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Michael Thompson: His Seminal Contributions to Nonlinear Dynamics – and Beyond

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In this meeting we are honouring the outstanding achievements of Michael Thompson, who over a period of four decades, has become a world leader in the development of modern concepts of nonlinear dynamics and the application of these concepts to modern problems.

Michael came up to Clare College, Cambridge in 1955, where he studied mechanical sciences. He was a brilliant undergraduate. In Part I of the Mechanical Sciences Tripos he won the Rex Moir Prize. In Part II he won the Archibald Denny Prize. Both of these were the top prizes in Mechanical Sciences. After graduating in 1958, he was determined to pursue a research career.

At that time, research in structural engineering in Cambridge was dominated strongly by the work of Lord Baker and his colleagues in the plastic behaviour of metal structures. There were though, a number of smaller research cells in the Engineering Department, developing independently from the plastic structures group. There was a developing group in soil mechanics, another in the dynamics and vibrations of structures, as well as others.

I had come from Bristol to Cambridge in 1954, with structural stability interests in both teaching and research. In teaching I had developed a series of lectures on structural stability in Part II of the Mechanical Sciences Tripos, and this brought me into contact with Michael and other final year students. This led to Michael deciding, on graduating, that he would like to research into some of the most challenging stability problems of engineering structures. And so began the career of one of the most distinguished researchers, in our time, in nonlinear mechanics and its applications.

In 1958, when Michael graduated, the leading thinkers in the field of structural stability were concerned with, what one might call, static elastic stability, and researchers concentrated on the extension of simple static stability principles to new and evolving structural forms. One of the most baffling problems, at that time, was our inability to predict accurately the uniform, external, elastic-buckling pressure of thin spherical shells.

Michael began his researches with the study of very thin copper shells, which he formed by the electro-chemical deposition of a very thin spherical layer of copper on a solid internal sphere of paraffin wax. After deposition, the internal paraffin wax was melted slowly through a pin-hole in the copper shell, to yield probably the most perfect spherical shells ever produced for such research. The shells were great works of art.

What became evident from these studies was that, well before the theoretical critical external pressure could be achieved, the spherical geometry of the sphere was becoming minutely distorted from its original spherical form. As external pressure increased, the shell reached a highly dynamic condition of instability at an external pressure well below the theoretical elastic buckling pressure. It was clear that the simple linear theory of elastic stability alone was inadequate for the analysis of such a problem.

The uniformly compressed spherical shell is a highly efficient structural form which optimises the weight of material in the shell to resist external pressure. Work on the buckling of shells drew Michael's attention to the fact that structural optimisation leads to structural forms which are highly sensitive to small deviations from perfect structural geometry. This had a very important influence on his future work. It showed the need for a fuller understanding of the nonlinear behaviour of structures, in not only static but also in dynamic situations.

In 1960, while still a research student, Michael won the John Winbolt Prize for a research essay, thereby making a "clean sweep" of all the top graduate and undergraduate prizes. In the following year, and towards the end of his PhD researches, he won a research fellowship in Peterhouse. This enabled him to continue over the next 3 years, with complete independence, his studies of nonlinear mechanics. During the second year of this fellowship, Michael and his young wife Margaret spent a year in California where Michael was a Fulbright Research Associate in the Department of Aeronautics and Astronautics at Stanford University.

In 1961, I myself moved from Cambridge to take up the Chadwick Chair at University College London (UCL). At the end of his Research Fellowship in Peterhouse, in 1964, Michael also came to UCL, where he began a remarkably successful research career in nonlinear phenomena, and its application to practical problems. A research group in Structural Stability at UCL was quick to develop, and very considerable progress was made in fundamental research.

Michael proved to be a very able builder of a research team, in which individual researchers were allowed great independence in pursuing their own ideas. Michael became a Reader in Structural Mechanics at UCL in 1968. I myself resigned from the Chadwick Chair in 1969, to do other things, and since then I have watched with great interest the tremendous progress Michael and his colleagues have made in the ensuing years.

In 1973, Michael and Giles Hunt (with whom Michael had many successful collaborations) published their book on *A General Theory of Elastic Stability*. In this treatise, which is recognised as a definitive one, we see the bringing together of the new concepts that Michael and Giles had developed during their researches, leading to a unified conceptual framework for stability theory. In the treatise, the authors indicate the importance of the critically unstable states of highly-optimised structural systems, which Michael first encountered in his PhD work on spherical shells.

During the 1970s, Michael and his colleagues broadened their interests widely, into numerous areas of science and engineering, including stellar collapse and crystal fracture. In 1977, Michael became Professor of Structural Mechanics at UCL, and was awarded the degree of Sc.D. by Cambridge University. In 1982, he published his book on *Instabilities and Catastrophes in Science and Engineering* (subsequently translated into Japanese and Russian), and organized his first scientific symposium on *Collapse: The Buckling of Structures in Theory and Practice* under the auspices of the International Union of Theoretical and Applied Mechanics (IUTAM).

During the 1970s and 1980s much thought was given by Michael and Giles to the nonlinear modal interactions generated in optimised structures. This led, in 1984, to their joint book on *Elastic Instability Phenomena*.

By the mid-1980s, the work of Michael's group had achieved an international reputation. In 1985, Michael was elected a Fellow of The Royal Society. All his colleagues and students were delighted at this highly deserved recognition of his outstanding work in nonlinear statics and dynamics. As new challenges appeared, Michael and his group moved further away from static buckling, concentrating their work more and more in the rapidly growing field of nonlinear dynamics.

In the field of marine technology, Michael's interest was drawn by Rod Rainey of W.S. Atkins to some unexpected resonances of articulated ship-mooring towers. For his innovative work on this problem Michael won an OMAE Award from the American Society of Mechanical Engineers "in recognition of outstanding originality and significance". He generalised the problem to that of an impacting oscillator, in which he showed the existence of wide regimes of chaos. This stimulated Michael and his new collaborator Bruce Stewart (then a research mathematician at the National Brookhaven Laboratory, New York) into writing their book on *Nonlinear Dynamics and Chaos*, which was published in 1986. This seminal book introduced the new geometrical phase-space ideas of nonlinear dynamics to applied scientists and engineers. The book has gone to many reprints, and 14,000 copies have been sold worldwide. A second edition was published in 2002, and the book has been translated into Japanese and Italian.

During the 1980s, Michael's work was attracting an increasing readership and interest amongst scientists and others, and in 1988, he was awarded a Senior Fellowship by the Science Research Council of the United Kingdom. This 5-year appointment allowed him to give his full time and energy to the building-up of a broader research group in nonlinear dynamics. This was to be a very important development for the future of nonlinear dynamics at UCL.

The increasing breadth of Michael's studies, at this time, is epitomised in his work on chaotic phenomena triggering the escape from a potential well, which was published in 1989. The general conclusions of this work are relevant to a number of practical situations, including ship capsize, the loss of synchronisation in electrical circuits, the dynamic buckling of slender structures and the mobility of oxygen in myoglobin which is essential for the functioning of muscles. In the case of ship capsize, new methods of design devised by Michael and Rod Rainey have been adopted by naval architects worldwide. Michael and his colleagues showed how transient laboratory wave-tank tests can quickly and economically assess the stability and safety of a ship against beam-sea excitation.

In the ensuing research programmes, Michael showed how the escape from a potential well involves an intricate interplay of chaotic transients, fractal basin boundaries and indeterminate bifurcations. In collaboration with his research student, Mohamed Soliman, he discovered that jumps to resonance can be highly indeterminate in outcome, and that this can lead to the unpredictable failure of an engineering system. This conclusion is very important for any modern philosophy of engineering safety.

The Senior SRC Fellowship had enabled both Michael and UCL to prepare plans for a formal *Centre for Nonlinear Dynamics and its Applications*. The new Centre was set up in 1991, with financial resources to support future work in nonlinear dynamics. Michael became Director of the Centre, and Professor of Nonlinear Dynamics, posts which he held until his retirement. The Centre was a great success, attracting very able staff and many research students. It earned over £2 million in grants and awards and many major fellowships were won by members of the Centre. Steve Bishop was an Advanced SERC Fellow; Allan McRobie, Mike Davies and Gert van der Heijden all won prestigious Royal Society Research Fellowships; and Jaroslav Stark was awarded a Royal Society Leverhulme Fellowship. It is a happy circumstance that Allan McRobie, who married Michael's daughter Helen in 1995, has been appointed to a Readership in the Cambridge Engineering Department where Michael launched his research career with his electroplated spherical shells.

The Centre at UCL addressed an increasingly wide range of problems of nonlinear dynamics, and was acclaimed internationally. A useful industrial link was formalised by the appointment of Michael as Chairman of the Board of Directors of *ES-Consult*. This specialised Danish consultancy founded by Eilif Svensson has a strong interest in the aeroelastic instabilities of slender bridge structures, and has worked on tuned mass dampers for the Great Belt bridge, the largest single span suspension bridge in the world (at the time).

In 1992, Michael was awarded the James Alfred Ewing Medal, given jointly by The Royal Society and the Institution of Civil Engineers; this medal is awarded for "special meritorious contributions to the science of engineering in the field of research". In the following year the Centre hosted Michael's second IUTAM Symposium on *Nonlinearity and chaos in engineering dynamics*.

In some of his most recent papers, Michael has brought together two major strands of his earlier work, in buckling and dynamics. Together with Giles Hunt, Alan Champneys and Gert van der Heijden, he has demonstrated how the static-dynamic analogy can shed new light on the localisation of post-buckling deformations. Introducing the twisted rod (which is mathematically equivalent to the spinning top) as an archetypal model, he has clarified the mechanics of localisation in simple systems. For more complex systems, he and his colleagues have shown how "spatial chaos" can generate highly indeterminate forms of localisation which in practice will depend very sensitively on initial imperfections. One significant application of the twisted-rod theory is to the supercoiling of DNA molecules.

On Michael's retirement in 2002, the Centre for Nonlinear Dynamics has matured into a virtual centre, a network linking researchers in many UCL Departments. A significant feature of this network is the *Centre for Mathematics and Physics in the Life Sciences and Experimental Biology* (*CoMPLEX*) in the creation of which Jaroslav Stark played a leading role. In the same year, Michael was elected a member of the Council of The Royal Society, an honour which we all warmly acclaim.

Throughout his career, Michael has always been concerned to achieve communication of his ideas to the widest possible audiences of engineers, applied scientists and others. The elegance and clarity of his many hand-drawn diagrams have long been recognised by international readers of his work. Eight figures from his book on *Nonlinear Dynamics and Chaos* were reproduced by Ian Stewart in his popular book *Does God Play Dice? The Mathematics of Chaos* (Blackwell, 1989).

In 1990, he became acting Editor of The Royal Society's *Philosophical Transactions*, Series A, which covers mathematics, the physical sciences and the engineering sciences. This led to his editing the first Theme Issue of the journal in 1990, entitled (I think very appropriately) *Chaos and dynamical complexity in the physical sciences*. Over the period from 1992 to 1998, he organised further theme issues of *Phil. Trans. A* on: the nonlinear dynamics of engineering systems; chaotic behaviour in electronic circuits; localisation and solitary waves in solid mechanics; and nonlinear flight dynamics of high performance aircraft.

With these achievements behind him, in 1998 he was appointed to the full Editorship of *Phil. Trans A*, the world's longest running scientific journal. In his role of Editor, he prepared three special millennium issues of the journal in which young scientists were invited to give their visions of the future. These were subsequently rewritten as three paperback books published by Cambridge University Press covering Astronomy and Earth Science, Physics and Electronics, and Chemistry and Life Science. A similar series of Christmas issues is continuing this successful initiative for young researchers, drawing particularly on the holders of Royal Society Research Fellowships. These Christmas issues will form the basis of a new Royal Society book series, *Advances in Science*, that Michael has launched in collaboration with Imperial College Press. Michael's endeavours, in the direction of dissemination, represent a major achievement in communication, and a great encouragement to young researchers to communicate their ideas to the wider field of science.

On his retirement last year, Michael became an Emeritus Professor of Nonlinear Dynamics at University College London. The subsequent award of an honorary fellowship at the Department of Applied Mathematics and Theoretical Physics (DAMTP) of Cambridge University has allowed him to diversify his interests in many new directions. In particular he is now deeply involved in the Millennium Mathematics Project at DAMTP, which seeks to boost the public understanding of mathematics by lectures and video conferences to schools and the general public. Subsequent to today's meeting, in 2004, I have been delighted to hear that Michael's lifetime contributions to mathematics have been given recognition by the award of a Gold Medal by the Institute of Mathematics and its Applications.

Throughout his career, a central theme in his research has been, in Michael's own words: "a search for order and regularity within the sensitivities and unpredictability of structural buckling and dynamical failure".

Michael's progress from a student in mechanical sciences to the founder and director of an international scientific centre is a remarkable history. His work has opened up many new vistas of research, and has inspired all those who have worked with him. We are all deeply honoured to have been able to work with him, in one way or another, during his scintillating career, and to have learnt so much from him. I am sure Michael will never retire, and we all hope to continue to meet him, and Margaret, and his family, for many years to come.

Henry Chilver
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Publications of J.M.T. Thompson, FRS (www.homepages.ucl.ac.uk/$\sim$ucess21)

(a) Authored Books

A General Theory of Elastic Stability, J.M.T. Thompson & G.W. Hunt, Wiley, London, 1973.
Instabilities and Catastrophes in Science and Engineering, J.M.T. Thompson, Wiley, Chichester, 1982. Translated into Russian and Japanese.
Elastic Instability Phenomena, J.M.T. Thompson & G.W. Hunt, Wiley, Chichester, 1984.
Nonlinear Dynamics and Chaos, Geometrical Methods for Engineers and Scientists, J.M.T. Thompson & H.B. Stewart, Wiley, Chichester, 1986. Translated into Japanese and Italian. Second Edition, 2002.

(b) Edited Books and Proceedings

Collapse: The Buckling of Structures in Theory and Practice (eds. J.M.T. Thompson & G.W. Hunt), Cambridge University Press, Cambridge, 1983 (Proc. IUTAM Symp., UCL, 1982). Translated into Russian.
Chaos and Dynamical Complexity in the Physical Sciences (eds. J.M.T. Thompson & P. Gray), Royal Society, London, 1990 (Theme Issue, *Phil. Trans. R. Soc. London A*, **332**, 1990).
Nonlinear Dynamics of Engineering Systems (eds. J.M.T. Thompson & W. Schiehlen), Royal Society, London, 1992 (Theme Issue, *Phil. Trans. R. Soc. London A*, **338**, 1992).
Nonlinearity and Chaos in Engineering Dynamics (eds. J.M.T. Thompson & S.R. Bishop), Wiley, Chichester, 1994 (Proceedings of the IUTAM Symposium, UCL, 1993).
Chaotic Behaviour in Electronic Circuits (eds. J.M.T. Thompson & L.O. Chua), Royal Society, London, 1995 (Theme Issue, *Phil. Trans. R. Soc. London A*, **353**, 1995).
Localization and Solitary Waves in Solid Mechanics (eds. A.R. Champneys, G.W. Hunt & J.M.T. Thompson), Royal Society, London, 1997 (Theme Issue, *Phil. Trans. R. Soc. London A*, **355**, 1997).
Nonlinear Flight Dynamics of High Performance Aircraft (eds. J.M.T. Thompson & F.B.J. Macmillen), Royal Society, London, 1998 (Theme Issue, *Phil. Trans. R. Soc. London A*, **356**, 1998).
Millennium Issue, Part I, Astronomy and Earth Sciences (ed. J.M.T. Thompson), Royal Society, London, 1999 (Special Issue, *Phil. Trans. R. Soc. London A*, **357**, 1999).

Millennium Issue, Part II, Mathematics, Physics and Engineering (ed. J.M.T. Thompson), Royal Society, London, 2000 (Special Issue, *Phil. Trans. R. Soc. London A*, **358**, 2000).

Millennium Issue, Part III, Chemistry and Biological Physics (ed. J.M.T. Thompson), Royal Society, London, 2000 (Special Issue, *Phil. Trans. R. Soc. London A*, **358**, 2000).

Localization and Solitary Waves in Solid Mechanics (eds. A.R. Champneys, G.W. Hunt & J.M.T. Thompson), World Scientific, Singapore, 1999.

Solitary Waves and Localisation Phenomena in Elastic Structures (eds. J.M.T. Thompson & G.H.M. van der Heijden), Kluwer, Dordrecht, 2000 (Special Issue, *Nonlinear Dynamics*, **21**, 2000).

The Nonlinear Dynamics of Ships (eds. K.J. Spyrou & J.M.T. Thompson), Royal Society, London, 2000 (Theme Issue, *Phil. Trans. R. Soc. London A*, **358**, 2000).

Visions of the Future: Astronomy and Earth Science (ed. J.M.T. Thompson), Cambridge University Press, Cambridge, 2001. Translated into Chinese.

Visions of the Future: Physics and Electronics (ed. J.M.T. Thompson), Cambridge University Press, Cambridge, 2001. Translated into Chinese.

Visions of the Future: Chemistry and Life Science (ed. J.M.T. Thompson), Cambridge University Press, Cambridge, 2001. Translated into Chinese.

Astronomy and Earth Science (ed. J.M.T. Thompson), Royal Society, London, 2002 (Christmas Issue, *Phil. Trans. R. Soc. London A*, **360**, 2002).

Mathematics, Physics and Engineering (ed. J.M.T. Thompson), Royal Society, London, 2003 (Christmas Issue, *Phil. Trans. R. Soc. London A*, **361**, 2003).

The Mechanics of DNA (ed. J.M.T. Thompson), Royal Society, London, 2004 (Theme Issue, *Phil. Trans. R. Soc. London A*, **362**, 2004).

Chemistry and Life Science (ed. J.M.T. Thompson), Royal Society, London, 2004 (Christmas Issue, *Phil. Trans. R. Soc. London A*, **362**, 2004).

Astronomy and Earth Science (ed. J.M.T. Thompson), Royal Society, London, 2005 (Christmas Issue, *Phil. Trans. R. Soc. London A*, **363**, 2005).

Advances in Astronomy: From the Big Bang to the Solar System (ed. J.M.T. Thompson), Royal Society Series on Advances in Science, Vol. 1, Imperial College Press, London, 2005. (Distributed by World Scientific Publishing)

(c) Selected Papers

1. J.M.T. Thompson, Elastic buckling of thin spherical shells, Symposium on *Nuclear Reactor Containment Buildings & Pressure Vessels*, Glasgow, 1960 (ed. A.S.T. Thomson et al., Butterworths, London, 1960, 257–285).
2. J.M.T. Thompson, Making of thin metal shells for model stress analysis, *J. Mech. Eng. Sci.*, **2**, 105–108 (1960).
3. J.M.T. Thompson, Stability of elastic structures and their loading devices, *J. Mech. Eng. Sci.*, **3**, 153–162 (1961).
4. J.M.T. Thompson, The elastic instability of a complete spherical shell, *Aeronaut. Q.*, **13**, 189–201 (1962).
5. J.M.T. Thompson, The post-buckling of a spherical shell by computer analysis, World Conference on *Shell Structures*, San Francisco, 1962 (ed. S.J. Medwadowski, et al., *Nat. Acad. Sci.*, Washington, 1964, 181–188).
6. J.M.T. Thompson, Basic principles in the general theory of elastic stability, *J. Mech. Phys. Solids*, **11**, 13–20 (1963).

7. J.M.T. Thompson, The rotationally-symmetric branching behaviour of a complete spherical shell, *Proc. R. Neth. Acad. Sci.*, **67B**, 295–311 (1964).
8. J.M.T. Thompson, Eigenvalue branching configurations and the Rayleigh-Ritz procedure, *Q. Appl. Math.*, **22**, 244–251 (1964).
9. J.M.T. Thompson, Discrete branching points in the general theory of elastic stability, *J. Mech. Phys. Solids*, **13**, 295–310 (1965).
10. J.M.T. Thompson, Dynamic buckling under step loading, Internation Conference on *Dynamic Stability of Structures*, Northwestern University, 1965 (ed. G. Herrmann, Pergamon Press, Oxford, 1966, 215–236).
11. J.M.T. Thompson, Localized Rayleigh functions for structural and stress analysis, *Int. J. Solids Struct.*, **3**, 285–292 (1967).
12. J.M.T. Thompson, The estimation of elastic critical loads, *J. Mech. Phys. Solids*, **15**, 311–317 (1967).
13. J.M.T. Thompson, Towards a general statistical theory of imperfection-sensitivity in elastic post-buckling, *J. Mech. Phys. Solids*, **15**, 413–417 (1967).
14. J.M.T. Thompson & A.C. Walker, The nonlinear perturbation analysis of discrete structural systems, *Int. J. Solids Struct.*, **4**, 757–768 (1968).
15. J.M.T. Thompson, The branching analysis of perfect and imperfect discrete structural systems. *J. Mech. Phys. Solids*, **17**, 1–10 (1969).
16. J.M.T. Thompson & A.C. Walker, A general theory for the branching analysis of discrete structural systems, *Int. J. Solids Struct.*, **5**, 281–288 (1969).
17. J.M.T. Thompson & G.W. Hunt, Perturbation patterns in nonlinear branching theory, *IUTAM Symposium on Instability of Continuous Systems*, Herrenalb, 1969 (ed. H. Leipholz, Springer, Berlin, 1971, 338–343).
18. J.M.T. Thompson & G.W. Hunt, Comparative perturbation studies of the elastica, *Int. J. Mech. Sci.*, **11**, 999–1014 (1969).
19. J.M.T. Thompson, A general theory for the equilibrium and stability of discrete conservative systems, *J. Appl. Math. Phys. (ZAMP)*, **20**, 797–846 (1969).
20. J.M.T. Thompson, A new approach to elastic branching analysis, *J. Mech. Phys. Solids*, **18**, 29–42 (1970).
21. J.M.T. Thompson, Basic theorems of elastic stability, *Int. J. Eng. Sci.*, **8**, 307–313 (1970).
22. J.M.T. Thompson, On the simulation of a gravitational field by a centrifugal field, *Int. J. Mech. Sci.*, **13**, 979–986 (1971).
23. J.M.T. Thompson & G.W. Hunt, A theory for the numerical analysis of compound branching, *J. Appl. Math. Phys. (ZAMP)*, **22**, 1001–1015 (1971).
24. J.M.T. Thompson & G.M. Lewis, On the optimum design of thin-walled compression members, *J. Mech. Phys. Solids*, **20**, 101–109 (1972).
25. J.M.T. Thompson, Optimization as a generator of structural instability, *Int. J. Mech. Sci.*, **14**, 627–629 (1972).
26. J.M.T. Thompson & G.M. Lewis, Continuum and finite element branching studies of the circular plate, *Comput. Struct.*, **2**, 511–534 (1972).
27. J.M.T. Thompson & W.J. Supple, Erosion of optimum designs by compound branching phenomena, *J. Mech. Phys. Solids*, **21**, 135–144 (1973).
28. J.M.T. Thompson, An engineering approach to interactive buckling, *Int. J. Mech. Sci.*, **16**, 335–336 (1974).

29. J.M.T. Thompson, J.D. Tulk & A.C. Walker, An experimental study of imperfection-sensitivity in the interactive buckling of stiffened plates, *IUTAM Symposium on Buckling of Structures*, Harvard, 1974 (ed. B. Budiansky, Springer, Berlin, 1976, 149–159).
30. J.M.T. Thompson & G.W. Hunt, Dangers of structural optimization, *Eng. Optim.*, **1**, 99–110 (1974).
31. J.M.T. Thompson & P.A. Shorrock, Bifurcational instability of an atomic lattice, *J. Mech. Phys. Solids*, **23**, 21–37 (1975).
32. J.M.T. Thompson, Experiments in catastrophe, *Nature*, **254**, 392–395 (1975).
33. J.M.T. Thompson, Instabilities, bifurcations and catastrophes, *Phys. Lett.*, **51A**, 201–203 (1975).
34. J.M.T. Thompson & G.W. Hunt, Towards a unified bifurcation theory, *J. Appl. Math. Phys. (ZAMP)*, **26**, 581–604 (1975).
35. J.M.T. Thompson & P.A. Shorrock, Hyperbolic umbilic catastrophe in crystal fracture, *Nature*, **260**, 598–599 (1976).
36. J.M.T. Thompson, Catastrophe theory and its role in applied mechanics, *14th IUTAM Congress on Theoretical and Applied Mechanics*, Delft, 1976 (ed. W.T. Koiter, North-Holland, Amsterdam, 1977, 451–458).
37. J.M.T. Thompson & G.W. Hunt, The instability of evolving systems, *Interdiscip. Sci. Rev.*, **2**, 240–262 (1977).
38. J.M.T. Thompson, Bifurcational aspects of catastrophe theory, *Ann., New York Acad. Sci.*, **316**, 553–571, (1979).
39. J.M.T. Thompson & Z. Gaspar, A buckling model for the set of umbilic catastrophes, *Math. Proc. Camb. Phil. Soc.*, **82**, 497–507 (1977).
40. J.M.T. Thompson & G.W. Hunt, A bifurcation theory for the instabilities of optimization and design, *Synthese*, **36**, 315–351 (1977).
41. J.M.T. Thompson, Imperfection-sensitivity uninfluenced by pre-stress, *Int. J. Mech. Sci.*, **20**, 57–58 (1978).
42. J.M.T. Thompson, J.K.Y. Tan & K.C. Lim, On the topological classification of post-buckling phenomena, *J. Struct. Mech.*, **6**, 383–414 (1978).
43. J.M.T. Thompson, An evolution game for a prey-predator ecology, *Bull. Inst. Math. Appl.*, **15**, 162–167 (1979).
44. J.M.T. Thompson, Stability predictions through a succession of folds, *Phil. Trans. R. Soc. London A*, **292**(1386), 1–23 (1979).
45. J.M.T. Thompson & R.J. Thompson, Numerical experiments with a strange attractor, *Bull. Inst. Math. Appl.*, **16**, 150–154 (1980).
46. J.M.T. Thompson & T.S. Lunn, Resonance-sensitivity in dynamic Hopf bifurcations under fluid loading, *Appl. Math. Modelling*, **5**, 143–150 (1981).
47. J.M.T. Thompson & T.S. Lunn, Static elastica formulations of a pipe conveying fluid, *J. Sound Vib.*, **77**, 127–132 (1981).
48. J.M.T. Thompson, Paradoxical mechanics under fluid flow, *Nature*, **296**, 135–137 (1982).
49. J.M.T. Thompson, Catastrophe theory in mechanics: progress or digression, *J. Struct. Mech.*, **10**, 167–175 (1982).
50. J.M.T. Thompson & R. Ghaffari, Chaos after period-doubling bifurcations in the resonance of an impact oscillator, *Phys. Lett.*, **91A**, 5–8 (1982).
51. J.M.T. Thompson & R. Ghaffari, Chaotic dynamics of an impact oscillator, *Phys. Rev.*, **27A**, 1741–1743 (1983).

52. J.M.T. Thompson & G.W. Hunt, On the buckling and imperfection-sensitivity of arches with and without prestress, *Int. J. Solids Struct.*, **19**, 445–459 (1983).
53. J.M.T. Thompson, On the convection of a cusp in elastic stability, *J. Mech. Phys. Solids*, **31**, 205–222 (1983).
54. J.M.T. Thompson, Complex dynamics of compliant off-shore structures, *Proc. R. Soc. London A*, **387**, 407–427 (1983).
55. J.M.T. Thompson, A.R. Bokaian & R. Ghaffari, Subharmonic resonances and chaotic motions of a bilinear oscillator, *IMA J. Appl. Math.*, **31**, 207–234 (1983).
56. J.M.T. Thompson, Sir Isaac Newton's pendulum experiments on fluid damping, *Bull. Inst. Math. Appl.*, **20**, 8–11 (1984).
57. J.M.T. Thompson & J.S.N. Elvey, Elimination of sub-harmonic resonances of compliant marine structures, *Int. J. Mech. Sci.*, **26**, 419–426 (1984).
58. J.M.T. Thompson & H.B. Stewart, Folding and mixing in the Birkhoff-Shaw chaotic attractor, *Phys. Lett.*, **103A**, 229–231 (1984).
59. J.M.T. Thompson, A.R. Bokaian & R. Ghaffari, Subharmonic and chaotic motions of compliant offshore structures and articulated mooring towers, *J. Energy Resourc. Technol. (Trans ASME)*, **106**, 191–198 (1984).
60. J.M.T. Thompson & L.N. Virgin, Predicting a jump to resonance using transient maps and beats, *Int. J. Nonlinear Mech.*, **21**, 205–216 (1986).
61. H.B. Stewart & J.M.T. Thompson, Towards a classification of generic bifurcations in dissipative dynamical systems, *Dyn. Stab. Syst.*, **1**, 87–96 (1986).
62. J.M.T. Thompson, S.R. Bishop & L.M. Leung, Fractal basins and chaotic bifurcations prior to escape from a potential well, *Phys. Lett.*, **121A**, 116–120 (1987).
63. J.M.T. Thompson, The *Principia* and contemporary mechanics: chaotic dynamics and the new unpredictability, *Notes Rec. R. Soc. London*, **42**, 97–122 (1988).
64. J.M.T. Thompson & L.N. Virgin, Spatial chaos and localization phenomena in nonlinear elasticity, *Phys. Lett.*, **126A**, 491–496 (1988).
65. J.M.T. Thompson & S.R. Bishop, From Newton to chaos, *Phys. Bull.*, **39**, 232–234 (1988).
66. J.M.T. Thompson, Chaotic dynamics and the Newtonian legacy, *Appl. Mech. Rev.*, **42**, 15–25 (1989).
67. J.M.T. Thompson, Chaotic phenomena triggering the escape from a potential well, *Proc. R. Soc. London A*, **421**, 195–225 (1989).
68. J.M.T. Thompson, Loss of engineering integrity due to the erosion of absolute and transient basin boundaries, *IUTAM Symposium on Nonlinear Dynamics in Engineering Systems*, Stuttgart, 1989 (ed. W. Schiehlen, Springer, Berlin, 1990, 313–320).
69. G.W. Hunt, H.M. Bolt & J.M.T. Thompson, Structural localization phenomena and the dynamical phase-space analogy, *Proc. R. Soc. London A*, **425**, 245–267 (1989).
70. J.M.T. Thompson & Y. Ueda, Basin boundary metamorphoses in the canonical escape equation, *Dyn. Stab. Syst.*, **4**, 285–294 (1989).
71. M.S. Soliman & J.M.T. Thompson, Integrity measures quantifying the erosion of smooth and fractal basins of attraction, *J. Sound Vib.*, **135**, 453–475 (1989).
72. F. Aghamohammadi & J.M.T. Thompson, An experimental study of the large amplitude fish-tailing instabilities of a tanker at a single point mooring, *Appl. Ocean Res.*, **12**, 25–33 (1990).
73. J.M.T. Thompson & M.S. Soliman, Fractal control boundaries of driven oscillators and their relevance to safe engineering design, *Proc. R. Soc. London A*, **428**, 1–13 (1990).

74. J.M.T. Thompson, Transient basins: A new tool for designing ships against capsize, *IUTAM Symposium on Dynamics of Marine Vehicles and Structures in Waves*, Brunel, 1990 (ed. W.G. Price, et al., Elsevier, Amsterdam, 1991, 325–331).
75. F.A. McRobie & J.M.T. Thompson, Chaos, catastrophes and engineering, *New Sci.*, **126**(1720), 41–46 (1990). Rewritten as Chapter 12, *The New Scientist Guide to Chaos* (ed. Nina Hall, Penguin, London, 1991, 149–161).
76. J.M.T. Thompson, R.C.T. Rainey & M.S. Soliman, Ship stability criteria based on chaotic transients from incursive fractals, *Phil. Trans. R. Soc. London A*, **332**, 149–167 (1990).
77. Y. Ueda, S. Yoshida, H.B. Stewart & J.M.T. Thompson, Basin explosions and escape phenomena in the twin-well Duffing oscillator: compound global bifurcations organizing behaviour, *Phil. Trans. R. Soc. London A*, **332**, 169–186 (1990).
78. J.M.T. Thompson, Chaos and fractal basin boundaries in engineering, in *The Nature of Chaos* (ed. T. Mullin), Oxford University Press, Oxford, 1993, 201–221.
79. A.N. Lansbury & J.M.T. Thompson, Incursive fractals: a robust mechanism of basin erosion preceding the optimal escape from a potential well, *Phys. Lett.*, **150A**, 355–361 (1990).
80. M.S. Soliman & J.M.T. Thompson, Stochastic penetration of smooth and fractal basin boundaries under noise excitation, *Dyn. Stab. Syst.*, **5**, 281–298 (1990).
81. F.A. McRobie & J.M.T. Thompson, Global integrity in engineering dynamics: methods and applications, *EPRI Workshop on Applications of Chaos*, San Francisco, 1990 (in *Applied Chaos,* eds. J.H. Kim, et al., Wiley, New York, 1992, 31–49).
82. J.M.T. Thompson & M.S. Soliman, Indeterminate jumps to resonance from a tangled saddle-node bifurcation, *Proc. R. Soc. London A*, **432**, 101–111 (1991).
83. H.B. Stewart, J.M.T. Thompson, A.N. Lansbury & Y. Ueda, Generic patterns of bifurcation governing escape from potential wells, *Int. J. Bifn Chaos*, **1**, 265–267 (1991).
84. M.S. Soliman & J.M.T. Thompson, Basin organization prior to a tangled saddle-node bifurcation, *Int. J. Bifn Chaos*, **1**, 107–118 (1991).
85. J.M.T. Thompson, Chaos and the danger of unpredictable failure, *Fellowship Eng. Newslett.*, Supplement to the Spring Newsletter, 1991, 1–7.
86. M.S. Soliman & J.M.T. Thompson, Transient and steady state analysis of capsize phenomena, *Appl. Ocean Res.*, **13**, 82–92 (1991).
87. R.C.T. Rainey & J.M.T. Thompson, The transient capsize diagram: a new method of quantifying stability in waves, *J. Ship Res.*, **35**, 58–62 (1991).
88. J.M.T. Thompson, Global unpredictability in nonlinear dynamics: capture, dispersal and the indeterminate bifurcations, *Physica D*, **58**, 260–272 (1992).
89. S. Foale & J.M.T. Thompson, Geometrical concepts and computational techniques of nonlinear dynamics, *Comput. Methods Appl. Mech. Eng.*, **89**, 381–394 (1991).
90. F.A. McRobie & J.M.T. Thompson, Lobe dynamics and the escape from a potential well, *Proc. R. Soc. London A*, **435**, 659–672 (1991).
91. F.A. McRobie & J.M.T. Thompson, Invariant sets of planar diffeomorphisms in nonlinear vibrations, *Proc. R. Soc. London A*, **436**, 427–448 (1992).
92. J.M.T. Thompson, R.C.T. Rainey & M.S. Soliman, Mechanics of ship capsize under direct and parametric wave excitation, *Phil. Trans. R. Soc. London A*, **338**, 471–490 (1992).
93. M.S. Soliman & J.M.T. Thompson, Global dynamics underlying sharp basin erosion in nonlinear driven oscillators, *Phys. Rev. A*, **45**, 3425–3431 (1992).
94. M.S. Soliman & J.M.T. Thompson, The effect of damping on the steady state and basin bifurcation patterns of a nonlinear mechanical oscillator, *Int. J. Bifn Chaos*, **2**, 81–91 (1992).

95. M.S. Soliman & J.M.T. Thompson, Indeterminate sub-critical bifurcations in parametric resonance, *Proc. R. Soc. London A*, **438**, 511–518 (1992).
96. A.N. Lansbury, J.M.T. Thompson & H.B. Stewart, Basin erosion in the twin-well Duffing oscillator: two distinct bifurcation scenarios, *Int. J. Bifn Chaos*, **2**, 505–532 (1992).
97. M.S. Soliman & J.M.T. Thompson, Indeterminate trans-critical bifurcations in parametrically excited systems, *Proc. R. Soc. London A*, **439**, 601–610 (1992).
98. F.A. McRobie & J.M.T. Thompson, Driven oscillators, knots, braids and Nielsen-Thurston theory, *IUTAM Symposium on Nonlinearity and Chaos in Engineering Dynamics*, London, 1993 (eds. J.M.T. Thompson & S.R. Bishop, Wiley, Chichester, 1994, 317–328).
99. J.M.T. Thompson & F.A. McRobie, Indeterminate bifurcations and the global dynamics of driven oscillators, 1st European *Nonlinear Oscillations* Conference, Hamburg, 1993 (eds. E. Kreuzer et al., Akademie Verlag, Berlin, 1993, 107–128).
100. J.M.T. Thompson, H.B. Stewart & Y. Ueda, Safe, explosive and dangerous bifurcations in dissipative dynamical systems, *Phys. Rev. E*, **49**, 1019–1027 (1994).
101. H.B. Stewart, J.M.T. Thompson, Y. Ueda & A.N. Lansbury, Optimal escape from potential wells: patterns of regular and chaotic bifurcation, *Physica D*, **85**, 259–295 (1995).
102. T. Mitsui, Y. Ueda & J.M.T. Thompson, Straddle-orbit location of a chaotic saddle in a high-dimensional realization of R^∞, *Proc. R. Soc. London A*, **445**, 669–677 (1994).
103. E. Infeld, T. Lenkowska & J.M.T. Thompson, Erosion of the basin of stability of a floating body as caused by dam breaking, *Phys. Fluids A*, **5**, 2315–2316 (1993).
104. A.G. MacMaster & J.M.T. Thompson, Wave tank testing and the capsizability of hulls, *Proc. R. Soc. London A*, **446**, 217–232 (1994).
105. F.A. McRobie & J.M.T. Thompson, Braids and knots in driven oscillators, *Int. J. Bifn Chaos*, **3**, 1343–1361 (1993).
106. E. Infeld, T. Lenkowska & J.M.T. Thompson, On the interaction of solitons with floating bodies, *Nonlinear World*, **1**, 65–71 (1994).
107. F.A. McRobie & J.M.T. Thompson, Knot-types and bifurcation sequences of homoclinic and transient orbits of a single-degree-of-freedom driven oscillator, *Dyn. Stab. Syst.*, **9**, 223–251 (1994).
108. E. Infeld & J.M.T. Thompson, Vibrational coupling in floating bodies, *J. Tech. Phy.*, **36**, 49–59 (1995).
109. J.M.T. Thompson & A.R. Champneys, From helix to localized writhing in the torsional post-buckling of elastic rods, *Proc. R. Soc. London A*, **452**, 117–138 (1996).
110. M.S. Soliman & J.M.T. Thompson, Indeterminate bifurcational phenomena in hardening systems, *Proc. R. Soc. London A*, **452**, 487–494 (1996).
111. J.M.T. Thompson, Global dynamics of driven oscillators: fractal basins and indeterminate bifurcations, in *Nonlinear Mathematics and its Applications, Chapter 1* (ed. P.J. Aston), Cambridge University Press, Cambridge, 1996, 1–47.
112. A.R. Champneys & J.M.T. Thompson, A multiplicity of localized buckling modes for twisted rod equations, *Proc. R. Soc. London A*, **452**, 2467–2491 (1996).
113. J.M.T. Thompson & J.R. de Souza, Suppression of escape by resonant modal interactions: in shell vibration and heave-roll capsize, *Proc. R. Soc. London A*, **452**, 2527–2550 (1996).
114. J.M.T. Thompson, Danger of unpredictable failure due to indeterminate bifurcation, *ZAMM*, **S4**, 199–202 (1996).
115. G. Baker, F.A. McRobie & J.M.T. Thompson, Implications of chaos theory for engineering science, *Proc. Inst. Mech. Eng.*, C **211**, 349–363 (1997).

116. A.R. Champneys, G.W. Hunt & J.M.T. Thompson, Localization and solitary waves in solid mechanics, *Phil. Trans. R. Soc. London A*, **355**, 2077–2081 (1997).
117. A.R. Champneys, G.H.M. van der Heijden & J.M.T. Thompson, Spatially complex localization after one-twist-per-wave equilibria in twisted circular rods with initial curvature, *Phil. Trans. R. Soc. London A*, **355**, 2151–2174 (1997).
118. J.M.T. Thompson, Designing against capsize in beam seas: recent advances and new insights, *Appl. Mech. Rev.*, **50**, 307–325 (1997).
119. G.H.M. van der Heijden & J.M.T. Thompson, Lock-on to tape-like behaviour in the torsional buckling of anisotropic rods, *Physica D*, **112**, 201–224 (1998).
120. J.M.T. Thompson & G.H.M. van der Heijden, Homoclinic orbits, spatial chaos and localized buckling, *IUTAM Symposium on, New Applications of Nonlinear and Chaotic Dynamics in Mechanics*, Cornell, 1997 (ed. F.C. Moon, Kluwer, Dordrecht, 1999, 127–138).
121. A.A. Popov, J.M.T. Thompson & F.A. McRobie, Low dimensional models of shell vibrations: parametrically excited vibrations of cylindrical shells, *J. Sound Vib.*, **209**, 163–186 (1998).
122. G.H.M. van der Heijden, A.R. Champneys & J.M.T. Thompson, The spatial complexity of localized buckling in rods with non-circular cross-section, *SIAM J. Appl. Math.*, **59**, 198–221 (1999).
123. S. Foale, J.M.T. Thompson & F.A. McRobie, Numerical dimension-reduction methods for nonlinear shell vibrations, *J. Sound Vib.*, **215**, 527–545 (1998).
124. G.H.M. van der Heijden & J.M.T. Thompson, Helical and localised buckling in twisted rods: A unified analysis of the symmetric case, *Nonlinear Dyn.*, **21**, 71–99 (2000).
125. J.M.T. Thompson, G.H.M. van der Heijden & A.R. Champneys, Twisting, writhing and buckling of pipelines, *Offshore Pipeline Technology Conference*, Oslo, 1998 (IBC UK Conferences, London, 1998).
126. A.A. Popov, J.M.T. Thompson & J.G.A. Croll, Bifurcation analyses in the parametrically excited vibrations of cylindrical panels, *Nonlinear Dyn.*, **17**, 205–225 (1998).
127. F.B.J. Macmillen & J.M.T. Thompson, Bifurcation analysis in the flight dynamics design process? A view from the aircraft industry, *Phil. Trans. R. Soc. London A*, **356**, 2321–2333 (1998).
128. G.H.M. van der Heijden, A.R. Champneys & J.M.T. Thompson, Spatially complex localisation in twisted elastic rods constrained to lie in the plane, *J. Mech. Phys. Solids*, **47**, 59–79 (1999).
129. C.R. Laing, F.A. McRobie & J.M.T. Thompson, The post-processed Galerkin method applied to non-linear shell vibrations, *Dyn. Stab. Syst.*, **14**, 163–181 (1999).
130. F.A. McRobie, A.A. Popov & J.M.T. Thompson, Auto-parametric resonance in cylindrical shells using geometric averaging, *J. Sound Vib.*, **227**, 65–84 (1999).
131. J.M.T. Thompson, *Philosophical Transactions* into the 21st century: An editorial, *Phil. Trans. R. Soc. London A*, **357**, 3187–3195 (1999).
132. N. Morgan & J.M.T. Thompson, Engineering and the physical sciences: The EPSRC takes an informal look into the future, *Phil. Trans. R. Soc. London A*, **357**, 3205–3220 (1999).
133. K.J. Spyrou & J.M.T. Thompson, Damping coefficients for extreme rolling and capsize: an analytical approach, *J. Ship Res.*, **44**, 1–13 (2000).
134. K.J. Spyrou & J.M.T. Thompson, The nonlinear dynamics of ship motions: a field overview and some recent developments, *Phil. Trans. R. Soc. London A*, **358**, 1735–1760 (2000).
135. A.A. Popov, J.M.T. Thompson & F.A. McRobie, Chaotic energy exchange through auto-parametric resonance in cylindrical shells, *J. Sound Vib.*, **248**, 395–411 (2001).
136. J.M.T. Thompson, G.H.M. van der Heijden & S. Neukirch, Supercoiling of DNA plasmids: mechanics of the generalized ply, *Proc. R. Soc. London A*, **458**, 959–985 (2002).

137. S. Neukirch, G.H.M. van der Heijden & J.M.T. Thompson, Writhing instabilities of twisted rods: from infinite to finite length, *J. Mech. Phys. Solids*, **50**, 1175–1191 (2002).
138. G.H.M. van der Heijden, A.R. Champneys & J.M.T. Thompson, Spatially complex localisation in twisted elastic rods constrained to a cylinder, *Int. J. Solids Struct.*, **39**, 1863–1883 (2002).
139. J.M.T. Thompson, Supercoiling of DNA molecules, in *New Approaches to Structural Mechanics, Shells and Biological Structures* (ed. H.R. Drew & S. Pellegrino), Kluwer, Netherlands 2002, 513–524.
140. G.H.M. van der Heijden & J.M.T. Thompson, The chaotic instability of a slowly spinning asymmetric top, *Math. Comput. Modelling*, **36**, 359–369 (2002).
141. J.M.T. Thompson, Research frontiers in the physical sciences, *Phil. Trans. R. Soc. London A*, **360**, 2651–2669 (2002).
142. G.H.M. van der Heijden, J.M.T. Thompson & S. Neukirch, A variational approach to loaded ply structures, *J. Vib. Control*, **9**, 175–185 (2003).
143. G.H.M. van der Heijden, S. Neukirch, V.G.A. Goss & J.M.T. Thompson, Instability and self-contact phenomena in the writhing of clamped rods, *Int. J. Mech. Sci.*, **45**, 161–196 (2003).
144. J.M.T. Thompson & G.H.M. van der Heijden, Patterns of bifurcation suppressing escape at internal resonance, *IUTAM Symposium on Chaotic Dynamics and Control of Systems and Processes in Mechanics*, Rome, June 2003. Proceedings, (eds. G. Rega & F. Vestroni) pp. 69–78, Springer, Netherlands (2005).
145. A.A. Travers & J.M.T. Thompson, An introduction to the mechanics of DNA, *Phil. Trans. R. Soc. London A*, **362**, 1265–1279 (2004).
146. J.M.T. Thompson, Duffing Equation, article in *Encyclopedia of Nonlinear Science* (ed. Alwyn Scott), Routledge, New York, 2005.
147. J.M.T. Thompson, Stability, article in *Encyclopedia of Nonlinear Science* (ed. Alwyn Scott), Routledge, New York, 2005.
148. V.G.A. Goss, G.H.M. van der Heijden, J.M.T. Thompson & S. Neukirch, Experiments on snap buckling, hysteresis and loop formation in twisted rods, *Experimental Mechanics*, **45**, 101–111 (2005).
149. J.M.T. Thompson & C.H.T. Wang, Future perspectives in astronomy and the earth sciences, *Phil. Trans. R. Soc. London A*, **363**, 2665–2673 (2005).

(d) Public Understanding of Science: Lectures, DVDs and Websites

[1] Personal Website of J.M.T. Thompson. Address: www.homepages.ucl.ac.uk/∼ucess21/.
[2] Introduction to Chaos and Nonlinear Dynamics. Website of T. Kanamaru & J.M.T. Thompson. Address: http://brain.cc.kogakuin.ac.jp/∼kanamaru/Chaos/e/Thompson/.
[3] Website maintained by the Science Media Network in association with Cambridge University Science Production. Address www.culive.org/MichaelThompson.
[4] Chaos and Fractals: Understanding the Unpredictable by J.M.T. Thompson. Lecture in the *Millennium Maths Project* for public understanding of mathematics (Centre for Mathematical Sciences, Cambridge, 22 Jan. 2004). Power-points can be viewed as a slide show on [2]. A video can be viewed on-line from [3]. A DVD is available from *Millennium Maths Project*, DAMTP, Cambridge, CB3 0WA.
[5] Chaos Theory: The Historical Emergence of a New Branch of Mathematics by J.M.T. Thompson. Lecture at the 40th Anniversary Conference of the Institute of Mathematics and its Applications

(Manchester, 2 Sept., 2004). At this meeting the lecturer was awarded the IMA Gold Medal for lifetime contributions to mathematics. Power-points can be viewed as a slide show on [2].

[6] Instabilities and Catastrophes by J.M.T. Thompson. Lecture in the *Millennium Maths Project* for public understanding of mathematics (Centre for Mathematical Sciences, Cambridge, 11 Nov. 2004). Power-points can be viewed as a slide show on [2]. A video can be viewed on-line from [3]. A DVD is available from *Millennium Maths Project*, DAMTP, Cambridge, CB3 0WA.

[7] Predicting the Unpredictable: Seeing Order Within Chaos by J.M.T. Thompson. Plenary lecture, International Science Summer School (Cambridge University, 29 July 2005).