Michael James Lighthill
(1924–1998)

David G. Crighton and T. J. Pedley

David G. Crighton

James Lighthill was acknowledged throughout the world as one of the great mathematical scientists of this century. He was the prototypical applied mathematician, immersing himself thoroughly in the essence and even the detail of every engineering, physical, or biological problem he was seeking to illuminate with mathematical description, formulating a sequence of clear mathematical problems and attacking them with a formidable range of techniques completely mastered, or adapted to the particular need, or newly created for the purpose, and then finally returning to the original problem with understanding, predictions, and advice for action.

His published legacy of six books and some 150 papers (most of them republished in four volumes in 1997 by Oxford University Press) show at every stage a well-nigh perfect correspondence between a clearly identified physical process or mechanism and its expression and description in mathematical terms. His papers or lectures often emphasised the physical aspects and gave the mathematics almost as a throwaway for those who like everything formalised, but in fact his style of working was usually the reverse.

In one of his most celebrated works, his first paper on "Sound generated aerodynamically" by jet aircraft and the like, he developed the essential mathematical structure completely in two weeks, but felt that the users (aeroengine designers) would not be able to grasp the implications, and so he delayed submission of his manuscript for sixteen months, in which time he worked backwards from the conclusions, isolating the meaning at each stage—and refining and simplifying the mathematics as he did so.

He was in no sense simply the deployer of existing mathematics against a rich range of practical problems. To be sure, his earliest papers on supersonic flight already showed brilliant mastery and exploitation of classical techniques. But much more powerful techniques were needed for problems such as those of how waves in fluids are generated and propagated, and for this Lighthill made great developments in the theory of Fourier analysis, generalised functions, and asymptotics—all set out with elegance and economy, and full rigour, in a delightful 1958 book, *Introduction to Fourier Analysis and Generalised Functions*. Rather different ideas were needed for nonlinear problems, such as the propagation and focusing of sonic booms, and here Lighthill provided equally

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original and elegant new techniques, permanent and frequently used additions to the armoury.

Michael James Lighthill was born in Paris in 1924 and excelled across the board at Winchester before going up to Trinity College, Cambridge, in 1941 for a two-year wartime B.A. He worked on supersonic flight at the National Physical Laboratory, Teddington, for the rest of the Second World War, publishing his first paper before he was twenty. He then went as Senior Lecturer to Manchester University at the age of twenty-two, before taking the Beyer Professorship of Applied Mathematics there, aged twenty-six, in succession to Sydney Goldstein. In his thirteen years at Manchester (1946–59) Lighthill ran one of the most powerful and inventive fluid dynamics groups ever formed anywhere.

He had many Ph.D. students who often rose to considerable heights themselves. Indeed, there was a period in which no fewer than seventeen of his Manchester students held chairs in the UK, and that at a time when the number of universities was no more than a third of its present number. Although prepared to share the credit on a paper with a colleague, Lighthill almost never allowed his name to appear as author on any paper wirtten by a student. And he was, then and since, tireless in his support for young scientists of any promise and for scientists working in disadvantaged circumstances.

During these Manchester years Lighthill worked extensively on gas dynamics, including effects important at very high speed, in his studies of ionisation processes and the diffraction of shock and blast waves. He also launched two major new fields in fluid mechanics. The first of these, "aeroacoustics", or "sound generated aerodynamically", was announced in a remarkable paper published by the Royal Society in 1952. Unusually but significantly, that paper neither contains nor needs so much as a single reference to any prior work. This work has remained for nearly fifty years the progenitor of all subsequent work in the field and has been cited in many thousands of later papers. It had immediate implication for noise reduction in jet aeroengines, motivating the trend begun later in the 1950s and still continuing to engines with higher bypass ratio, greater diameter, and lower exhaust speed, as mandated by Lighthill's famous eighth power law for jet noise. Remarkably, the Lighthill theory was sufficiently versatile to be applied also in problems as diverse as the heating of the Sun's corona and the noise heard under water due to breaking surface waves and splashing drops.

The second new field, "nonlinear acoustics", was initiated by a famous 100-page article written in 1956 in honour of the seventieth birthday of another great mechanics scientist, Geoffrey Taylor. This field is now represented by many thousands of papers, and applications include kidney-stone-crushing lithotripsy machines and, with the same mathematics, flood waves in rivers and traffic flow on highways.

Photograph courtesy of University College London.

Sir James Lighthill

From Manchester, Lighthill went on in 1959 to become director of the Royal Aircraft Establishment, Farnborough, where his leadership extended to the critical examination of every report emanating from the RAE. The years 1959 to 1964 saw him again in his element ("Wouldn't change it for anything!"), working on the aerodynamics of the slender delta wing for Concorde, on spacecraft, and on short-haul aircraft. He also worked with the post office in developing commercial use of television and communications satellites while managing in unusual detail the work of the 8,000 RAE staff, of whom 1,400 were professional scientists and engineers. Towards the end of his RAE time he became dissatisfied with the support in national societies for applied mathematics and founded the Institute of Mathematics and Its Applications, of which he was the first president, in 1965–67. From 1964 to 1969 Lighthill held a Royal Society research professorship at Imperial College, and here he began his great development of mathematical biofluiddynamics: the quantitative understanding of the flow of blood in mammalian cardiovascular systems, of air in the human airways, and of the flying of birds and insects and the swimming of fish. Mastery of biology was, he insisted, the sine qua non for entry into this field. He revelled in lectures, not only in the articulation of all the Latin names, but in his ability to perform the appropriate gymnastics to illustrate certain flying characteristics—in particular the "clap and fling" mechanism employed by the tiny wasp, *Encarsia formosa,* to endow it with a lift coefficient far above that obtainable from the ordinary aerodynamics in which the component parts of the body do not break apart.

In 1969 he succeeded Paul Dirac, founder of much of quantum mechanics, in the Lucasian Professorship of Mathematics at Cambridge—though when he referred to "my predecessor in the chair," one sensed he was thinking primarily of Newton.

Here he taught indefatigably and with enormous gusto six days of the week at nine in the morning. He widened his range yet further with work on control systems; on active control of sound, or anti-sound; more and more on waves; on oceanography and atmospheric dynamics, including monsoon prediction and propagation; and on biological mechanics at the microscopic level.

From 1979 to 1989 Lighthill was provost of University College London, much engaged in fundraising; in new developments in the college, particularly in the biology and biotechnology sides; and in dramatically improving the representation of women in senior posts. He still maintained his scientific work with studies on the unpredictability of large systems, on wave energy extraction devices, and on features of the human auditory system. After retirement he took up chairmanship of the Special Committee on the International Decade for Natural Disaster Reduction and travelled and lectured worldwide.

His achievements were widely recognised—through election as Fellow of the Royal Society at the age of twenty-nine, through the award of 24 honorary doctorates, through foreign membership of the most prestigious academies, through receipt of many medals and prizes, and through knighthood in 1971.

Stories about Lighthill are legion, and no amount of discounting for exaggeration makes them less amusing or less essentially accurate. It is well known that he was fined £1 for jumping from a train as it passed, to his dismay, through Crewe without stopping and that on more than one occasion he successfully defended himself on charges of speedy driving, turning the spotlight of his presence, charm, and authority on the magistrates as he explained how, as Lucasian Professor, he was fully seized both of the laws of mechanics and of his duty to society not to waste energy, the latter compelling him to desist from applying the brake on any downhill section of road.

He saw everything as a challenge to his brain, or to his physique, or to the coordination of the two. And if no challenge was obviously at hand, he would create one: mastering Portuguese in three weeks to the extent that he could give a (long) after-dinner speech in the language, for example. He listed his leisure interests as music and swimming, to which surely literature, poetry (especially Portuguese), and languages (French, German, Russian, Portuguese) should be added.

His swimming exploits were legendary—careful in his homework on tides and local currents, bold in his ignoring of everything else. On countless occasions he came home safely, against the odds. Last Saturday he almost completed a nine-hour swim round Sark (he was the first ever to do this, at the age of forty-nine) against high winds and huge waves before dying close to the shore.

T. J. Pedley

It was during the fifteen years after he left the Royal Aircraft Establishment (1964–79), first as a Royal Society Research Professor at Imperial College and then as Lucasian Professor of Mathematics at Cambridge, that Lighthill totally transformed the study of biological fluid dynamics. He wrote major reviews of aquatic animal propulsion (1969), of animal flight (1974 and 1977), and of low Reynolds number flagellar hydrodynamics (1976). Each of these is characterised by an exhaustive survey of the animal kingdom to make sure that all actual modes of locomotion are covered by the preliminary fluid dynamical analyses that he then presents in qualitative if not quantitative forms. (The lectures based on these surveys were always splendid occasions, in which Lighthill would alternate between demonstrating his mastery of the relevant taxonomic terminology and making his fluid dynamical audience feel at home by incorporating standard terms from other applications, such as—in the flight context—payload, wing-loading, induced drag, etc.) He himself concurrently made major advances in fluid dynamical analysis in all three areas.

In fact, his first analysis of fish swimming (1960) was published while he was director of the RAE, and in it he set out the principal features of what has become the standard model of fish swimming using body undulations. This small-amplitude, slender- (or elongated-) body theory explains how thrust is generated from the reactive (added-mass) forces experienced by an undulating body as it gives sideways acceleration to fluid which is moving backwards relative to the fish at the approximately steady swimming speed. Moreover, Lighthill showed a full appreciation of the difficulties involved with calculating *recoil* (stemming from the fact that an arbitrary displacement wave will not in general give rise to instantaneous forces and couples that exactly balance the fish's transverse and angular momentum fluctuations) and with analysing the three-dimensional *boundary layer*, needed to check whether the computed thrust does indeed balance the drag at the supposed swimming speed. These features were later expanded (1970), and the whole theory adapted to large amplitudes (1971). Other aspects were taken further by visitors to Cambridge in the early 1970s (D. Weihs, M. G. Chopra, T. Kambe). Lighthill

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himself returned to fish swimming after he had retired from University College, London, through a series of four papers on "Balistiform and gymnotiform locomotion" (1990) and, more recently, with a fascinating analysis of how a herring can control the motion of its head to enable it to sense pressure differences across the head of external origin without being swamped by self-generated pressures (1993).

For flagellar locomotion Lighthill developed a new viscous slender body theory superior to the customary resistive force theory, in which a long, narrow, cylindrical flagellum, beating with a long wavelength, is replaced by a distribution of Stokeslets and dipoles on its centre-line whose strengths are obtained by solving an integral equation representing the no-slip condition on the cylinder surface (1976). In the context of flight Lighthill's collaboration with the then professor of zoology at Cambridge, T. Weis-Fogh, led to an elegant analysis of a newly observed mode of lift generation in small hovering insects, the clap-and-fling (1973). However, in both these areas many of his ideas were put into effect and subsequently taken much further by Ph.D. students: namely, J. R. Blake, J. J. L. Higdon, and J. M. V. Rayner.

Despite these pivotal contributions to external, or zoological, fluid dynamics, Lighthill's most significant contribution to the field may have been in internal, or physiological, fluid dynamics—and not through his publications, but through his administrative vision. In the middle 1960s he joined forces with C. G. Caro from St. Thomas's Hospital to persuade Imperial College to create the Physiological Flow Studies Unit. This research group started work, attached initially to the Aeronautics Department, in 1966. Many students, fellows, academic staff, and visitors have worked there over the years (including this writer, from 1968–73), and now, as part of the Department of Biological and Medical Systems, it has a strong international reputation, especially in the study of the response of artery walls to haemodynamic stresses, an important part of understanding arterial disease.

Lighthill's direct contributions to physiological fluid dynamics were quite few—though including several masterly, specially written chapters in his 1975 book *Mathematical Biofluiddynamics*—until towards the end of his career he developed an interest in the inner ear. In particular, he demonstrated that the ability of the hair cells of the cochlea to sense different frequencies of sound according to their distance from the entrance could be associated with a phenomenon of critical layer absorption of the elasto-acoustic waves set up in that organ (1981, 1991, 1992).

To the students and colleagues who worked with him, Lighthill gave much more than intellectual stimulus. In addition to the generosity with which he shared his ideas and gave his support (he adhered to the by now rarely found view that a supervisor's name should not appear on the papers of his students, however much of the work he had done himself), he instilled his own uncompromising principles for interdisciplinary research. The motive for doing fluid mechanics in biology is to help biologists understand how their systems work. To this end it is essential "to talk to zoologists and go on talking to them; to read their works and go on reading them; to study their collections and go on studying them" (1973). He did it, and we must do it too.

Those of us working in biological fluid dynamics know that James Lighthill made huge contributions to many areas of fluid mechanics and applied mathematics in addition to ours. That merely intensifies our admiration for the transformation he wrought in our subject. We honour him deeply and miss him greatly.