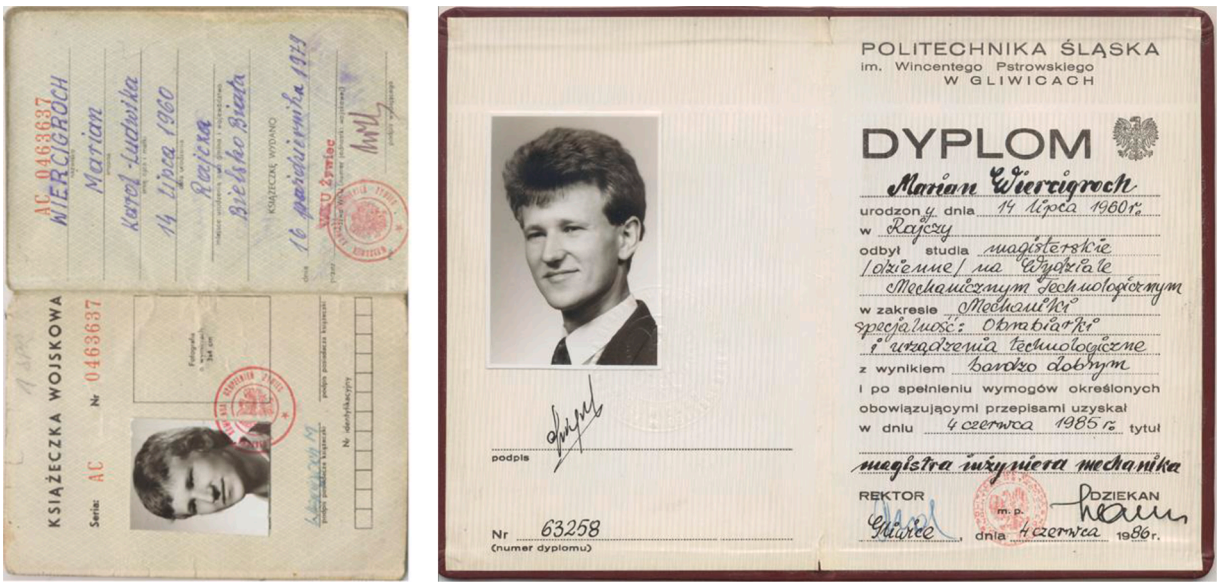

Fig. 3. On the left is my military record book from 16 October 1979, the time when I passed the medical check-ups and was eligible to serve in the Polish Army; on the right is my alma matter graduation certificate specifying the field of mechanical engineering and the first class degree obtained on 4th June 1985 and issued on 4th June 1986.

Fig. 4. Soldiers meeting in Kyoto in November 2011 during the historical conference, IUTAM Symposium on 50 Years of Chaos and Beyond, organised to celebrate the discovery of the Japanese attractor by Professor Yoshisuke Ueda.

In that time, personal computers and computational methods have been under a vast and rapid development. To illustrate this point, I did all computations for my master project on quasi-statics of the cutting process supervised by Professor Jan Kosmol, on a microcomputer ZX-81. Thereafter I had an access to a more graphically advanced ZX Spectrum to finally get my hands on my first IBM PC. From this point on, I had started a long running and passionate *flirt* with computers and scientific computations. In that time I wrote my own code in Pascal to simulate dynamics of discrete dynamical systems. This code proved to be useful in lots of projects in the area of dynamics.

On 4 January 1986 I started one year military training (see the left panel of Fig. 3 with the photograph page of my military record book) aimed for future officers in the Army Regiment located in Chełmno Pomorskie. At that time I have experienced a global bifurcation, which has changed my attitude to science and approach to life, from somehow linear to dominantly nonlinear, which occasionally goes chaotic.

This bifurcation was caused by Professor Tomasz Kapitaniak, a close friend and colleague, whom I met in Chemno Pomorskie for the first time and with whom we have been meeting regularly in various locations around the world (see photograph from 2011 meeting in Kyoto shown in Fig. 4). At that time he was a private lieutenant, with a PhD degree, and now he is an internationally renowned scientist and a full member of the

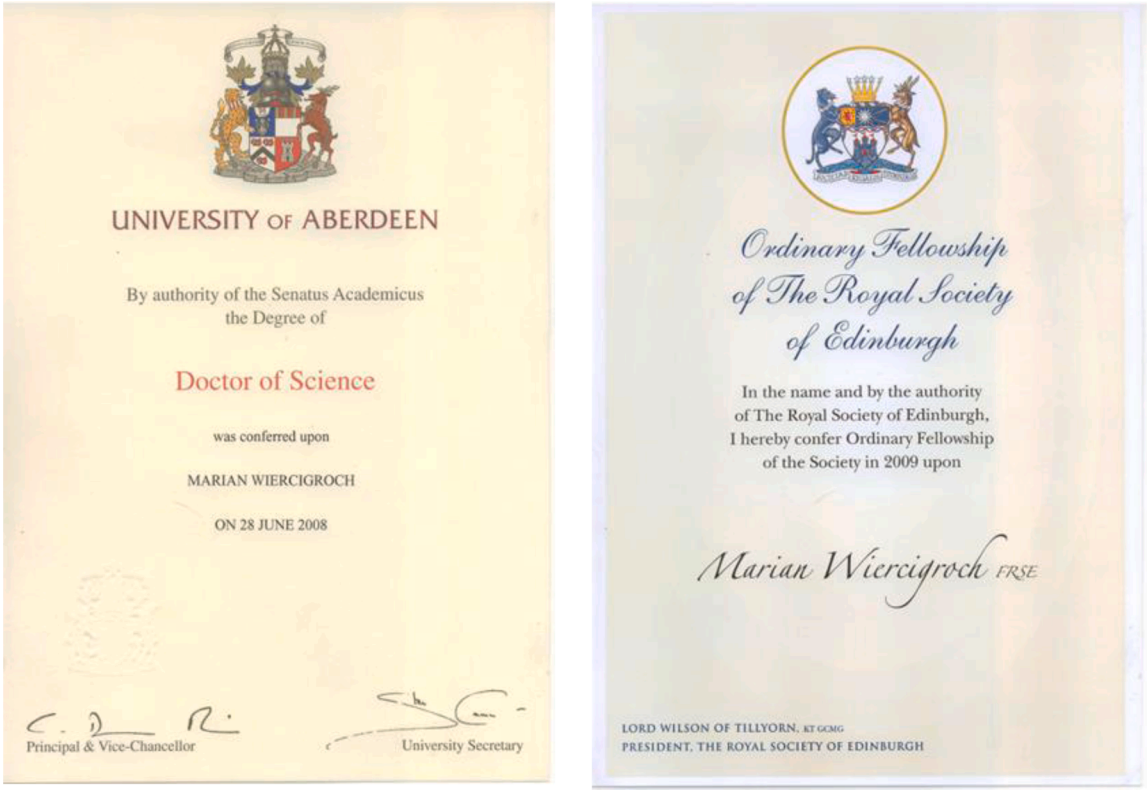

Fig. 5. On the left, a DSc degree certificate conferred in 2008; on the right a certificate of being elected a Fellow of the Royal Society in Edinburgh from 2009.

Fig. 6. Left panel presents a photograph from the annual meeting of the Centre for Applied Dynamics Research held in Linklatter Rooms on 25 October 2006. In the front row from the left: Dr Ekaterina Pavlovskaia, Adriane Schelin, Professors Celso Grebogi and Michael Thompson, Elena Sitnikova, Marian Wiercigroch (CADR Director), Dr Dragan Jovcic. In the middle row from the left: Dr Kaliyaperumal Nakkeeran, Marko Keber, Scott Davidson, Drs Andrew Starkey, Alessandro de Moura, Qingjie Cao, Gyorgy Karolyi and Charles Wang, Tamas Bodai, Bryan Horton, Ravindran Manoharan. In the back row from the left: Olusegun Ajibose, Ronny Sternberger, Nick Burns, Christian Rodriguez, Paulo Bonifacio, Dr Jan Sieber and James Ing. Right panel photograph is from the Graduation ceremony held in July 2004 at the University of Aberdeen. From the left the former Rector (Lord Wilson, the former Governor of Hong Kong), honorary graduate (Professor Mike Thompson) and the Promoter (myself).

Polish Academy of Sciences. From that time on I started my *swift military scientific march*. In 1991 I defended with a distinction my PhD thesis entitled *'Modelling of dynamic interactions in metal cutting based on the turning process on a horizontal boring-milling machine'*. The work was supervised by the late Professor Tadeusz Tyrlik. Just after I accepted the invitation extended by late Professor Allan Barr FRSE to join the University of Aberdeen as a postdoctoral research fellow, which was a crucial decision in my career. In 1994 I underwent a pitchfork bifurcation, namely, I was awarded a Senior Fulbright Fellowship, wrote a habilitation dissertation on *'Dynamics of Discrete Mechanical Systems with Discontinuities'*, and was appointed a lecturer at the University of Aberdeen.

In parallel to the Fulbright Scholarship at the University of Delaware, I was also a lecturer at the University of Aberdeen, supervising undergraduate projects. At that time the main means of communication for large documents exchange was fax. This led to numerous long fax transmissions between Universities of Aberdeen and Delaware, causing a few problems for secretaries. In the middle of 1996 just after

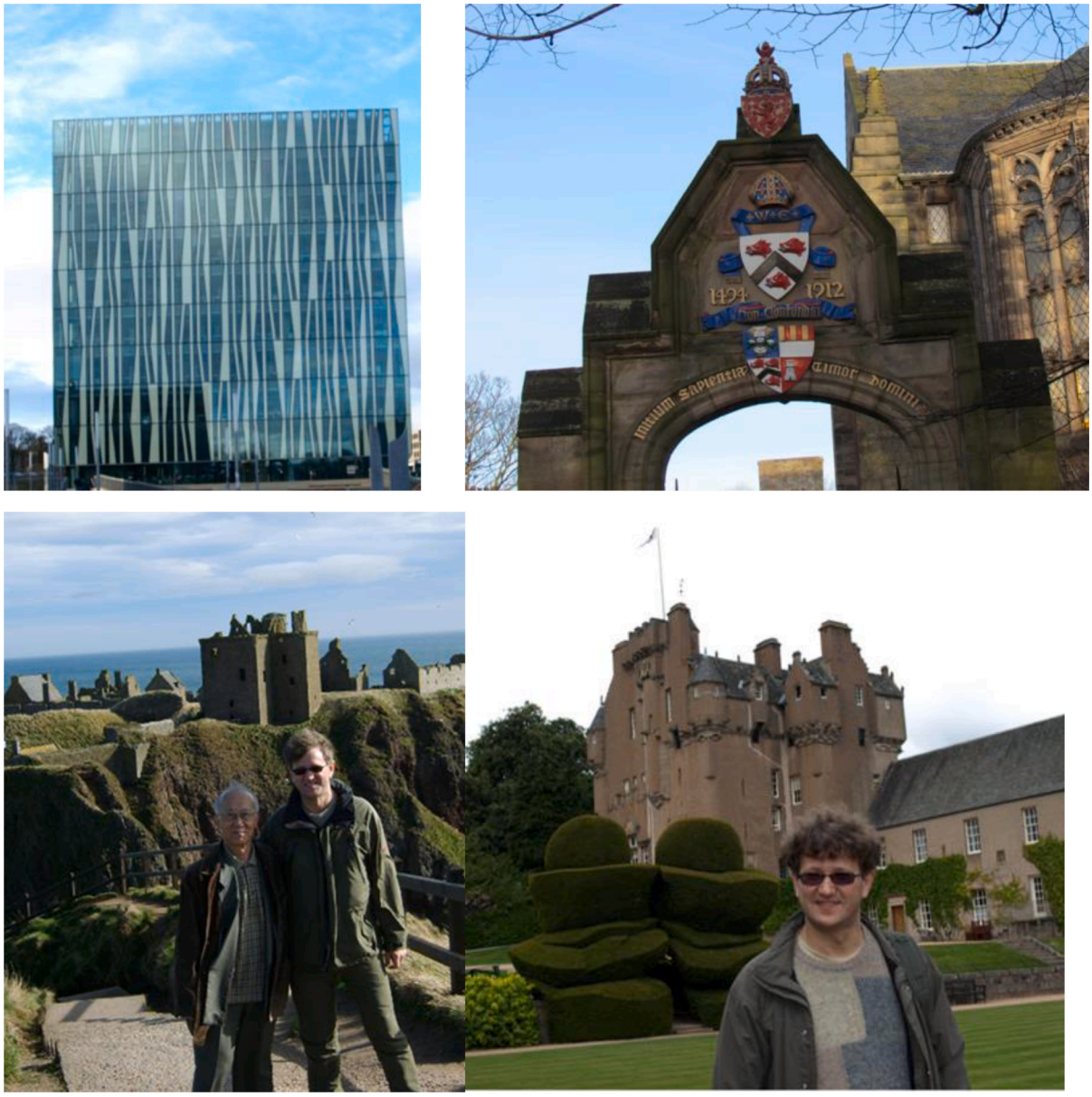

Fig. 7. Upper left panel depicts the Sir Duncan C Rice Library and the upper right the gate to the New Kings buildings at the University of Aberdeen. At the bottom left, with my colleague and friend, Emeritus Professor Yoshi Ueda of Kyoto University, who discovered chaos in 1961, at the front of dramatic ruins of medieval Dunnotar Castle. On the right bottom at the front of the Crathes Castle located in the Royal Deeside.

completing my Fulbright Scholarship and a research project sponsored by the Office of Naval Research, I returned to Scotland and started to build my research group.

Since then I have been promoted through the ranks to a senior lecturer in 1999, reader in 2000 and to a personal chair in 2002. Four years later in 2006, in the frame of the Sixth Century Campaign, I was promoted to a Sixth Century Chair for my scholarly contributions and international reputation in the field of applied dynamics. According to my many colleagues, I have excelled as a talented administrator and organizer. Among others, I served as a Head Engineering at the University of Aberdeen between 2003 and 2007, when Aberdeen Engineering had grown significantly in research strength with appointments of Professors Steve Reid, Michael Thompson and Celso Grebogi.

In 2008 I obtained the highest academic degree in the British system (see the left panel of Fig. 5), a Doctor of Science from the University of Aberdeen for a monograph entitled *Engineering Dynamics of Non-smooth Mechanical Systems: Modelling, Analysis and Experimental Studies*, which was based on a selection of my works published in the best peer review journals. This monograph presents a systematic approach to modeling, analysis, verification and design of strongly nonlinear dynamical systems. In 2009 for my contribution to nonlinear dynamics and its applications, I was elected a Fellow of the Royal Society of Edinburgh, the Scotland National Academy (see the right panel of Fig. 5).

2. Research interests and place of work

My research interests are focused on advancing understanding of engineering and physical systems undergoing complex dynamical phenomena involving nonlinear resonances. And throughout my career, I have been very fortunate and privileged to tackle a broad spectrum of fundamental and applied problems originating from mechanics and engineering systems. Most of them have had a strong focus on dynamics and vibration of predominantly mechanical systems in form of structures and processes. These investigations can be grouped into four major categories, namely, non-smooth [1–117] and smooth [118–158] dynamical systems, dynamics and control [159–165], and solid

Fig. 8. A group photograph from the first international conference on nonlinear mechanics entitled *Recent Advances in Nonlinear Mechanics* organized at Aberdeen in August 2005. The conference attracted the international authorities in dynamics (e.g. Prof Philip Holmes, Princeton; Prof JMT Thompson, UCL; Prof G Rega, Rome), solid mechanics (Prof John Willis, Cambridge) and fluid mechanics (Prof Paul Manneville, Paris). The picture was taken in the background of the King College Chapel, the oldest building of the University of Aberdeen.

mechanics [166–179]. The studies on non-smooth dynamical systems dynamics, can be further divided into problems with non-smooth stiffness [1–58], non-smooth friction [59–70], and a combination of those two effects [70–117,]. The investigations into smooth dynamical systems have been focussed predominantly on complex dynamics of pendula systems [118–133], vortex induced vibration [134–142], underwater acoustics [143–149] and neurodynamics [150–158].

My research group is organized in a form of the Centre for Applied Dynamics Research (CADR), which was officially opened in 2003. On average the Centre would have 25 members comprised of academics and PhD students (see left panel of Fig. 6 with a group photograph from CADR annual meeting held in 2006). The main aim of CADR is to develop robust solutions for the fundamental problems in dynamics and to apply them to engineering practice. CADR has modern and well equipped experimental laboratories, which attract visitors from around the world. It has a rich seminar programme, has hosted many international visitors, has organized half a dozen of international conferences and collaborates with the leading scholars (see right panel of Fig. 6).

The University of Aberdeen (UoA) located in the North East of Scotland, is an ancient institution founded in 1495 by William Elphinstone, the Bishop of Aberdeen and Chancellor of Scotland at that time. The UoA is Scotland's 3rd oldest university and the 5th oldest in the English-speaking world and its motto *is 'Initium sapientiae timor domini'* (The fear of the Lord is the beginning of wisdom). It has been consistently ranked among the top 160 universities in the world and within the top 20 universities in the United Kingdom.

It is an institution with a great heritage and achievements including 5 Nobel Prize winners. James Clerk Maxwell, the founder of modern physics, was the University professor before joining the University of Cambridge. It has over 15000 students and around 2500 of academic and administrative staff. UoA researches and educates in the whole spectrum of academic disciplines ranging from art, through medicine and mathematics to engineering. Late University Principal, Professor Sir Duncan Rice had run a unique in the UK and very successful fund raising campaign allowing to upgrade many university facilities including the library, which was named after him (see Sir Duncan Rice Library on the top left panel of Fig. 7).

Aberdeen is the third largest city in Scotland and the Europe capital of the energy industry. At the same time Aberdeen is the doorstep of a picturesque and historic North-East coast. This part of Scotland is Aberdeenshire, having one of the highest densities of castles (see the bottom photographs of Fig. 7) and distilleries in the United Kingdom.

3. International collaborations, conferences and editorial work

Undertaking high quality research especially in science and engineering must involve interactions with the leading researchers and I have realized this fact very early in my career. As my academic and research identity has been shaped by Polish, American and British higher education systems, I have naturally developed many collaborative links and projects within UK and internationally. These includes EPSRC funded projects undertaken in collaboration with the University of Glasgow, Polish Academy of Sciences and Rolls Royce. I have had over two dozens international exchange projects with Brazil, China, Check Republic, India, Italy, Israel, Netherlands, Poland and Russia, funded by the British Council, London Mathematical Society, Royal Society of Edinburgh, Royal Society of London, Royal Academy of Engineering and others.

I have participated in numerous international conferences and visited many collaborators and colleagues delivering in total over 50 keynote and plenary addresses and around 150 talks around the world. I have organized and co-organized around 100 sessions at various international conferences and have helped to shape long running conference series such as *Advanced Problems in Mechanics* organized by the Russian Academy of Sciences in St Petersburg.

I have established two conference series, *Recent Advances in Nonlinear Mechanics (RANM)* and *International Conference on Engineering Vibration (ICoEV)* in 2013. The first series, RANM, started in Aberdeen in 2005 (see Fig. 8) with some 150 delegates including leading international figures in dynamics, fluid and solid mechanics. The following RANM conferences were held in Kuala Lumpur (2009), Harbin (2014), Lodz (2019) and Hangzhou (2021). The last one was organized in a hybrid mode with some 30,000 attending online.

The ICoEV series of conference originates from long running

conferences organized by two Indian colleagues, Profs M Baneerjee and P Biswas, named as *International Conferences on Vibration Problems (ICoVP)*, which started in India and then became more international. My involvement in the ICoVP conferences was in 2011 and 2013, when these conferences were held in Prague and Lisbon. The first ICoEV conference was held in Ljubljana in 2015, the second was in Sofia (2015), the third was hosted by the University of Aberdeen in 2020 and it was online due to the COVID-19 pandemic.

Throughout my career I have been involved in development and stimulating research in my area of engineering dynamics also by organizing special issues of various journals [180–193]. These include Philosophical Transactions of the Royal Society, Proceedings of the Institution of Mechanical Engineers, Meccanica, Chaos Solitons and Fractals, IMA Journal of Applied Mathematics, International Journal of Bifurcation and Chaos, International Journal of Nonlinear Mechanics and International Journal of Mechanical Sciences. In total, together with my guest co-editors, I have published 14 special issues.

4. Closure

In summary, my academic career has been formed and developed in the UK, after having been educated in Poland and undertaking research spells in the US in mid-nineties. Since 2006, I am holding a prestigious Sixth Century Chair in Applied Dynamics and I am the founding director of the Centre for Applied Dynamics Research at the University of Aberdeen. My area of research is theoretical and experimental nonlinear dynamics, which I apply to various engineering problems.

I am also the inventor of new patented drilling technology called Resonance Enhanced Drilling and the Founder and Chief Technology Officer of a spinoff company iVDynamics Ltd. In Aberdeen I have established unique experimental laboratories allowing to investigate complex nonlinear dynamic interactions in mechanical systems with the focus on energy generation.

I have received many awards and distinctions including a Senior Fulbright Scholarship (1994), Fellowship of the Royal Society of Edinburgh (2009), DSc *honoris causa* by the Lodz University of Technology (2013), Distinguished Professorships at the Perm National Research Polytechnic University (2017), Balseiro Institute (2018) and Yanshan University (2021), a Scottish Champion of Knowledge Exchange (2020). In 2014 and 2021 I was a panelist of the Research Excellence Framework assessing the quality of research in the UK.

I have published over 500 journal and conference papers and I have been a frequent keynote and plenary speaker at major international conferences. I sit on a dozen editorial boards of peer review journals and since 2013 I have been the Editor-In-Chief of International Journal of Mechanical Sciences, a leading journal in mechanics and mechanical engineering [194].(Fig. 1,Fig. 2)

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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