Michael Thompson: some personal recollections

Giles Hunt¹ and Lawrence Virgin²

¹Centre for Nonlinear Mechanics, University of Bath, Bath BA2 7AY, UK
²Department of Mechanical Engineering, Duke University, Durham, NC 27708-300, USA

For each of us, it is a great pleasure to come together in this tribute to Michael Thompson’s remarkable contributions to nonlinear statics and dynamics over the best part of half a century. Although having been friends and colleagues for many years, we have never written anything together, so it is entirely fitting that this should be happening for the first time in this piece. Each of us had Michael as an inspirational research supervisor over a different period in his research career: between us we must span, as close colleagues and collaborators, most of his lifetime of research.

Mentoring is of course a hot topic these days, but as we hope to demonstrate in this piece, Michael is a natural mentor. And when it works, the mentor–mentee relationship extends over a considerably longer period than the initial duration of the PhD.

We have both read with great interest and some nostalgia Michael’s article in this Theme Issue, giving advice to up-and-coming young researchers [1]. What we each can testify from personal experience is the absolute importance of choosing the right supervisor or advisor. One enters the business without knowing much about the world of research, and it is an enormous leap into the unknown to pick a problem and start working on it. How important is it then to have best guidance? As with many other things in life timing in research is crucial, and especially at the beginning it is critical to be in the right place at the right time, as ideas start to germinate and collaborations develop. Michael Thompson’s expertise and experience is the absolute reason for this Theme Issue, and is reflected in his contribution to it. We have an addendum: there is nothing like finding the right supervisor at the right time, as each of us separately will be describing below.

But let us begin with the man himself. Figure 1 shows a rather grainy and out-of-focus photograph, taken perhaps in 1975 or thereabouts (nice shirt). We
Figure 1. Michael, ca 1975.

particularly like this one not just for the bright-eyed enthusiasm it conveys, but for the models in the background that we both remember well as early physical demonstrations of stability phenomena. Behind Michael, we can just see the load hanger, for instance, for a simple truss buckling experiment. These models set the scene for much of what we have both learned from Michael: find some interesting (almost undoubtedly nonlinear) phenomenon, and tease it apart in whatever manner possible—diagrammatically, experimentally, numerically or otherwise—to reveal what often turns out to be an underlying simplicity.

We will each be demonstrating this in our own way, according to our separate experiences. For one of us (G.W.H.), this happened during Michael’s supervision of my undergraduate project [2]. I first came across him in 1966 in the final year of my BSc in civil engineering at University College London (UCL), when he taught an optional course on structural mechanics. I was immediately taken by what I heard, and my subsequent choice of Michael as project supervisor turned out to be a life-changing event. The project catapulted me as a naive undergraduate to the sharp end of what was understood in mechanics at the time—to the edge of chaos so to speak.

The project comprised releasing a ball from various positions on a double-welled potential surface shown in figures 2 and 3, and observing whether it escaped into the other well or not. We mapped releases from different positions in both potential wells, looking in particular for the stability boundary that marked the edge of the escape region. Releases were filmed from a fixed position directly above the surface, so the path of the ball could be tracked. Different regions—particularly on one of the wells—gave rise to significantly different modes of escape, and we did our best to distinguish between them by marking their edges on the surface. In certain areas, we found that there seemed to be no standard modes of escape: the ball would respond periodically or nearly so over some undetermined number of cycles, before suddenly breaking the sequence and escaping; we painted these areas grey on the surface and called them zones of indeterminacy. In the present age, we would probably think of them as regions leading to chaotic transient responses.

Figure 4 shows a couple of pages from the project report [2], suitably yellowing with age. Under Michael’s farsighted direction, it appears now that we were feeling our way towards an experimental study of chaos. The left-hand diagram focuses on bifurcation or divergence of dynamical responses in the presence of saddle points, whereas that on the right demonstrates the underlying inherent unpredictably in such circumstances. This work was conducted some years before chaos became a buzz word in the scientific community, but it seems now that its underlying characteristics were somehow part of Michael’s unconscious thought processes even
Figure 2. Rolling-ball analogy to escape from a potential well, from an undergraduate project in 1967 [2]. A superball is released from various positions on the surface, and the boundary between points of release with the ball staying in the first well, or escaping into the other, is marked on the surface. Responses from one well turned out to be highly predictable, whereas the other demonstrated an increasingly complex sequence of dynamical modes of escape.

Figure 3. A different perspective of the surface of figure 2.

Figure 4. (a) Bifurcation of releases from a ‘point’ on the edge of stability boundary; one release escapes, whereas the other does not. (b) Zones of indeterminacy suggesting chaotic transients from releases within these zones.
back then. After such an initiation, how could I not want to go on to a PhD? My problem was that, having spent some time on extracurricular activities—it was the 1960s—I was not expecting a good enough degree result to obtain a postgraduate grant. I signed up for an MSc at Imperial College as a potentially different means of getting into research. As it turned out, having found my direction in life all fell naturally into place, and I eventually obtained a good enough result in my finals anyway. I hurried back to UCL as quickly as I could and started a PhD under Michael’s direction.

In retrospect, the very nature of this undergraduate project, conducted over the academic year 1966–1967, contained many of the characteristics that have later gone on to define Michael’s unique contributions to the world of mechanics. It embraced both statics and dynamics, for instance, and was inherently nonlinear and generic: the shapes were deliberately skewed with respect to the box they were sitting in, for example, to avoid imposing effects that might arise from symmetry. The importance of dynamical bifurcation was highlighted, as was sensitivity to initial conditions—all characteristics that in later years came to take on increasing significance as the world of nonlinear dynamics embraced concepts of chaos. It is perhaps no coincidence that Michael’s most cited paper also deals with escape from an asymmetric potential well [3].

Since then, I have had the good fortune to engage with Michael in many ways over the years, both socially and intellectually. I do not want to bore the reader with anything like a full account of either, but would like to mention our two books together. The first came a year or two after I completed my PhD, and although a lot of work from my thesis appeared in it, it was in essence a greatly expanded version of an earlier extended article by Michael [4]. Nevertheless, *A general theory of elastic stability* [5] turned out to be a thoroughly timely publication and, although we stood at different points in our respective careers, in separate ways it cemented each of our reputations. I am sure, for instance, that it helped me in securing funding for eight great postdoctoral years, working directly with Michael on nonlinear statics and buckling, and eventually embracing the mathematical discipline of catastrophe theory.

The culmination of these years was our second book, *Elastic instability phenomena* [6], which appeared some 11 years after the first. By this time it was noticeable that Michael was moving towards nonlinear dynamics, in that alongside this effort he had also published separately *Instabilities and catastrophes in science and engineering* [7]. At about the same time we held the ‘Collapse’ symposium at UCL [8], where Potier-Ferry’s pioneering work on localization was presented. Having left UCL and started a lectureship at Imperial College, I thought I would stick to nonlinear statics and leave the dynamics to Michael. I focused on localization issues in statics, but could not escape the net. Two apparently disparate areas of mechanics suddenly converged as we started to use a ‘time like’ portrayal of space in a *dynamical phase-space analogy*—we were back again in collaboration [9]. This was also about the time that Lawrence entered the frame, as I am sure he will mention later. By then, having started the Centre for Nonlinear Dynamics at UCL, Michael was well on his way through writing his most successful book, *Nonlinear dynamics and chaos*, with Bruce Stewart [10].

Before passing over to Lawrence, I should mention the considerable legacy that Michael has left with me, and I suspect many others during the course of his half century of activity. I continue to work on localization and related issues, both with Michael [11] and a number of others. The concept of an energy landscape and the parallel description of the natural world expressed via differential equations—the complementary viewpoints of Lagrange/Hamilton and Newton—were introduced to me during my undergraduate project and remain central to my work today. This should be immediately apparent from my contribution, in close collaboration with two members of the next generation of research workers in mechanics, to this Theme Issue [12]. I fully anticipate that Lawrence will echo these sentiments as I now hand over to him.

My transition to postgraduate life under Michael’s direction was quite different from Giles’s (my academic sibling), but certain aspects of his account certainly resonate. Of course, we have had plenty of time to compare notes over the years, sometimes over a pint at the local pub as well as between sets on the tennis court (when neither of us was ‘carrying’ Michael as a tennis partner). In 1982, I already had a masters degree and was spending a year at the University of
Illinois on an exchange scholarship when I started to think about my next move. I was trained in structural engineering, with a focus on buckling, but it was clear that many of the fundamental avenues in this area were relatively well understood. This did not appear to be the case in (nonlinear) dynamics. Some of my friends were getting involved with finite element analysis, but this kind of large-scale computation held limited appeal to me. In Michael’s essay, he mentions the satisfaction he gained from writing books, and there is no question that reading his lucid accounts of instability phenomena sparked my interest. How could it not be rewarding to work with someone whose natural enthusiasm and deep understanding of nonlinear behaviour leapt from every page? I was especially impressed with the range of his interdisciplinary scope and his enthusiastic style and creative figures and diagrams (more of this a little later). Combining the prospect of working under his direction, at an appealing institution (UCL) ‘the godless university on Gower Street!’ back in London became my goal, and thanks to an SRC postgraduate scholarship, I embarked on a more serious research trajectory.

At this time (the early 1980s), Michael’s research interests were shifting from elastic instability and buckling (for which his contributions had been profound) towards the exciting new discoveries in nonlinear dynamics and chaos. It was difficult not to be inspired by his sheer enthusiasm. I read with interest his advice to young researchers included in this Theme Issue. Some of it even rang true! In thinking about the process of passing on the academic baton (and of course I have now been the supervisor to many PhD students since my time with Michael), I thought it might be interesting to relate a couple of ways in which Michael’s vicarious reach has extended to the present.

One of my early projects with Michael involved Kirchoff’s analogy. That is, the equations describing the classical elastica and the simple pendulum are essentially the same. We did some numerical simulations to show some spatial chaotic looping [13], and it strikes me that this in some ways also works as a metaphor in describing the transition in Michael’s primary focus from elastic stability to dynamics. Giles was also involved in this transition as described earlier. I found Michael’s ability to visualize behaviour in three dimensions with beautifully rendered Indian-ink figures inspirational. When trying to examine the instability of a nonlinear oscillator in terms of various parameters Michael suggested I actually try to build a three-dimensional model. Figure 5a shows a photograph of a couple of models built by routing certain shapes at regular sections and then placing them in a sequence to create a three-dimensional response diagram.

Fast forward nearly 30 years. Last year our department acquired a three-dimension printer. In this system, layers of plastic are deposited according to a digital file, and a typical result is shown in figure 5b and this can be compared directly with the left-hand model in figure 5a. I also produced the elementary catastrophe models in figure 5c, and these nicely mirror a similar three-dimensional model that Giles and Michael had worked on (without the benefit of a three-dimension printer, but with considerable artistic ability) some 40 years earlier. The benefit of a three-dimensional rendition is self-evident.

Another perspective inspired by Michael’s keen visual sense also relates to the rolling ball experiment that Giles described earlier. I think I recall seeing that model stacked at the back
of a storage space in the structural engineering laboratory at UCL when I was a postgraduate student. Fast forward again. A few years ago, I decided to build a smooth curved surface, mainly inspired by an experiment built to mimic the (two-dimensional) twin-well Duffing model [14], but perhaps subconsciously by Giles and Michael’s model. Again, benefiting from rapid advances in technology, I used a computer numerical control milling machine to produce, from a solid block of Lexan, the precisely controlled shape shown in figure 6a. This surface consists of four minima or 'wells', four saddles and a hilltop at the centre. It is not quite symmetric, but given a small ball (a rubber-coated ball bearing—interestingly the key part of a now old-fashioned computer mouse, but an unimagined device in the days Giles referred to earlier) that rolls under the action of gravity it is relatively easy to view this system as a potential energy surface with a four-dimensional phase space ($x$ position, $y$ position and their associated velocities). Figure 6b shows a comparison between experimental data (acquired using a high-speed digital camera mounted about the surface—see figure 6a) and the output from a numerical simulation [15]. For these specific trajectories, the motion starts from close to an edge, rolls into a couple of the adjacent wells before energy dissipation causes the motion to come to rest at a position of stable equilibrium in the bottom of one of the wells. If we repeat this for many initial positions, we obtain figure 6c. Here, the colours correspond to which well the ball will end up in given a certain initial position. It should be borne in mind of course that we have assumed the ball starts from rest, and thus the two initial velocities are both zero. This figure is based on numerical simulation but experimental results give essentially the same picture (without quite the perfect symmetry!) and necessarily fewer data points to characterize the domains. Not surprisingly motion initiated close to a position of equilibrium remains within the confines of the local well but around the outer perimeter one can see other

**Figure 6.** A ball rolling on a curved surface. (a) The machined surface and camera mounted on a shake table, (b) a comparison of individual (unforced) trajectories from experiment (dashed red line) and simulation (continuous blue line), (c) numerically generated basins of initial position for the unforced system, (d) a Scotch-yoke (harmonic) mechanism and (e) initially adjacent experimental chaotic trajectories for the harmonically shaken system.
colours, and these are the regions in which a trajectory has some trouble ‘deciding’ where it will eventually end up. That is, there are regions in which all four different colours are appearing close together. This is essentially the same study that Giles and Michael conducted all those years ago.

However, in the intervening years, the study of chaos has reached full maturity, and my primary focus in this study was to illustrate what happens when the surface is shaken harmonically. Placing the surface (and camera) on a shake table and applying a sinusoidal horizontal base excitation (figure 6d) causes the small ball to exhibit persistent oscillatory behaviour. This, of course, increases the dimension of the phase space to five dimensions, with the initial forcing phase providing another initial condition. But the forcing frequency and amplitude are new parameters that can be easily controlled and varied, and a truly rich variety of dynamic behaviour is exhibited, including chaos. Figure 6e shows a superposition of chaotic trajectories from experimental data given nominally the same starting condition (at rest in the bottom of one of the wells). Further characterization reveals a broadband power spectrum and a positive Lyapunov exponent, a confirmation that this system can exhibit an extreme sensitivity to initial conditions [15]. The unforced problem certainly gives a hint to a dependence on initial conditions, but it is the forced problem (in which the input of energy somewhat cancels the effect of energy dissipation) that is properly classified as persistent, bounded chaos.

I suppose it is not too fanciful to imagine that at different times, prior to starting to work with Michael, Giles and I had been poised at a kind of starting point, perhaps close to a boundary of diverging trajectories in our future directions. It is not possible to run life forwards along different tracks of course (the movie Sliding Doors notwithstanding), but I think Giles would agree that our subsequent research careers would not have been as well founded or enjoyable if we had ended up in a different research or supervisor ‘well’.

I have conducted many experimental studies on nonlinear dynamical systems over the years, and although Michael is primarily a theoretician, I am sure his quest for solid physical understanding has been passed on to me. Just like my earlier examples about the three-dimensional shapes, it is also interesting to again witness the march of technology in the rolling ball experiment—the high-speed digital camera used to track a target, machining a precise equation-defined surface, and plotting the data in vivid colour are all facets not available a few decades ago.

Finally, reiterating the importance of having a natural enthusiasm for research, I recall once meeting with Michael on a Friday afternoon. I had produced an interesting but slightly puzzling picture of a Poincaré section related to the rolling motion of a ship in regular seas just prior to capsizing. We concluded that rather than extracting a stroboscopic sampling of the trajectory at intervals of the forcing period, I had been off by a single time step at each section. It is amusing to think that we often used 40 time steps per cycle, because in those days computers were not especially fast. Anyway, this had the effect of producing an interesting (but incorrect) projection, and Michael finished by saying that correcting this would be a useful way to spend the weekend. First thing Tuesday morning (as I recall, he tended to work from home about half the time), I stopped by his office to show him my revised plot. Before I had the chance to show him though, he slapped down his admittedly much more impressive version with a big grin on his face (like his grin after a rarely successful sneaky drop shot in tennis). I suppose he could not resist the temptation, and of course he had taken things an artistic step further and used my little error to illustrate the evolving stretching and folding of the chaotic attractor. Well, that kind of enthusiasm (and extreme intelligence goes without saying) is what has sustained Michael over such an impressive research career. Nearly 30 years later, I still try to follow the path of curiosity-driven research.

We close this reflective piece with a brief tribute to Henry Chilver, Michael’s supervisor, who sadly has just recently died. Many years ago, in his final year of undergraduate study and burdened by his lack of prospects, one of us (G.W.H.) plucked up the courage to make an appointment to see his then Head of Department with the outlandish suggestion of a possible career in research. It was Henry who suggested an MSc at Imperial College might be a possible
route forward, and to his great credit encouraged me with the words, ‘It’s not always the ones who get the top firsts who are good at research you know’. This brief but insightful comment has lived in my memory ever since, and we think it reflects much of the spirit of Michael’s advice to young researchers given in this Theme Issue [1]. It so happens that Michael did get the top first for his year at Cambridge as an undergraduate, but we would not hold that against him.

Let it finally be said that we take great pride in the genealogy of our research supervision. We were both supervised by Michael, himself the student of Henry Chilver, who got his PhD from the University of Bristol under the supervision of Alfred Pugsley (1903–1998), the father of structural safety to engineering in the UK over most of the last century. We feel that this is a worthy legacy to pass on to our own clutch of research students, past and present.

References