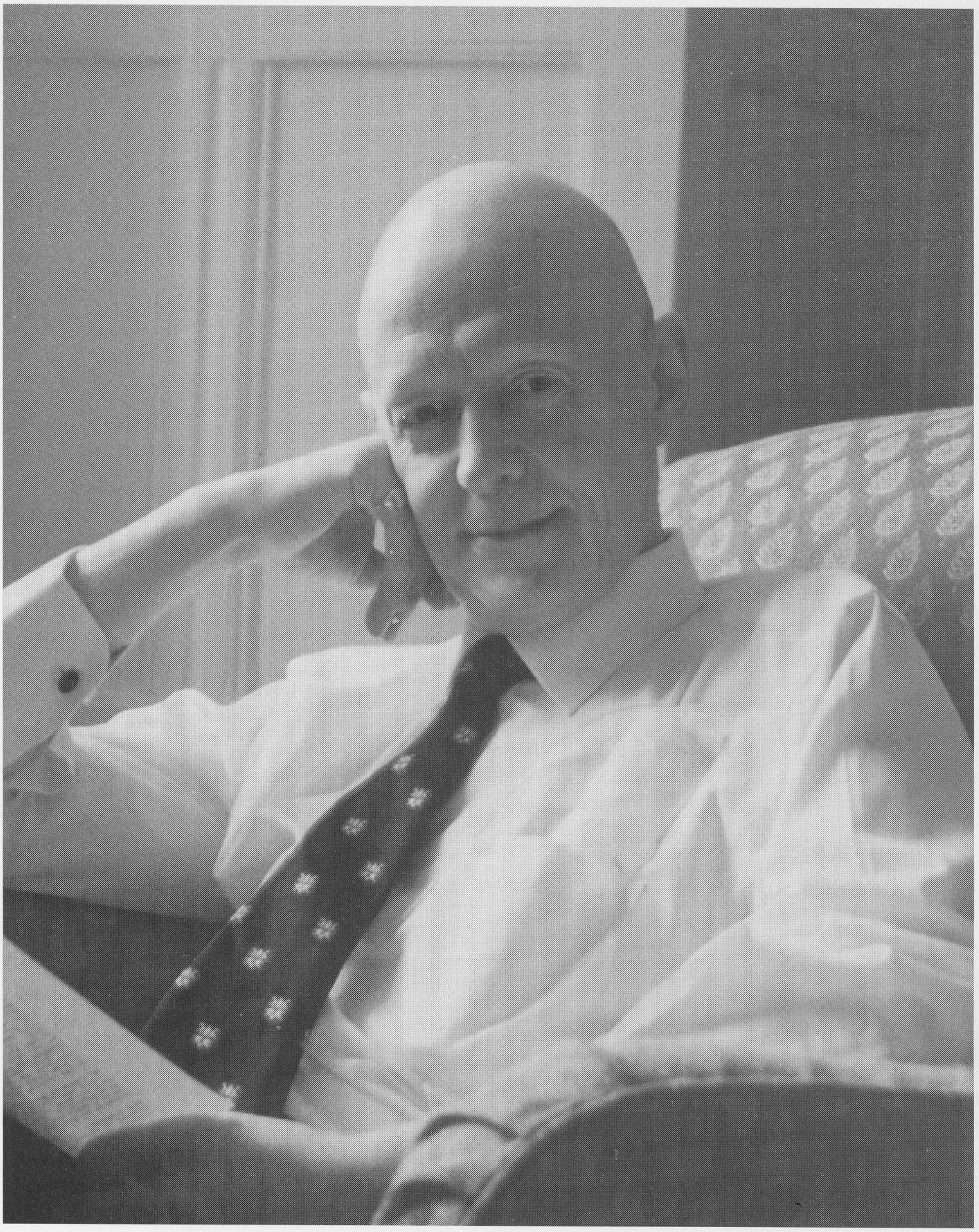
DAVID GEORGE CRIGHTON

15 November 1942 — 12 April 2000

Biog. Mems Fell. R. Soc. Lond. **47**, 105–123 (2001)



DAVID GEORGE CRIGHTON

15 November 1942 — 12 April 2000

Elected F.R.S. 1993

By Herbert E. Huppert[1,2], F.R.S., and Nigel Peake[2]

[1] *Institute of Theoretical Geophysics, Silver Street, Cambridge CB3 9EW, UK*
[2] *Department of Applied Mathematics and Theoretical Physics, Silver Street, Cambridge CB3 9EW, UK*

For the last decade of his life, David Crighton was the undisputed leader of the applied mathematics community in Britain. He made penetrating research contributions to the subject of aeroacoustics, which involves the emission and control of aircraft and engine noise, to our understanding of the propagation and evolution of linear and nonlinear waves and to the excitation of structural vibrations. He was a widely respected scientific administrator, working imaginatively as the chairman or president of many national and international committees. He was the enlightened editor of prestigious international journals and founded a series of texts in applied mathematics. At the time of his death from cancer at the tragically early age of 57, he was in addition filling with distinction the roles of a visionary department head and a much loved Master of Jesus College, Cambridge.

Despite these heavy administrative burdens and his research schedule, David exuded warmth, gregariousness and a selfless interest in the careers of others. He seemed to have unlimited amounts of time to help and motivate his colleagues. He also found time to run regularly and to develop his prodigious knowledge of music, particularly the works of Wagner, on whose operas he was an international authority.

Early life

David George Crighton was born on 15 November 1942 in Llandudno, North Wales. His father, George (1899–1976), who in 1939 married David's mother, Violet (b. 1912), was a civil servant who worked in the Stamp Duty Department at Somerset House. The whole department was evacuated to Llandudno early in the war. At some time after David's birth, the department returned to London and the family moved to a flat in the vicarage of the Church of St Lawrence in Abbots Langley, Hertfordshire, where David's sister, Frances, was born in 1945. A classmate of David's at the village primary school remembers that after the first few weeks he was already known by all to be a very gifted boy with a lively and enquiring mind that enjoyed soaking up knowledge. While at the vicarage, David's interest in music was aroused as a choirboy in the local church, just 100 yards away, where his father was a churchwarden. In 1953 the Crighton family moved about a mile to a council house in Bedmond, where David's mother still lives. Excelling in his 11+ exam, David became a pupil at Watford Boys Grammar School from 1953 to 1961, where he not only shone academically but also displayed considerable sporting and leadership abilities. For his O-levels, taken when he was 15, he studied modern languages (and could speak French, German and Italian fluently in later life), classics (his favourite at that time) and science. It is a well-known story that the headmaster, Harry Rée (subsequently Foundation Professor of Education at York University), once remarked, 'David, you will be a success at absolutely anything except mathematics'. In response, David concentrated for his A levels on the 'forbidden subject'. In his typically modest way, David occasionally mused in later life that he thought Rée might have been correct! While at school, David displayed a passion for long-distance cycling and would regularly undertake solo journeys of over a hundred miles a day. He had been introduced by an uncle to the pleasure of being able to identify different types of aircraft and in pursuit of this interest would often cycle to advertised air shows. He also developed an interest in running to keep fit and played rugby for the school, for which he was appointed as captain of the first XV. A school friend said that David differed from all their chums in that, as each interest came along, he added it to his repertoire rather than substituting it—in contrast to the style of the other boys. In addition to this, David undertook a number of physically taxing holiday jobs. His first employment was as a mortuary porter at the former Leavesden Mental Hospital and he worked a couple of times during the Christmas vacations for the Post Office.

Undergraduate years, 1961–64

David came up to St John's College, Cambridge, in 1961 to read mathematics. From the start, he was ambitious, well organized and a hard worker, who achieved a First in both Parts I and II of the Mathematical Tripos. He was inspired by lectures on fluid mechanics given by George Batchelor, F.R.S., who had an enormous influence on David's subsequent career. In addition, he enjoyed life, often going to the pub and playing darts or bar billiards with his friends after a long day's work. He had distinctive long jet-black hair and a reputation for wearing the longest sharp-toed winkle-picker shoes in Cambridge. He continued to cycle, often cycling to and from Watford at the beginning and end of terms. He was cycling with an undergraduate friend, Peter Lapwood, in early December 1962, when Peter was killed by a car near Babraham, Cambridgeshire. This tragic accident marred the rest of David's undergraduate time in Cambridge and was partly responsible for his surprising decision not to go on to do Part III mathematics and research. The decision was also motivated by David's belief, reflecting his early upbringing, that having grown up, it was time for him to get a proper job.

WOOLWICH POLYTECHNIC, LONDON, 1964–66

David was appointed, aged 21, as a lecturer at Woolwich Polytechnic, now the University of Greenwich, to teach a wide range of courses in physics and mathematics, for up to 24 hours per week at times. He was rapidly promoted to be a senior lecturer because he was one of few on the staff who could deliver more advanced courses such as quantum mechanics. While at Woolwich, David learnt to control large classes of rather uninterested students. He used to recall that occasionally some of the tougher elements of the class, seated near the front and clad in traditional leather and studs, would pull out large knives and fastidiously inspect the blades for their sharpness. David himself was typically decked out in leather at this time and rode around London on a motor scooter. After two years he saw that his talents could not be suitably developed at Woolwich and he sought to attempt research.

IMPERIAL COLLEGE, LONDON, 1966–74

Almost by chance, as a result of an off-hand remark by Professor R.S. Scorer, at Imperial College, David demanded (in a charming, sophisticated way of course) an interview with J.E. (Shon) Ffowcs Williams, who had recently returned from a postdoctoral position in the USA to a readership at Imperial College. David wanted to research into turbulence. Shon thought this would not be fruitful, but was willing to supervise work on fluid effects resulting from turbulent flows, such as the effect of bubbles on the noise transmitted through turbulently agitated water, a topic of considerable interest to the military.

David, who was already very knowledgeable about aviation, started work on his PhD in 1966 at a time when there was perhaps more intense interest in acoustics than during any period before or since, driven by crucial practical problems in two quite distinct fields. First, it was becoming clear that Concorde, then under development, would suffer severe noise problems owing to the high-speed jets exiting from the engines and owing to the sonic booms formed while cruising. M.J. (later Sir James) Lighthill, F.R.S., had developed in 1952 his famous theory of aerodynamic noise generation, but it was well known by 1966 that his prediction of acoustic intensity varying as the eighth power of flow speed needed to be significantly modified if it were to shed light on practical situations. Secondly, the problem of noise generation by submarines underwater was at the fore. Although many of the questions being addressed were similar to those being considered in aeroacoustics, the significant loading of an underwater structure by the surrounding water (so-called 'fluid loading') meant that the elastic properties of surfaces had to be included. The exceedingly broad range of issues associated with these two areas (the first later developing into studies of noise from the engines of more conventional subsonic aircraft and propellers) really motivated David's research for the rest of his career. In a short time he became established as a leading authority on the mathematical modelling of unsteady wave phenomena, ranging in application right across the technological activities described above, and beyond.

David's second published paper (1)*, co-authored with Ffowcs Williams, was concerned with the sound generated by a turbulent air–water mixture, the topic suggested by Ffowcs Williams for David's PhD. Lighthill's approach of rewriting the governing fluid equations in

* Numbers in this form refer to the bibliography at the end of the text.

the form of a wave equation with source terms was repeated for the two-phase system, and led to the prediction that the sound from Lighthill's quadrupole sources (corresponding to the gradients of turbulent shear stresses within the fluid) would be overwhelmed by monopole sources arising from the volume fluctuations of the pulsating air bubbles. David quickly grasped the power of using Lighthill's approach in this manner, and a long series of important papers, including (2–9, 15, 17), followed this first one in short order. These reported a number of studies on the way in which neighbouring boundaries could enhance turbulent noise generation, further modifying Lighthill's predictions. For instance, the effects of plate elasticity were included (2), and the strong amplification provided by the presence of sharp edges was described (3, 4, 6). There were also further papers on the fluid loading problem (5, 7), which were to be characteristic of much of his later work in this area—namely the involvement of careful analysis and exact solution of the model equations, thorough asymptotic approximation of the results, and extensive interrogation and interpretation of the asymptotics to yield physical insight. One particular achievement (5) was a greatly improved description of the beaming of acoustic radiation by waves travelling supersonically in the surface.

Later, when at Leeds, he was to produce two definitive papers, one describing in full detail the structure of the sound field above a fluid-loaded elastic membrane (17), and another (15) describing the possible types of wave motion along an elastic plate (especially the so-called leaky modes, waves that propagate along a structure with decaying amplitude while radiating energy into the far field). David was awarded his PhD in 1969 with a dissertation entitled 'Wave motion and vibration induced by turbulent flow'. He then continued to work as a research assistant in the aeroacoustics group of Ffowcs Williams.

Jet noise was also a key concern of many acousticians during this period. One paper (8) that proved especially important was on so-called jet 'excess' noise, i.e. the excess between the noise predicted by Lighthill's theory and that actually measured for an installed engine in flight. The essential contribution here was to consider the interaction between instability waves on the jet shear layer and the jet nozzle, leading to fluctuations in the mass flux and thrust of the jet which, although weak, were sufficient to introduce important features not present in Lighthill's model predictions. These included enhanced noise in the forward arc, acoustic intensity proportional to the sixth (rather than the eighth) power of jet velocity and a quite different frequency spectrum, all of which had been observed in experiment but had not previously been predicted theoretically in such a unified and coherent way. Another issue that David considered, which was later developed and extended by several researchers, concerned the linear instability of a jet with an elliptical cross-section (9). In later years, while at Leeds, David wrote with M. Gaster (F.R.S. 1985) a very influential paper (12) on jet stability, the important feature being that the slow spreading of the jet downstream was accounted for by using WKB asymptotics, which are appropriate for studying gradually varying situations. In many ways this paper proved to be the major inspiration for the considerable body of work undertaken subsequently by many others on the stability of spatially inhomogeneous shear flows. In a similar vein to this work, David also described (30), jointly with P. Huerre, his then postdoctoral research associate in Leeds, a mechanism whereby a slowly modulated jet can produce strong, 'super-directive', acoustic beaming.

At Imperial College David enjoyed a very formative and fruitful interaction with Frank Leppington, then a young lecturer. Two of their joint papers have already been referenced above, but two others deserve special mention. The first (10) considered the scattering of acoustic waves by the edge of a plate of small, but non-zero, thickness on the wavelength scale. The basic idea was that close to the edge the unsteady flow was incompressible, whereas further away the acoustic field, although driven by this 'inner' interaction, behaved essentially like the diffracted field from a sharp edge. Crighton and Leppington (10) solved this problem by using the method of matched asymptotic expansions (MAE), which were brought to prominence in the book by van Dyke (1964). They included in this paper a small, but very significant, extension of van Dyke's matching rule, to describe how logarithmic terms had to be grouped with algebraic terms of the same asymptotic order. David did much to popularize the use of MAE in acoustics. Another paper in this vein, this time authored by David alone (6), proved very influential, and concerned the radiation produced by the motion of a point vortex round a sharp edge. The basic idea here parallels that in (10), with a local, hydrodynamic motion being matched onto an acoustic farfield, which renders the source region small on the wavelength scale.

The second paper by Crighton and Leppington that we wish to highlight specifically here (11) is concerned with the radiation produced by a vortex sheet attached to a rigid trailing edge (as a model of a jet shear layer), which is excited impulsively by a nearby sound source. To solve this problem, delicate mathematical issues associated with causality (a recurring theme in David's work, to which we shall return later) were addressed by using the Wiener–Hopf technique (there will be more on that later as well) with an ingeniously distorted inversion contour. It turns out that instability waves on the vortex sheet arise as a direct consequence of the need to enforce causality, and are directly coupled to the external excitation in a way that Crighton and Leppington were able to calculate explicitly. The resulting concept of the 'receptivity' of flows to such instabilities was something that David believed to be crucially important. Whereas many engineers at the time were concerned with the rather simpler notion of determining the free modes of a given acoustic system, he was much more interested in determining precisely how, with what amplitude and phase, such waves could be generated by external forcing. In many ways this paper was the forerunner of much continuing research activity in shear-layer receptivity.

In 1964, while attending the Wagner Festival in Bayreuth, David met Mary West, an accomplished pianist with a vibrant personality. They married in 1968 and had two much-loved children, a son Ben born in 1970, who works in the music industry, and a daughter Beth born in 1971, who is a schoolteacher. David and Mary continued to enjoy many shared musical events, particularly in Bayreuth, for several years after the children were born. With time, however, their interests diverged and they divorced in 1986.

During his years at Imperial College, David greatly enjoyed his research and life. He resisted approaches to join the lecturing staff at Imperial, or elsewhere, because he was ambitious and wished to devote himself entirely to research. But as time went by he became nervous of his continuing ability to be supported as a research assistant on research grants. However, Shon Ffowcs Williams reassured him, confident that David's tremendous talents and rapid development would soon allow him to take on the burden and responsibilities of a chair.

Leeds, 1974–86

The Electors to the Chair of Applied Mathematics at Leeds University, previously occupied by T.G. Cowling, F.R.S., invited David, then aged 31, for an interview. He charmed and greatly impressed them with his knowledge and potential. They decided to take the risk of appointing this young research assistant to the professorship. (Figure 1 was taken shortly after his arrival.) He had immediate impact. He totally transformed the department by revitalizing many who were already there and bolstering their confidence, and by vigorously recruiting many graduate students and postdoctoral fellows.

While at Leeds, David's dress style changed. He had his long hair cut and discarded the leather jackets in favour of suits (often pinstriped), white shirts, tie and black lace-up shoes. He occasionally indicated that he felt uncomfortable working without a tie on and is said never to have owned a pair of jeans or sandals, and wore T-shirts only while running or gardening. Nevertheless, he would sometimes enjoy wearing unconventional colours and was the proud owner of a bright green jacket that once earned him the Most Vulgar Jacket Prize at an American conference dinner.

In Leeds David's work on fluid loading continued apace, with, for example, a real *tour de force* on the resonant modes of finite structures (19). However, two pieces of his work in this area are so novel as to deserve further discussion. First, there was the problem of energy transmission along a membrane supported by an array of periodically spaced ribs. During his long association with the consultancy company Top Express, owned by his former PhD supervisor, Ffowcs Williams, David was closely involved with American and British naval studies that had shown that the surface-wave coupling between the ribs leads to the sort of pass-band/stop-band structure familiar in solid-state physics, with energy either being transmitted or decaying away from one driven rib depending on the oscillation frequency. David's crucial input was the observation that once the long-range coupling through the fluid is included, as it must be under conditions of heavy fluid loading, the stop-band decay is short-circuited and is replaced by a much slower algebraic decay. This means that the phenomenon of Anderson localization, in which the pass-bands are disrupted by inclusion of small random fluctuations in the rib locations, leading to exponential decay in response along the structure for all frequencies, does not occur in these fluid-loaded structures. David's first paper on this topic considered an infinite structure (18), but several other papers on finite structures followed (43–45).

The second investigation concerned the effects of a mean flow on the dynamics of an elastic plate under heavy fluid loading. It turned out that the mean flow introduces a number of exceedingly unusual features, and that the correct handling of the issue of causality is absolutely crucial to obtaining the correct solution describing these features. Most intriguingly to David, the requirement of causality led to the discovery of a mode with 'anomalous group velocity' (i.e. with group velocity directed towards the point where the wave is excited), contradicting the universally accepted, but as it turned out not universally applicable, radiation condition of outgoing group velocity.

David started his investigation of fluid loading with mean flow in the mid-1980s, with the definitive publication (33) being in 1991, with some intriguing details on the amplification of surface waves by reflection (Oswell 1990). He greatly enjoyed describing this research in seminars and invited lectures all over the world, not least because it gave him the opportunity to demolish so many of his audiences' preconceptions, and he continued to work on different aspects of the problem right up to the time of his death (46). He presented a particularly powerful review of this work when receiving the Otto Laporte Medal of the American Physical Society in 1998.

Figure 1. David in 1974, shortly after his arrival in Leeds.

David's outgoing personality helped him considerably in his interactions with knowledgeable applied scientists and engineers from many sources. The contacts that he made often suggested important problems to which David could apply his penetrating mathematical abilities. Agencies that he was particularly involved with included the US Office of Naval Research (who sponsored much of his work on fluid loading), Electricité de France (work on noise generation by unsteady flow through obstacles in pipes (42)) and Hitachi (original but unpublished work with H.L. Meitz on noise generation by ventilation fans), but perhaps his most substantial and sustained collaboration was with Rolls-Royce in the UK. One particular issue was the prediction of noise generation by propellers. This was at a time when there was great interest in the development of so-called 'Propfans' as alternative power plants for passenger aircraft. Although very efficient, the Propfan suffered from high noise levels, and it was very important for Rolls-Royce to be able to predict this noise. Starting with A.B. Parry in Leeds, and followed by N. Peake in Cambridge, David developed a comprehensive armoury of prediction methods that included a wide variety of physical effects (for instance, the Propfans were to be mounted in tandem, and the interactions between the two blade rows was one potent source of noise). The approach adopted was first to apply asymptotic analysis (making use of the fact that the number of Propfan blades was usually large) and then to simplify markedly the radiation integrals used to compute the noise. This led to results that were previously quite unexpected and to the identification of the key source mechanism out of a bewildering array of possibilities. Many papers were published on various aspects of this problem, including far-field noise (26, 34, 35), interaction between two blade rows (27), cabin noise (37) and nonlinear effects (32). However, perhaps even more significantly, the methodology that David developed found its way into much industrial practice within Rolls-Royce for the next decade. David regarded this whole project as a model of how industrial applied mathematics should work, and remained a great advocate of how mathematical modelling, especially asymptotics, could be used to unravel otherwise intractable technological problems.

David's interest in nonlinear acoustics was long-standing, first arising from considerations of the evolution of the sonic boom produced by Concorde, but later developing into a fascination with both the mathematical structure and physical implications of several model partial differential equations. He was interested in a whole range of possible mechanisms for the generation of nonlinearity, including long-range propagation, large amplitudes and a range of effects associated with unusual properties of the background medium. One of his first results (16) in this area involved a proof that a very general form of the Burgers equation (balancing dissipation with quadratic nonlinear propagation, but providing for arbitrary variation in ray-tube area) was integrable only in the special case described by the famous Cole–Hopf transformation. This meant that exact solutions would be highly unlikely, and David made progress instead by using asymptotics in the small-dissipation limit (14, 21, 25, 28). Quite remarkably, analytical expressions were found for virtually all aspects of the behaviour of a decaying N-wave in two and three dimensions (14). A particular aim of this and others of David's papers was to identify the range of validity, and possible breakdown, of the commonly used *ansatz* 'weak shock theory'. Essentially inviscid wave propagation is assumed, with a shock (and by implication an inner viscous region described by the well-known Taylor shock structure (Taylor 1910)) inserted according to some global conservation principle. He showed that the Taylor shock does not, in fact, describe all of the evolution of the N-wave (for example, viscosity leads to an accumulating correction to the shock location), and that rather different structures, fully elucidated in (14), develop in the old-age solution.

The less well-known modified Burgers equation (MBE), which possesses cubic rather than quadratic nonlinearity and is relevant to the propagation of electromagnetic waves in nonlinear dielectrics, was also analysed in this way (23). The key feature uncovered here, for a very wide class of initial conditions, was that the MBE equivalent of the Taylor shock starts to form an internal singularity in a finite time after initiation, leading to the creation of a quite different, 'sonic', shock before decaying in old age. In (31), a great deal of progress was made towards understanding the notoriously difficult Zabolotskaya–Khokhlov (ZK) equation, which describes the propagation of intense sound beams. Here a new symmetry group for the ZK equation was found, a major achievement in itself, but more impressive still was the considerable amount of physical information extracted from this formal result. The paper includes: a precise expression of how the ZK equation describes refraction for strong signals (an important issue for the development of nonlinear ray theory); a demonstration that a wide variety of wave fronts are focused into caustics; and, perhaps most significantly, the first description of smooth solutions to the ZK equation, demonstrating that shock formation is not a necessary consequence of wave propagation in this regime.

David played a large role in university affairs. As always, he sought to initiate new schemes and enable those around him to realize their potential as efficiently as possible. For example, he was the driving force behind the foundation of the Leeds Centre for Nonlinear Studies, which combined research efforts in this subject over a range of departments, and he initiated the first Leeds University Open Day. He became Chair of the School of Mathematics, during which time the photograph shown in figure 2 was taken. In 1983 he was appointed the warden of an undergraduate hostel, the Charles Morris Hall, which accommodated over 300 undergraduates. This position brought him into daily contact with students over a range of disciplines and no doubt prepared him for the role of Master of Jesus College, Cambridge, which he was to occupy later. While warden, he concentrated particularly on helping the new undergraduates to adapt to their new surroundings and to the requirements of university study. In these duties he was copiously helped by the presence and input of Johanna Veronica Hol, a charming and highly intelligent lady who had grown up in war-ravaged Holland. While at Leeds she completed a Master's degree in comparative education and worked in policy development for international schools. To David's enormous and continuing pleasure Johanna became his second wife in 1986 (figure 3). She now works as an independent international education consultant to the George Soros Foundation, the World Bank, the United Nations Children's Fund (UNICEF), the Organization for Economic Co-operation and Development (OECD) and similar organizations.

Like Johanna, David was international in outlook and much enjoyed travelling. He would fly halfway around the world to attend a one-day research symposium or chair a meeting. He worked during most of these journeys—an indication of his dedication, his ability to concentrate and his superb time-management skills.

CAMBRIDGE, 1986–2000

In October 1986 David returned to Cambridge to take up the professorship of applied mathematics. He thus became a member of one of the biggest and best-known departments of applied mathematics in the world with a faculty numbering 32, five of whom were professors. The first holder of the chair, George Batchelor, had throughout David's career helped to stimulate his interest in fluid mechanics and had taken early retirement from this position in 1983. David, who was also elected to a Professorial Fellowship at his old college, St John's, took up his new duties with enthusiasm. He built up a strong group of research students, postdoctoral fellows and senior visitors in his subdiscipline as well as continuing his own research. David began working, first in collaboration with Grisha Barenblatt (For.Mem.R.S. 2000), on the way in which turbulent fluctuations in the Burgers equation could thicken and distort a classical Taylor shock that passed through them. Once again, a self-consistent low-dissipation asymptotic solution was produced, perhaps rather surprisingly demonstrating the formation of internal structure within the shock, a point that was confirmed numerically (49). Away from acoustics, the evolution of initially small voidage waves in gas-fluidized beds was analysed (41). David knew that weakly nonlinear waves were described by the Korteweg–DeVries equation, but with a slowly growing perturbation. The evolution of these solitary waves right up to finite amplitude, over a range of time-scales, is presented in (41), thereby describing the full development of initial perturbations into the 'voidage slugs' observed in industrial gas fluidization.

Figure 2. David in 1982.

David's academic interests ranged even further than those described in detail above. For instance, he completed significant work in a number of different areas. These included combustion theory (asymptotic description of shock-induced ignition (29)) and the generation of internal gravity waves (22). He worked on the Wiener–Hopf technique, and in particular on the use of MAE to complete the factorization of the kernel. This was used with great effect on a particularly intractable kernel arising in the problem of the jet-edge feedback cycle (38). The technique was also set out in great detail in a paper published after his death (48). The stability of spatially varying flows was considered in a paper (39) that included a particularly ingenious exact solution of the linearized Ginzburg–Landau equation with non-constant coefficients. David also took up issues associated with numerical computations in the rapidly developing subject of computational aeroacoustics. In particular, in the infancy of the subject he published a very influential article setting out a range of challenging problems (24). This last subject was perhaps the most surprising for someone who made no use of computers whatsoever personally. However, the fact that he was well able to understand the crucial

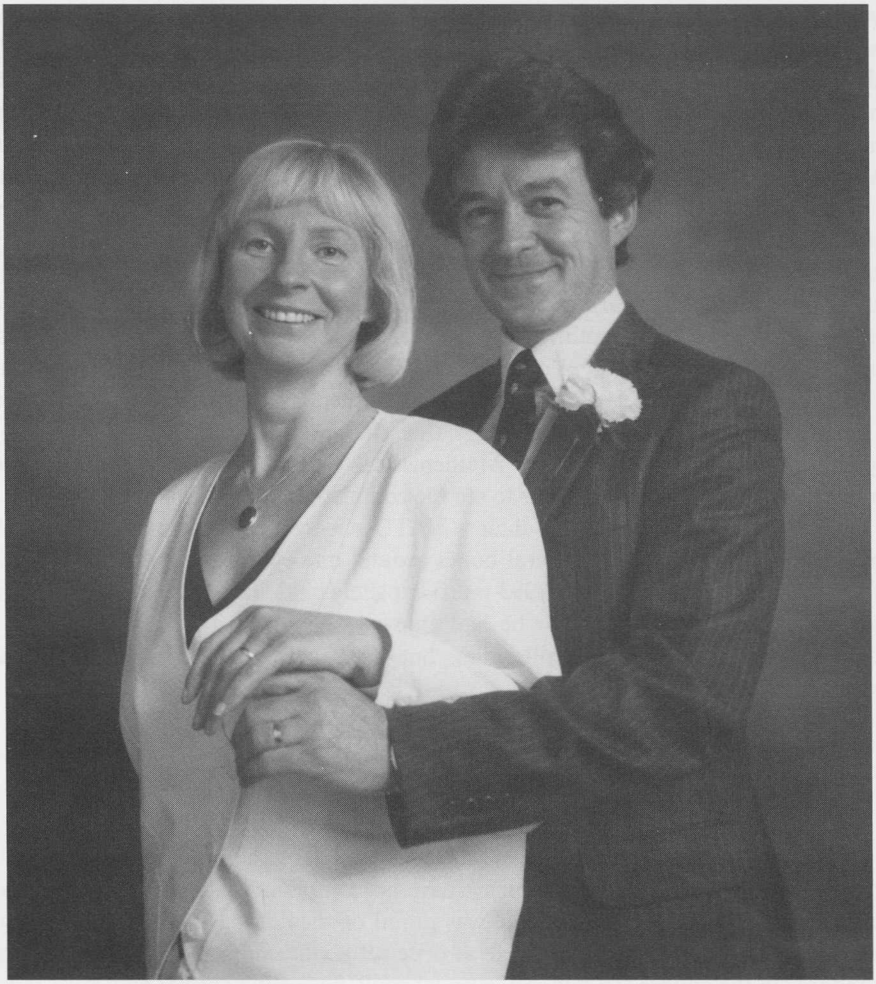


Figure 3. David and Johanna in 1986 just after their marriage.

hurdles to be overcome in the numerical computation of sound, and indeed to provide initial leadership in the emerging field, is as much a testament to his physical understanding of wave phenomena and his general far-sightedness as are any of his other research achievements.

Although admired for his original research, David's talents as a writer of compendious, influential and much-cited review articles was also recognized. He wrote three articles in *Annual Review of Fluid Mechanics*: a survey of nonlinear acoustics (13); the most useful reference article on the role of viscosity in setting up a smooth unsteady flow past the trailing edge of an airfoil (20), the so-called unsteady Kutta condition; and, most recently, a review of research on the active control of noise (47). A particularly wide-ranging survey written for NASA on airframe noise has also proved influential (36). With other distinguished acousticians, including A.P. Dowling, M.A. Heckl, F. Leppington and J.E. Ffowcs Williams, he participated in what became a famous series of instructional lectures, delivered in several different venues around the world over a period of several years. The notes from these lectures were written up as a book (40).

On the retirement in 1991 of the always popular Professor H.K. Moffatt, F.R.S., from the headship of the Department of Applied Mathematics and Theoretical Physics (DAMTP), David was elected to the position by the unanimous vote of all the members of staff. His vision and leadership drove the department to recruit staff and develop research groups in new areas such as solid mechanics, nonlinear systems and mathematical biology. At the time of his death there were 15 Fellows of The Royal Society on the permanent staff in DAMTP, more than in any other department in any subject anywhere in the world. After nine years of his leadership the faculty of DAMTP had increased to 50, 19 of whom were professors.

David's charm and persuasive power made him particularly successful in fund-raising ventures. For example, he spearheaded discussions with Hitachi to place a large multi-parallel processor supercomputer in Cambridge, which was used by a consortium of individuals from at least 10 different departments. With others in Cambridge, he helped to raise £50 million to move DAMTP and its sister department, Pure Mathematics and Mathematical Statistics, from the early nineteenth-century buildings that they had occupied since 1964 to occupy jointly the specially built Centre for Mathematical Sciences next to the Isaac Newton Institute. Unfortunately, he did not live to see the completion of this project.

In late 1991, while in Brussels to chair a NATO science panel, David was attacked by a mugger who broke his nose and several bones around one eye. David started losing his hair about a year later and by the end of 1993 was completely bald. This new look was in complete contrast to the wealth of black hair he had enjoyed previously. The transformation was a shock to his many friends and colleagues, but it somehow added to his good-natured charisma.

JESUS COLLEGE, 1997–2000

On 1 October 1997 David took up the Mastership of Jesus College, Cambridge, after an election which 'had an outcome of which I have no complaint' as he once commented. His impact on the college was immediate. He was proud of the college and its achievements and enormously enjoyed being the Master. He at once set about improving academic aspirations and standards in the college. To this end, even when ill, he spent a special half hour talking to each one of the final-year students about their studies, their extracurricular activities and their hopes and plans for the future; and was saddened and puzzled when he encountered any who were not minded to work hard to achieve as much as they could. He was on first-name terms with all of the students and Fellows and they all admired his openness and honesty. He moved the Master's Study from the Master's Lodge into the interior of the college so that he was more easily accessible. He interacted equally easily with the college staff and particularly enjoyed being a member of the Jesus College running team that won the Sir Arthur Marshall Cup for the Chariots of Fire Charity Race. Other members of the team included the head gardener, the deputy butler and a carpenter. He enthusiastically oversaw the building of Library Court during his Mastership.

Leadership qualities

David was a leader from an early age. As noted earlier, he was Captain of the first XV and Head Boy at school. While an undergraduate he determined what pub the 'lads' should attend in the evenings, often walking them over a mile to the Salisbury Arms in Tenison Road, passing many other pubs on the way, because he believed that the exercise would be good for them. At Leeds he led the department from a period in the doldrums to make it one of the more vibrant departments of applied mathematics in the country. At Cambridge he stood out as one of the leading innovators and widely respected administrators among the heads of departments. He was far-sighted and always unstinting in his efforts to motivate and build confidence in others by saying just the right few words at the right time.

He enjoyed administrative work. He (again) succeeded George Batchelor as Chairman of the European Mechanics Council, from 1988 to 1992, at which time he successfully had it converted into the more powerful European Mechanics Society, of which he was the first President until 1997. He was a member of the Applied Mathematics panel of the Research Assessment Exercise in 1991, its Chair in 1996 and was Chair-elect for the 2001 exercise. In the mid-1980s he initiated and tirelessly steered the 'Pop Maths Road Show', a travelling display of mathematics aimed at stimulating schoolchildren. He was a popular President of the Institute of Mathematics and its Applications from 1996 to 1997; Chairman of the Conference of Professors of Applied Mathematics (in the UK) from 1995 to 1997; and at various times Chairman of the Engineering and Physical Sciences Research Council (EPSRC) and of NATO grant-awarding bodies. His influence extended so broadly throughout the mathematics community that, unusually for an applied mathematician, he was elected to the Presidency of the London Mathematical Society, although he died before taking up office. David also used his lucid writing style and desire to help others by frequently contributing to a travelling two-day course on scientific writing and through his many editorial positions. He was an Associate Editor of the prestigious *Journal of Fluid Mechanics* from 1979, became joint Editor in 1996 with George Batchelor, and was sole Editor from 1999 until his death. He initiated a series aimed at presenting stimulating applied mathematics at a level comprehensible to senior undergraduates, which he entitled *Cambridge Texts in Applied Mathematics*, under whose banner more than 25 books have already appeared. He also found time to be the hard-working Editor of the *Proceedings of The Royal Society* series A from 1994 to 1996.

As befits a scientist of David's standing, he received many awards and medals. Some of these are listed at the end. He was particularly moved by the award of the Gauss Medal and his hosts were impressed that he could deliver his acceptance lecture in fluent German. Just two days before his death he was delighted and amazed to hear that The Queen had agreed to his being awarded the C.B.E.

David brought to all the professional tasks he undertook a warmth, a sense of humour and sensitivity to others that made him a much sought-after colleague.

Music

No biography of David could be complete without mentioning his passion for classical music and in particular for the works of Wagner. His first of almost annual visits to Bayreuth was as an undergraduate in 1962, when he hitch-hiked across Europe and arrived with insufficient money to buy a ticket. He met a kindly horn player who invited David to sit by him in the pit. While David was to return to the pit in later years, on one occasion at the invitation of Daniel Barenboim—in reply to David's request for advice on how to conduct the college orchestra—he was generally able to afford better seats. However, he invariably stayed in the same small attic room in the little guesthouse that he had occupied as a student on his first visit to Bayreuth. David had a phenomenal understanding and encyclopaedic knowledge of Wagner and somehow found time, among all his other activities, to write regular and much-admired articles for the international *Wagner News*. His prodigious memory helped enormously here. One of his great pleasures was to buy a compact disc advertising a complete live recording and dissect its validity. His ear and expertise were such that he could recognise, for example, that the second scene of the first act had been spliced in from the previous day's performance, or that part of a scene had been lifted from an earlier recording.

David played the French horn in his younger days, played the piano occasionally throughout his life, and for his 55th birthday he treated himself to a very good Jupiter trumpet and took lessons along with schoolboys in shorts at the St John's Choir School. His teacher considered David to be a very talented, quick and engrossed student, and David derived a lot of pleasure from the trumpet until his illness made him too short of breath to play.

David was also an (amateur) musical impresario. He arranged two visits to Cambridge of the great Russian pianist Tatiana Nikolaeva. At the first, to celebrate David's 50th birthday in 1992, she played Bach's Goldberg Variations and at the next, in 1993, she gave two concerts performing Shostakovich's Preludes and Fugues, which Shostakovich wrote especially for her. Later he arranged two concerts by the superb Slovenian pianist Dobravka Tomsic, for the second of which she brought the whole Slovenia Philharmonic with her.

At Jesus College, David developed an enthusiasm for conducting. Under his baton the Jesus College Orchestra performed the overture to Die Meistersinger von Nürnberg, the Prelude and Liebestod from Tristan and Isolde and, just weeks before his death, the overture to Tannhäuser. David left a large musical library containing almost 3000 compact discs, over 2000 records, and more than 150 scores and books on music.

Final year

Around Christmas 1998 David quite suddenly developed what was said to be a bad cold, which developed into what was then diagnosed as pneumonia. Some months later, after many investigations and tests, the doctors told him that he had advanced cancer of the bowel with a considerable spread of secondary cancer to the liver. David was no doubt inwardly devastated, but outwardly he continued to work almost as hard as ever, and always to help others. His quiet and deeply held Christian faith helped him both to fight against and to come to terms with the diagnosis.

He slowly relinquished his many international commitments, but remained head of DAMTP and interested in research until the last moment. Many of his last days were difficult, but David fought bravely to maintain his balance and humour. For example, three days before his death, David was visited in Addenbrooke's Hospital by Stephen Hawking, F.R.S., and they engaged in a long conversation about how some of David's mathematical techniques could be fruitfully used on a problem in cosmology of considerable interest to Stephen. Too weak to leave hospital and chair a DAMTP Appointments Committee the next day, David asked one of us (H.E.H.) to do so. H.E.H. initially reported that he had persuaded the committee to fire 20 of the current staff and hire a different 15. A broad smile came to David's face and he said: 'Good in principle, but did you fire the right twenty?'.

His early, tragic death deprived many of a warm friend, a stimulating colleague and a wonderful mentor and role model. He lived to enrich the lives of all who came in contact with him, and succeeded admirably in this aim.

AWARDS

1986	Aeroacoustics Medal of the American Institute of Aeronautics and Astronautics
1988	Rayleigh Medal, Institute of Acoustics
1993	Fellow of The Royal Society
	Per Bruel Gold Medal, American Society of Mechanical Engineers
1995	Gauss Medal, Braunschweig
1996	Corresponding Member of Braunschweigische Wissenschaftliche Gesellschaft
1997	Honorary Fellow, International Institute of Acoustics and Vibration
1998	Otto Laporte Medal, American Physical Society
	Corresponding Foreign Member of Bologna Academy of Sciences
	Honorary Foreign Associate, American Academy of Arts and Sciences
1999	Honorary PhD, Technical University of Crete
	Honorary DSc, UMIST
	Honorary DSc, Loughborough University
2000	Member, Academia Europaea

ACKNOWLEDGEMENTS

We are grateful to Johanna Crighton, who supplied us with many of the details of David's life and copies of the photographs. An earlier version was improved by thoughtful inputs from many of David's former colleagues and friends.

The frontispiece photograph shows David in 1999 sitting for an oil portrait, which now hangs in the Jesus College Hall.

REFERENCES TO OTHER AUTHORS

Oswell, J.E. 1990 Fluid loading with mean flow. PhD thesis, University of Cambridge.

Taylor, G.I. 1910 The conditions necessary for discontinuous motion in gases. *Proc. R. Soc. Lond.* A **84**, 371–377.

Van Dyke, M. 1964 *Perturbations methods in fluid mechanics*. Stanford: Academic Press.

Bibliography

The following publications are those referred to directly in the text. A full bibliography appears on the accompanying microfiche, numbered as in the second column. A photocopy is available from The Royal Society's Library at cost.

(1) (2) 1969 (With J.E. Ffowcs Williams) Sound generation by turbulent two-phase flows. *J. Fluid Mech.* **36**, 585–603.

(2) (4) 1970 Radiation from turbulence near a composite flexible boundary. *Proc. R. Soc. Lond.* A **314**, 153–173.

(3) (5) (With F.G. Leppington) Scattering of aerodynamic noise by a semi-infinite compliant plate. *J. Fluid Mech.* **43**, 721–736.

(4) (6) 1971 (With F.G. Leppington) On the scattering of aerodynamic noise. *J. Fluid Mech.* **46**, 577–597.

(5) (7) Acoustic beaming and reflexion from wave-bearing surfaces. *J. Fluid Mech.* **47**, 625–638.

(6) (9) 1972 Radiation from vortex filament motion near a half-plane. *J. Fluid Mech.* **51**, 357–362.

(7) (11) Acoustic edge scattering of elastic surface waves. *J. Sound Vib.* **22**, 25–32.

(8) (14) The excess noise field of subsonic jets. *J. Fluid Mech.* **56**, 683–694.

(9) (15) 1973 Instability of an elliptic jet. *J. Fluid Mech.* **59**, 665–672.

(10) (17) (With F.G. Leppington) Singular perturbation methods in acoustics: diffraction by a plate of finite thickness. *Proc. R. Soc. Lond.* A **335**, 313–339.

(11) (18) 1974 (With F.G. Leppington) Radiation properties of the semi-infinite vortex sheet: the initial-value problem. *J. Fluid Mech.* **64**, 393–414.

(12) (22) 1976 (With M. Gaster) Stability of slowly diverging jet flow. *J. Fluid Mech.* **77**, 397–413.

(13) (29) 1979 Model equations of nonlinear acoustics. *A. Rev. Fluid Mech.* **11**, 11–33.

(14) (30) (With J.F. Scott) Asymptotic solutions of model equations in nonlinear acoustics. *Phil. Trans. R. Soc. Lond.* A **292**, 101–134.

(15) (31) The free and forced waves on a fluid-loaded elastic plate. *J. Sound Vib.* **63**, 225–235.

(16) (41) 1982 (With J.J.C. Nimmo) Backlund transformations for nonlinear parabolic equations: the general results. *Proc. R. Soc. Lond.* A **384**, 381–401.

(17) (42) 1983 The Green function of an infinite fluid-loaded membrane. *J. Sound Vib.* **86**, 411–433.

(18) (50) 1984 Transmission of energy down periodically ribbed elastic structures under fluid loading. *Proc. R. Soc. Lond.* A **394**, 405–436.

(19) (51) (With D. Innes) The modes, resonances and forced response of elastic structures under heavy fluid loading. *Phil. Trans. R. Soc. Lond.* A **312**, 295–341.

(20) (54) 1985 The Kutta condition in unsteady flow. *A. Rev. Fluid Mech.* **17**, 411–445.

(21) (57) 1986 (With J.J.C. Nimmo) Geometrical and diffusive effects in nonlinear acoustic propagation over long ranges. *Phil. Trans. R. Soc. Lond.* A **320**, 1–35.

(22) (62) 1987 (With J.C. Appleby) Internal gravity waves generated by oscillations of a sphere. *J. Fluid Mech.* **183**, 439–450.

(23) (63) (With I.P. Lee-Bapty) Nonlinear wave motion governed by the modified Burgers equation. *Phil. Trans. R. Soc. Lond.* A **323**, 173–209.

(24) (66) 1988 Goals for computational aeroacoustics. In *Proc. IMACS Symp. Yale Univ. 1986* (ed. D. Lee, R.L. Sternberg & M.H. Schultz), pp. 3–20. New York: Elsevier.

(25) (67) 1989 (With P.W. Hammerton) Old-age behaviour of cylindrical and spherical nonlinear waves: numerical and asymptotic results. *Proc. R. Soc. Lond.* A **422**, 387–405.

(26) (69) (With A.B. Parry) Asymptotic theory of propeller noise. Part 1. Subsonic single-rotation propeller. *AIAA J.* **27**, 1184–1190.

(27) (70) (With A.B. Parry) Prediction of counter-rotation propeller noise. *AIAA Paper* 89–1141.

(28) (72) (With P.W. Hammerton) Approximate solution methods for nonlinear acoustic propagation over long ranges. *Proc. R. Soc. Lond.* A **426**, 125–152.

(29) (73) (With P.A. Blythe) Shock-generated ignition: the induction zone. *Proc. R. Soc. Lond.* A **426**, 189–209.

(30) (74) 1990 (With P. Huerre) Shear-layer pressure fluctuations and super-directive acoustic sources. *J. Fluid Mech.* **220**, 355–368.

(31) (75) (With A.T. Cates) Nonlinear diffraction and caustic formation. *Proc. R. Soc. Lond.* A **430**, 69–88.

(32) (79) 1991 (With N. Peake) Lighthill quadrupole radiation in supersonic propeller acoustics. *J. Fluid Mech.* **223**, 363–382.

(33) (80) (With J.E. Oswell) Fluid loading with mean flow. I. Response of an elastic plate to localized excitation. *Phil. Trans. R. Soc. Lond.* A **335**, 557–592.

(34) (82) (With A.B. Parry) Asymptotic theory of propeller noise. Part 2. Supersonic single-rotation propeller. *AIAA J.* **29**, 2031–2037.

(35) (83) 1992 (With A.B. Parry) Higher approximations in the asymptotic theory of propeller noise. *AIAA J.* **30**, 23–28.

(36) (84) 1991 Airframe noise. In *Aeroacoustics of flight vehicles: theory and practice*, vol. 1 (ed. H.H. Hubbard), pp. 391–447. NASA Reference Publication 1258.

(37) (85) (With N. Peake) An asymptotic theory of near-field propeller acoustics. *J. Fluid Mech.* **232**, 285–301.

(38) (86) 1992 The jet edge-tone feedback cycle: linear theory for the operating stages. *J. Fluid Mech.* **234**, 361–391.

(39) (88) (With R.E. Hunt) Instability of flows in spatially developing media. *Proc. R. Soc. Lond.* A **435**, 109–128.

(40) (90) (With A.P. Dowling, J.E. Ffowcs Williams, M.A. Heckl & F.G. Leppington) *Modern methods in analytical acoustics.* London: Springer-Verlag.

(41) (96) 1994 (With S.E. Harris) Solitons, solitary waves, and voidage disturbances in gas-fluidized beds. *J. Fluid Mech.* **266**, 243–276.

(42) (102) 1995 (With F. van Herpe & P. Lafon) Computational aeroacoustics for duct flows. *CEAS/AIAA Paper* 95–035.

(43) (111) 1998 (With A.J. Cooper) Transmission of energy down periodically ribbed elastic structures under fluid loading: algebraic decay in the stop bands. *Proc. R. Soc. Lond.* A **454**, 1337–1355.

(44) (114) (With A.J. Cooper) Transmission of energy down periodically ribbed elastic structures under fluid loading: spatial periodicity in the pass bands. *Proc. R. Soc. Lond.* A **454**, 2893–2909.

(45) (115) 1999 (With A.J. Cooper) Response of irregularly ribbed elastic structures, under fluid loading, to localized excitation. *Proc. R. Soc. Lond.* A **455**, 1083–1105.

(46) (117) 2001 (With M. Green) Fluid-loaded elastic plate with mean flow: point forcing and three-dimensional effects. *J. Fluid Mech.* **428**, 305–331.

(47) (118) 2000 (With N. Peake) Active control of sound. *A. Rev. Fluid Mech.* **32**, 137–164.

(48) (120) 2001 Asymptotic factorization of Wiener–Hopf kernels. *Wave Motion* **33**, 51–65.

(49) (127) 2002 (With P.L. Rendon) Effects of small-amplitude fluctuations on the structure of a shock wave. *J. Fluid Mech.* (In the press.)