
T.J. Pedley


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SIR (MICHAEL) JAMES LIGHTHILL

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BY T.J. PEDLEY, F.R.S.

Department of Applied Mathematics and Theoretical Physics,
University of Cambridge, Silver Street, Cambridge CB3 9EW, UK

EARLY YEARS

Michael James Lighthill was born in Paris on 23 January 1924, son of Ernest Balzar Lighthill ('Bal'), a mining engineer who retired and returned to England in 1927 at the age of 59. James's mother, Marjorie, daughter of a Yorkshire engineer, L.W. Holmes, was 18 years younger than her husband; James had a brother, Olaf, 17 years older than himself, and a sister, Patricia, nine years older, who survives him. Bal had changed the family name from Lichtenberg (originally of Alsatian origin) in 1917.

James was a precocious child, showing early evidence not only of his mathematical ability and of his formidable memory but also in many other areas such as music, languages and chess: his father, quite a good player, gave up the game when James beat him at the age of about 10, blindfolded. James was educated at private schools, and at the age of 12 won a scholarship to Winchester. It was a wonderful coincidence that another 12-year-old scholar at Winchester in 1936 was Freeman Dyson (F.R.S. 1952), who later was for many years, and is still, at the Princeton Institute of Advanced Study. They were both passionate about mathematics, and were so far ahead of their fellows that they were allowed to learn as much mathematics as they could, from any available source. At the age of 14 they read (and profited from!) Principia mathematica by Whitehead & Russell, and the 1909 three-volume Cours d'analyse by Camille Jordan, For.Mem.R.S., which they read in French and which was undoubtedly a most important basis for James's subsequent mastery of analysis. It is interesting that James's school reports show that he was usually second in the class in mathematics throughout his time at Winchester.
At the age of 15, James and Freeman were both awarded major scholarships to Trinity College, Cambridge, but the college would not allow them to go up until 1941 when they were 17. They spent the intervening years learning more mathematics. Degree courses were reduced to two years during the war, but that did not matter to them because they had already covered all the undergraduate material, at least in pure mathematics. They attended only the lectures for Part III of the Mathematical Tripos, intended for graduate students, and James was particularly influenced by the analysts Hardy and Littlewood. In 1943 James and Freeman took the exams for both Part II (necessary to graduate) and Part III, and not surprisingly they each achieved a first class in the former and a distinction in the latter.

While he was an undergraduate, James threw himself vigorously into different areas of student life, notably music. It was in rehearsals for Mozart’s G minor piano quartet that he (the pianist) met Nancy Dumaresq (cellist, and also a mathematician) and they discovered with astonishment and pleasure that their families lived next door to each other in Highgate. They married in 1945, when James was just 21, and Nancy remained ‘the light of his life’ until his death. They had one son and four daughters.

NATIONAL PHYSICAL LABORATORY: AERODYNAMICS

At that time it was necessary for mathematicians after graduation to support the war effort in a research capacity. Nancy had taken a job with the Royal Aircraft Establishment at Farnborough so James asked to go there too. However, the authorities suspected his motives and sent him to the National Physical Laboratory (NPL) at Teddington to work with Sydney Goldstein, F.R.S., who convinced James that fluid mechanics was a rich subject to which talented mathematicians could make an important contribution. A.S. Besicovitch, F.R.S., a Cambridge pure mathematician, told Goldstein ‘not to spoil him’; Goldstein subsequently expressed satisfaction, which all fluid dynamicists can share, that he had spoiled him very effectively. Nevertheless, after the war, James wanted to go back to Cambridge to resume his studies in pure mathematics, notably algebra and number theory. He submitted the dozen or so reports that he had written at the NPL and was awarded a Prize Fellowship at Trinity College as a result. In a 1945 letter to Freeman Dyson, he wrote:

I have made an investigation on a silly thing called the Coanda effect (example: you can deflect small jets of water from bathroom taps by putting your finger halfway in) and wrote a fairly uninspiring paper on it with applications to wind-tunnel design, but I have really got quite sick of aerodynamics now. I have nothing more to say on it....

After six months, however, stimulated by questions about his wartime work, and encouragement to extend it, from Goldstein and Sir Geoffrey Taylor, F.R.S., among others, he came to realize that fluid dynamics had become his true subject.

In 1943 it was felt that World War II might go on for a long time and that the development of supersonic fighter aircraft could prove decisive in later years, so Lighthill’s first tasks at the NPL were analyses of supersonic flow past thin wings. The urgency was all the greater because almost all the papers on the subject were by Prandtl and his pupils, and written in German. Fortunately, Lighthill could read them and he was able to absorb their findings quickly. His first paper was published in 1944, when he was still 19, in the form of a report to the Fluid Motion Sub-Committee of the Aeronautics Research Council (ARC); three more
reports were published in 1944 alone. Lighthill's writing style at that time was elegant but
tense, as one would expect from a well-educated pure mathematician, but already in his third
paper he states that 'every effort has been made to clarify the physical and mathematical bases
of the theory', using words as well as equations. Here we can see both the direct influence of
Goldstein and the need to explain the value of what he was doing to the Fluid Motion Sub-
Committee. The desire for such clarification was to dominate the later evolution of Lighthill's
writing style.

In 1945 Lighthill published six more reports for the ARC, including the first aeronautical
achievement with which he himself was subsequently rather pleased: an exact, conformal
mapping method for the design of aerofoil shapes with a prescribed distribution of slip
velocity. This was desirable not only to achieve high lift but also to predict precisely where the
boundary layer would be expected to separate and hence to design suitable suction slots to
prevent that. The papers were remarkable not merely for the ingenuity of the theory but also
for the large numbers of examples for which the details were computed numerically (even a
low-accuracy design took 1.5 days of manual calculation with five-figure tables). Moreover, a
promising design would be constructed and tested immediately in the NPL's subsonic wind
tunnel. It has to be said that the aerofoil designs proposed by Lighthill do not look very
practical: there was one shaped like an ace of spades, for example.

MANCHESTER: THE GOLDEN YEARS

In 1946 Goldstein was appointed to the Beyer Chair of Applied Mathematics at the
University of Manchester and persuaded Lighthill to go there too, as a Senior Lecturer. In
1950 Goldstein left to go to Israel, and Lighthill was appointed to the Beyer Chair in his place
(at the remarkably young age of 26). At Manchester, Goldstein, Lighthill and Max Newman,
F.R.S. (Professor of Pure Mathematics), were pioneers (within Britain) in developing an
integrated centre for modern pure and applied mathematics in which applied mathematical
sciences would benefit from pure mathematical insight—and in which academic staff could
enjoy a high ratio of research time to teaching time. This took place at least 10 years before
G.K. Batchelor (F.R.S. 1957) founded the modern, scientific Department of Applied
Mathematics and Theoretical Physics at Cambridge. A parallel development at Manchester
was the setting up of the Fluid Motion Laboratory, directed successively by WA. Mair,
PR. Owen (F.R.S. 1971) and N.H. Johannesen, which both had an important research role
and formed a part of the education of undergraduate students from mathematics and physics
as well as engineering. This aspect of his work led to strongly held views on mathematical
education and science policy that informed many of James's later initiatives in these areas.

Supersonic aerodynamics

Lighthill remained at Manchester for 13 years, a period of intense intellectual activity during
which he produced a remarkable volume of highly original research output. To begin with he
continued the work on high-speed aerodynamics that he had begun at the NPL. In 1947 a set
of four papers was published in Proceedings of The Royal Society, Series A, in which he
showed how to use a version of the hodograph method for the analysis of two-dimensional
transonic flow (a flow that includes regions of both supersonic and subsonic flow). For
incompressible non-viscous fluids, the hodograph method involves transformation of the
problem from the (complex) physical plane to the plane defined by the magnitude and direction of the fluid velocity, in which the problem is linear. It is most useful for flows past either plane walls or surfaces on which the flow speed is given. For transonic flow the problem is much more difficult because of an infinite number of singular points in the transformed plane. Nevertheless, Lighthill showed great ingenuity in giving a complete theory for flow in a symmetrical duct. This was the first of many occasions on which Lighthill developed a virtually new mathematical method to solve an important practical problem and thereby open up a new branch of research endeavour. It is perhaps hard for modern fluid dynamicists to understand how vital it was to develop new analytical methods for the purpose of design as well as understanding, even if they required very intricate, not to say daunting, mathematics, in the days before large digital computers became available.

In 1948 Lighthill published six papers in the first volume of the *Quarterly Journal of Mechanics and Applied Mathematics*, most of them on supersonic flow past slender two-dimensional or axisymmetric bodies (wings or missiles), again displaying great virtuosity in the use of the well-tried mathematical methods associated with regular perturbation expansions, in order to predict quantities of importance to engineers, such as the pressure distribution on the body. However, in one paper he began to consider the complete flow field by calculating the positions of purely cylindrical, conical or spherical weak shock waves at some distance from their sources. For general shocks he found that standard methods break down in the far field, so he set to work and invented a new method to provide an approximate solution that would work everywhere. His 1949 paper on the subject was called ‘A technique for rendering approximate solutions to physical problems uniformly valid’ and is an early example of a singular perturbation method; the technique is now called the Method of Strained Co-ordinates.

Shock waves are an integral part of supersonic flow past a solid body or in a duct of non-uniform width. Inviscid aerodynamics treats shocks as surfaces of discontinuity. When two-dimensional perturbations to a uniform flow are small (for example in slender-body theory), shocks are weak and planar to leading order. In 1949 Lighthill published the first of a number of papers on shocks that are not necessarily of small strength; the key to making analytical progress was the recognition that, for a strong shock subjected to a small disturbance, the pressure perturbation still satisfies a linear equation everywhere. The principal papers in this series were a pair entitled ‘The diffraction of blast’ in which a strong planar shock encounters a small corner in an otherwise plane rigid boundary. Not only the geometry of the shock but also the practically important pressure distribution were calculated in numerical detail for particular parameter values. These papers, like most of Lighthill’s works, were totally original: the first had only three references, one to Busemann, for weak shocks, and one each to Sommerfeld and Friedlander for diffraction in acoustics, whereas the second had only two, one to the first paper and one, for analytical method, to Whittaker & Watson!

Lighthill’s prolific and innovative work during and after World War II was becoming increasingly famous internationally. Thus it was that he was invited to present a general lecture at the 7th International Congress for Applied Mechanics in London in 1948, at the age of only 24. He was also invited by W.R. Sears, the editor of volume VI of the Princeton series on *High Speed Aerodynamics and Jet Propulsion* (entitled *General theory of high speed aerodynamics*) to write a section on ‘Higher approximations’. This 147-page article (6)* was

* Numbers in this form refer to the bibliography at the end of the text.
later reprinted as a separate paperback and became highly influential. Full credit is given to the work of others, notably Lighthill's first research student, G.B. Whitham (F.R.S. 1965). This authoritative exposition can be thought of as the culmination of Lighthill's career up to about 1950, but another survey lecture (7) is worth a reference because it contains a number of informal remarks on the value of mathematical investigations in physical science, as long as they are firmly rooted to the physical reality. A characteristic quotation is:

If, when you have done one of these brilliant, involved bits of mathematics, you would just put it in a drawer, there would be so much the less for people to have to read! Then you could start gradually sorting out its meaning, in relation to the experimental data and to other bits of mathematics, until at last the basic physical ideas stood out quite clearly. Then, finally, you could write a much better paper! You would develop the subject in terms of these physical ideas and arguments right from the start, and include only the mathematics which was finally shown to be necessary in the light of them. The paper would be easier to read, and the reader would not have to change completely from one point of view to another at any stage. Of course you would not necessarily want to throw away all of the hard-won mathematics you had done originally, especially as some of it may still be valuable for increasing one's confidence in the physical arguments, but then what are appendices for?

Many of us would benefit from taking this advice (remembering to take the work out of its drawer again later, of course), and administrators and government 'assessors' would also do well to read and understand it.

**Boundary layers**

Lighthill was of course fully conversant with Prandtl's boundary-layer theory. The following comment on nineteenth-century aerodynamics is quoted from page 1 of the first of his essays of introduction to the book *Laminar boundary layers* (18):

The trouble had been by no means the lack of a theory, but rather the existence of an almost overwhelmingly large body of theory, constructed by many of the best mathematical physicists of the nineteenth century, according to the most respectable physical principles. This theory gave, for the motion of a wide variety of shapes through the atmosphere, which it treated as a 'perfect fluid' (that is, a continuous medium of constant density whose parts act on each other only by normal pressures), the fullest information, none of which accorded with the most elementary observation of the facts.

He knew well that inviscid aerodynamic theory would be meaningless for any flow in which the boundary layer separated, disrupting the outer, potential flow. He had delved deeply into real gas effects in shock waves (see below) and it was only a matter of time before he became involved in the theory of laminar boundary layers.

His first two boundary-layer papers, published in 1950, the same year that he took up the Beyer professorship, were directly associated with his work on compressible aerodynamics. The first (1) was on heat transfer through a constant-density boundary layer in which the flow field is known, and used a neat transformation to obtain an approximate solution of wide validity.

The second paper was Lighthill's first on shock-boundary-layer interaction (2), in which he analyses the reflection of a weak disturbance (not yet a shock) by the boundary layer on a rigid wall in a supersonic free stream. The key question was what will happen to the disturbance when it reaches the subsonic part of the flow, close to the wall, because disturbances can propagate upstream in subsonic flow. The solution involved the then unfamiliar use of generalized functions (or distributions) and asymptotic analysis by 'Langer's method' (otherwise known as the WKBJ or Liouville–Green approach). The
analysis was brilliantly executed, and the result was that the upstream influence of the disturbance was predicted to be far smaller than had been observed in a variety of experiments with shock waves. Such a disagreement with experiment represented a challenge that Lighthill could not ignore.

From this challenge emerged two more of Lighthill's most influential papers (5), 'On boundary layers and upstream influence', whose publication signals the birth of 'triple-deck theory', principally developed by K. Stewartson (F.R.S. 1965), A. Messiter, F.T. Smith (F.R.S. 1984), V. Sychev and many others in later years. The key point is not upstream propagation in the subsonic part of the boundary layer, but local compression of the boundary layer by the shock. This means that there is, locally, an adverse pressure gradient that has a significant effect on the viscous sublayer, causing it to thicken. This local thickening generates a displacement of the original boundary layer farther upstream, which causes the sublayer to thicken further, and so on. If the original disturbance is strong enough, the flow can separate upstream, as observed experimentally. The solution of the sublayer equations provides one relationship between pressure perturbation and boundary-layer displacement; another arises from the dynamics of the outer, inviscid flow, so the problem is closed. Lighthill's very last paper, in fact, was a survey of the problems of upstream influence in boundary layers, which appeared posthumously in 2000 (38). It is the text of a lecture that he gave at a conference in Manchester only 10 days before his death.

Only a year later another influential paper appeared, this time on unsteady boundary layers (9). Once more, Lighthill was the first to see how to analyse an incompressible boundary layer when small-amplitude fluctuations in the magnitude of the free stream velocity were imposed. He worked out the leading terms in expansions for important quantities (skin friction and heat transfer) for both small and large frequencies, and found good overlap at least for the skin friction. In fact Lighthill's solution scheme is not restricted to small-amplitude disturbances, as shown later by F.K. Moore and C.C. Lin. This paper, and the previous ones on upstream influence, can be regarded as a two-pronged initiation of the study of the effects of external disturbances on boundary layers, leading in many cases to instability and transition. Such effects are these days referred to as 'boundary-layer receptivity'.

Readers of Lighthill's papers in the late 1940s and early 1950s will have noted that his sentences were gradually getting longer; see the opening sentence of the abstract of his first boundary-layer paper, for example:

An approximation to the heat transfer rate across a laminar, incompressible boundary layer, for arbitrary distribution of main stream velocity and of wall temperature, is obtained by using the energy equation in von Mises's form, and approximating the coefficients in a manner which is most closely correct near the surface.

Lighthill's experience on the Fluid Motion Sub-Committee of the ARC had taught him that workers from other backgrounds need clear explanations in words even when the scientific results in question were derived more precisely and could be described more concisely in mathematical form. He assumes (correctly) that his readers will find the mathematics more difficult than he did and concludes that they will gain greater understanding from an explanation in precisely expressed, stylistic English. Lighthill often mentioned his admiration for the great nineteenth-century scientific writers. What he might not have taken fully into account was that mathematicians and engineers in Britain and the United States (and probably elsewhere) are not as well educated in literary style as he was. In
Michael James Lighthill

addition, we do not have such good short-term memories as his, so it is better for the reader not to let the start of any sentence become too distant a memory before the end is reached. But he would not have accepted such criticism, and invariably restored the full length of any sentence that a zealous editor tried to shorten.

Vorticity

Vorticity can be thought of as lying at the heart of fluid dynamics. The second of Lighthill's essays in *Laminar boundary layers* represents a wonderfully consistent exposition of viscous fluid dynamics in terms exclusively of vorticity, rather than the description involving pressure gradients and accelerations (and viscosity) that is more commonly taught to undergraduates. To quote:

> any flow development is in principle computable by studying the diffusion of vortex lines, and their convection and stretching by the associated flow, while supposing normal and tangential vorticity to appear at the surface continuously, in just such measure as is required to maintain, respectively, the solenoidality of the vorticity field and the no-slip condition.

This essay was also significant for its introduction of topological thinking into fluid dynamics, in the section on separation and attachment on three-dimensional bodies.

Lighthill's first venture into vortex dynamics was, however, concerned with the inviscid distortion of vorticity fields in a straining flow. For instance, when a shear flow encounters a solid body, vortex filaments are stretched and rotated, generating secondary motions with components of vorticity in all directions, including downstream. Lighthill's most famous paper (in a series of four on this topic) was the one provided for volume 1, part 1, of the *Journal of Fluid Mechanics* (*JFM*), which wins the prize for the shortest *JFM* title: 'Drift' (13). This follows Darwin (1953) in analysing how a plane of material particles is distorted by the passage of a solid body through it (neglecting viscosity), giving results that have proved very useful in analysing the dispersion and deposition of pollutant particles in flows past bodies.

In the context of vorticity, the work was important in calculating the complete secondary flow field for a sphere in a (weak) uniform shear.

Aeroacoustics

The topic of 'sound generated aerodynamically', now known as aeroacoustics, is probably the one in which Lighthill's impact has been most influential. It is certain that his first paper on the subject (3) has been referred to thousands of times, and it remains absolutely central, although of course it has been refined and reformulated several times since (often more confusingly and less informatively). What a remarkable paper that first one was! It has no references, as befits the first paper in a totally new field. No one before Lighthill had had any real idea of how to analyse the noise produced by jet engines, increasingly a problem in the early 1950s as jet-propelled aircraft developed rapidly. He had a simple, brilliant idea, worked out the mathematics of it in two weeks—and then put it in a drawer for 16 months while he carefully pondered how to explain the underlying physics in such a way that non-mathematicians could both understand the principles and understand their significance. He succeeded admirably.

The simple idea was based on little more than conservation of mass and Newton's laws of motion, but had vast consequences. Suppose that the sound originates in a bounded region of disturbed air, such as the turbulent jet behind a jet engine. Then, outside that region, where
the air is otherwise still, the sound satisfies the usual wave equation. Inside the disturbed region, the fluid motions can be thought of as the source of the sound that is radiated away. Moreover, if the source region does not contain any sources of mass (i.e. there are no bodies of variable volume) or of momentum (i.e. there are no boundaries exerting a force on the fluid), the far field will be dominated by quadrupole radiation.

The first part of this idea led Lighthill to write the exact equation for the fluid density, derivable from the Navier–Stokes and continuity equations, in a form with the linear wave operator on the left-hand side and everything else on the right, in the form of the second derivative of an effective applied stress tensor, normally dominated by a term quadratic in the fluctuating velocities. Then the sound field outside the source region can be written down immediately as an integral of that tensor over the source region, which is readily shown to imply quadrupole radiation in the far field. From this result it was not necessary to know very much about the turbulence itself to deduce rather a lot about the intensity of the radiated sound. A simple scaling argument predicted that, for subsonic jet motions, the intensity would be proportional to the eighth power of the jet speed. The eighth-power law at once had a revolutionary impact: aero-engine designers could see immediately, for example, that it was essential to reduce the fluid speed in their jets.

The next important step in aeroacoustics was to estimate the effect on the sound field of the fact that the source region is typically translating relative to the ambient air. Still in his first paper, Lighthill estimated that, for subsonic motion, the intensity would be modified by a factor \((1 - M \cos \theta)^{-6}\), where \(M\) is the Mach number and \(\theta\) is the angle that the line from the source to the observer makes with the direction of mean motion (this was later corrected to \((1 - M \cos \theta)^{-5}\) by J.E. Flowcs Williams). In his second paper on the subject, Lighthill (8) made a much more quantitative estimate of the distribution of the quadrupole strengths in subsonic jet turbulence and predicted the frequency spectrum of the radiated sound.

From then on, the subject took off explosively and Lighthill contributed principally through his interaction with students and junior colleagues. Flowcs Williams, for example, made a thorough application of Lighthill’s theory to supersonic jets. The total acoustic power radiated is in that case proportional to the cube of the speed, not the eighth power.

The noise made by jet aircraft is by no means the only phenomenon to which Lighthill’s theory of fluid dynamic sound generation can be, or has been, applied. He himself noted the monopole radiation generated in water by cavitating or entrained bubbles: the roaring of waves and the babbling of brooks (17). He also was instrumental in helping astrophysicists to discover the importance of acoustic radiation in stars and in cosmic gas clouds. Other, more recent, applications of Lighthill’s ideas have included the spontaneous emission of inertia-gravity waves by regions of vortical flow in stratified, rotating fluids, leading to a much deeper understanding of large-scale atmosphere and ocean dynamics (McIntyre 1998).

Nonlinear acoustics

His work on shock waves and, later, aerodynamic sound inspired in Lighthill a strong interest in understanding more generally the phenomena associated with the propagation of acoustic waves. What was the relationship between linear acoustic waves, in a fluid of small viscosity, and the fully nonlinear, energy-dissipating entity that is a shock wave? Whitham’s early work, accomplished while he was Lighthill’s research student in the late 1940s, showed how a radiating shock in two or three dimensions, which necessarily becomes weaker as it spreads out, can be analysed as a relatively small-amplitude phenomenon. Moreover, Whitham’s later
work (mid-1950s) showed how one-dimensional simple waves of moderate amplitude would develop into (weak) shocks whose asymptotic properties could be estimated by a simple geometrical rule. However, those theories took the dissipative properties of the shock waves for granted. Taylor (1910) had provided the first theory, based on the Navier–Stokes equations, for the structure of a (plane) shock, and Lighthill wanted to incorporate this into a rational theory for the generation, propagation and attenuation of nonlinear sound waves, including shocks.

He achieved this aim in another article that has become a classic, the 101-page chapter entitled ‘Viscosity effects in sound waves of finite amplitude’ appearing in the book *Surveys in mechanics*, which was published to celebrate G.I. Taylor’s 70th birthday. This chapter can be thought of as the initiation of the modern field of nonlinear acoustics (although, unlike aeros acoustic, it brings together the work of other people as well as Lighthill’s own: that of Burgers, Cole, Hopf, Whitham and Taylor). As befits a classic survey, the article begins with a careful outline of the fundamentals, in this case the thermodynamic properties of gases, followed by an analysis of the propagation and attenuation of small-amplitude sound waves, first (as was conventional) for known waveforms, but then deriving the equations from which the waveform can be calculated on the assumption that nonlinearity and viscosity are both small effects of comparable magnitude. Rational approximation for small values of the Mach number showed for the first time that a simple wave is governed by the Burgers equations, otherwise used merely as a (highly) simplified model for the Navier–Stokes equations. This equation was the key that unlocked much future research into nonlinear acoustics.

Subsequent sections of this chapter examine the structure of unsteady shocks by using the method of steepest descents; the merging of two shocks into one; the details of how a shock forms (involving use of the method of steepest descents for integrands with two nearly coincident maxima), demonstrating clearly how viscosity has a significant effect a long time before the shock is formed; and the generalization of everything to non-planar shocks propagating into undisturbed fluid, the analysis here being largely based on Whitham’s work. The final two sections concern shocks at moderate values of the Reynolds number (for small amplitude or in gases of higher viscosity), for which diffusion is important outside the shock as well as inside; and the relaxation effects that become important only at very high frequency. The dynamics of dissociating gases were considered in a pair of subsequent papers.

*Water waves: kinematic waves*

While he was at Manchester, Lighthill began to be interested in other sorts of waves, notably water waves. His first publication on the subject was like the paper discussed in the immediately preceding paragraphs, an investigation on the interaction between nonlinear and viscous effects, now in waves on shallow water. This was a famous joint paper with T. Brooke Benjamin (F.R.S. 1966) in which they showed that weakly nonlinear waves are capable of propagating away most of the energy that is necessarily lost at a hydraulic jump (or bore) when that jump is sufficiently weak, without the presence of wave-breaking or turbulence (10). The remainder of the energy is lost through laminar viscous dissipation at the jump. The reason for the discrepancy with gas dynamic behaviour, in which no shock, however weak, is accompanied by a propagating acoustic wave train, lies in the dispersive character of water waves: the fact that their phase velocity, and hence group velocity, depends on wavenumber. Apart from the clarity of its analysis and the importance of its conclusions, this paper was notable for its early recognition of the importance of the Korteweg–de Vries equation.
Lighthill’s next contribution to wave theory was another pair of (rare) joint papers, this time with Whitham, who was at this stage on the staff at Manchester (11, 12). The subject was kinematic waves, a term, and indeed a concept, invented by the authors to describe motions in which the dynamics is locally represented by a quasi-steady, quasi-one-dimensional balance between the flow rate of a conserved entity (mass, wavenumber, etc.), \( q \), and the amount of the entity per unit length, \( k \).

For flood waves in rivers, the principal fluid flow application, \( k \), is the cross-sectional area (proportional to depth for a rectangular cross section) and the balance is between gravity and friction, necessarily involving the small but significant free surface slope. The equation of conservation of the entity shows at once that disturbances propagate with speed \( c = \partial q/\partial k \), which will both be different from the entity’s flow speed \( v = q/k \) and will vary with \( k \), for all cases in which the \( q-k \) relation is not linear. Such variation with \( k \) means that wave speed varies with amplitude (‘amplitude dispersion’) so that discontinuities (‘kinematic shocks’) will tend to form on the front or back of a propagating disturbance, depending on the sign of the disturbance and whether \( c \) increases or decreases with \( k \).

In the first of the pair of papers, flood waves were indeed the principal area of application. In the second, the theory of kinematic waves was applied with brilliant originality to longitudinal waves in one-dimensional traffic flow on a long highway, modelled as a continuum in which \( k \) is the number of vehicles per unit length. Here the \( q-k \) relationship has to be obtained empirically, although it is qualitatively obvious that it must be linear for small \( k \), must reach a maximum, and must fall to zero again at some finite value of \( k \). It follows that shocks will form at the back of traffic surges, and this is indeed observed: the sharpest deceleration is required as we approach the rear of a jam, and once the traffic starts moving again it is normally possible to build up gradually but smoothly to full speed (such observations are of course affected by non-one-dimensional factors such as feeder lanes and lane changing).

During his time at Manchester, Lighthill supervised the research of large numbers of talented PhD students who have subsequently become national and international leaders in applied mathematics. Whitham being but the first. Although Lighthill had most of the initial ideas and in several cases performed much of the analysis himself, he adhered to the now defunct convention that a supervisor’s name should not appear on his students’ papers. All who worked with him comment on the generosity with which he shared (or rather, gave) his ideas, supported them in their later careers, and instilled in them his uncompromising intellectual standards. They also, especially his early students and colleagues, noted his ill-concealed impatience with the slowness with which they absorbed his ideas. The following is an extract from the valedictory resolution adopted by the Senate and Council of the University of Manchester on 4 and 17 February 1960, respectively, recording their gratitude for his contribution to that university:

Those of us who knew Lighthill in his younger days remember a man of almost frightening brilliance, a prickly mathematician intolerant of any argument which lacked precision and rigour, and devastating in his verbal attack on its author. His standards never changed: but his attitude towards people did. Latterly he would offer gentle criticism and advice and the most painstaking guidance; and his students, whether the brightest or the weakest, received the same patient interest and encouragement.

One might add that the mellow helpfulness did not begin to extend outside his circle of immediate colleagues until some time in the 1960s, but by the end of that decade it was bestowed on almost everyone.
Space does not permit a survey of all his students’ work, but one should be mentioned because of its role in developing Lighthill’s later contributions to biological fluid dynamics (see below). In the early 1950s Sir James Gray, F.R.S., Professor of Zoology at Cambridge, approached G.I. Taylor and James Lighthill for some hydrodynamic help in understanding animal swimming. Lighthill’s first contribution was ‘On the squirming motion of nearly spherical deformable bodies through liquids at very small Reynolds numbers’ (4), a highly idealized model of micro-organism swimming which nevertheless illustrates the principles that irreversible boundary motions are needed and that the mean swimming speed is proportional to the square of the (small) amplitude of those motions. Despite the apparent lack of biological realism, this model subsequently (in the 1970s) formed the basis of the successful envelope model of ciliary propulsion, developed initially by Lighthill’s student, J.R. Blake (1971).

Also in the early 1950s Lighthill had a research student, G.J. Hancock, who analysed the low-Reynolds-number hydrodynamics of swimming cells such as spermatozoa, that propel themselves through water by passing a wave of bending along a long, narrow, cylindrical flagellum, from cell body to flagellar tip. Hancock later became well known for the Gray–Hancock resistive force theory of flagellar locomotion (Gray & Hancock 1955), in which the normal and tangential components of the force exerted by an element of the flagellum on the fluid are taken to be directly proportional to the normal and tangential components of that element’s velocity relative to the fluid. The resistive force model is easy to use but rather crude, because it supposes that every element of the flagellum is independent of every other element. Hancock’s PhD research (Hancock 1953) consisted of the development of a new viscous slender-body theory, in which the flagellum, beating with a long wavelength, is replaced by a distribution of point forces and dipoles on its centreline whose strengths are obtained by solving an integral equation representing the no-slip condition on the cylinder surface. The fact that Lighthill’s name did not appear on the publication might explain why, when other, mostly American, scientists began in the 1970s to apply fluid dynamics to the study of animal locomotion, they were unaware of Hancock’s paper. Lighthill wanted to make sure it was given the recognition it deserved, and therefore made an extended version of that theory the centrepiece of his major review of flagellar hydrodynamics (32). The slender-body theory was taken further, with sophisticated computations, by other research students in the 1970s.

Lighthill’s first book was written while he was at Manchester: the remarkable, short (79 pages) and entirely mathematical Fourier analysis and generalised functions (14). Without any sacrifice of rigour, this book explained the theory of distributions in terms that applied mathematicians could both understand and use, in particular for the generation of asymptotic expansions using the method of stationary phase or steepest descents. There must be large numbers of mathematical scientists around the world who make frequent use of the excellent (and wonderfully compact) Table 1 in this book, which gives the Fourier transforms of powers of \( x \) or \(|x|\) and their product with \( \log |x| \), \( \text{sgn} \ x \) and the step function \( H(x) \).

**ROYAL AIRCRAFT ESTABLISHMENT**

In 1959 Lighthill was the unexpected choice as Director of the Royal Aircraft Establishment (RAE), which at that time had a staff of 8000 on more than one site. He helped the RAE to grow, in scientific excellence as in scientific manpower. Highlights of the programme during
his directorship included major developments in vertical take-off and landing, which led to the Harrier 'jump-jet', in supersonic transport aircraft, which led to Concorde; in automatic landing independently of weather; and in minimum-cost air transport, in which the phrase 'airbus' began to be used. Lighthill initiated collaboration with the neighbouring Institute of Aviation Medicine and inaugurated a powerful Space Department at the RAE (until then, the parallel between the RAE and NACA, the US National Advisory Committee for Aeronautics—later NASA—was rather close; it was later decisions of British governments that caused the RAE's subsequent decline). In hindsight, a weakness of the RAE at that time (shared by NASA) was a slowness to recognize the potential value of computers in aerodynamic design and therefore a lack of encouragement of computational fluid dynamics (CFD). It is doubtful whether Lighthill ever fully realized how computers could be used in qualitatively new ways, rather than merely calculating numbers inaccessible to even his human efforts.

Unprecedently, for a Director of the RAE, Lighthill continued to publish substantial scientific papers. However, the rate of production of original new ideas did slow down noticeably. Instead, he concentrated on works of synthesis, which of course had a huge influence on others. For example, his Bakerian Lecture to The Royal Society (17) was a masterly survey of the field of aeroacoustics, in which the many contributions that came after his foundation of the subject were summarized, evaluated and extended. In it he coined the word 'pseudo-sound' for turbulent or other pressure fluctuations that do not themselves propagate but can act as sound sources. Another synthetic work was his introductory pair of essays to Laminar boundary layers, which have already been mentioned.

Two, very different, original papers did appear in 1960. One, although only 13 pages in length (15), set out all the principal features of what has become the standard model of fish swimming, at least for those species that generate thrust by body undulation not by means of lift forces on a laterally oscillating lunate tail. This small-amplitude, slender-body (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 that is moving backwards relative to the fish at the approximately steady swimming speed. The theory also shows, with the use of an energy argument, that the mean thrust can be calculated from the displacement and slope of the fish centre-surface at the tail's trailing edge alone, which significantly reduces the number of observational data required to test the model. In that early, inviscid model, Lighthill also showed a full understanding 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 corresponding rates of change of the fish's transverse and angular momentum) 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. This paper, along with a contemporaneous one by T.Y. Wu (Wu 1961), initiated a whole new branch of fluid dynamics.

The other 1960 paper (16) showed that Lighthill had remained in touch with the work of his former student, G.B. Whitham, on waves in dispersive systems, a topic that would, like biology, become a major, post-Parnborough preoccupation.
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After five years at Farnborough, Lighthill spent the next five as a Royal Society Research Professor at Imperial College London, where he was also Physical Secretary and Vice-President of The Royal Society, and Editor of *Proceedings A*. Then, in 1969, he accepted the Lucasian Professorship of Mathematics in the Department of Applied Mathematics and Theoretical Physics at Cambridge (succeeding P.A.M. Dirac, F.R.S., not to mention Isaac Newton and G.G. Stokes, F.R.S., and preceding Stephen Hawking (F.R.S. 1974)). Here he threw himself with his usual enthusiasm into full-time research and teaching.

**Dispersive waves, ray-tracing and geophysical applications**

Lighthill’s work on aeroacoustics naturally made him think more widely about waves radiated away from a localized disturbance in other, homogeneous but dispersive, wave-bearing systems. Surface waves on deep water are the most obvious example, in which the medium is isotropic in the two horizontal space directions, but others include internal gravity waves in a stratified fluid, inertial and Rossby waves in a rotating fluid, magneto-hydrodynamic waves in conducting fluids and plasmas, and elastic waves in solid media, in most of which the wave propagation is anisotropic. In the context of linear waves, Lighthill wished to predict which distant points would experience significant wave activity and when, and what pattern of waves of different wavenumber vectors would be seen there. Today we all ‘know’ that the answer is that the energy in waves of a given wavenumber $k$ is transmitted with the frequency (or frequencies) $o(k)$ and at the group velocity $U(k)$ appropriate to that wavenumber. It also seems obvious that the mathematically most convenient way to demonstrate this is by means of spatial Fourier transforms whose inverses can be evaluated at large distances from the source using the method of stationary phase. However, in the 1950s neither the result nor the method was well known in fluid mechanics, and it was largely Lighthill who made them so.

The main contribution of Lighthill (16), further extended in a paper entitled ‘Group velocity’ (19), was mathematical, to develop the method of stationary phase in three dimensions for anisotropic media. This is in fact reasonably straightforward, given that it can be done in one dimension, as long as one ensures that the eventual solution satisfies the ‘radiation condition’, i.e. that only waves in which the energy flux (group velocity) is directed away from the source are acceptable consequences of a localized disturbance in a homogeneous medium.

The stationary-phase asymptotics reveal clearly that, sufficiently far from a general localized source, in a homogeneous medium in which sinusoidal waves of wavenumber vector $k$ have frequency $o(k)$, waves of different frequencies become dispersed, i.e. the waves are approximately sinusoidal locally with a wavenumber that varies gradually over a distance of many wavelengths. This then opens the way to the techniques of ray-tracing, originally developed for geometrical optics in dispersive media such as crystals; gradual spatial variation of the wave-bearing medium and, especially, non-uniform motion of the medium relative to the wave source are also permitted. The predictions for moving media, coupled to the great simplicity of the mathematical treatment, are the major novelty of Lighthill’s and Whitham’s contributions relative to geometrical optics.

Application of ray-tracing methods to reveal and understand physical phenomena abound, in Lighthill’s publications and elsewhere, particularly in Whitham’s. For example, Kelvin’s ship wave pattern can be deduced extremely simply by considering zero-frequency
waves in a medium moving at uniform velocity $V$ relative to the point source of disturbances. The refraction and increase in amplitude of initially planar surface gravity waves on the ocean, as they approach a sloping beach, is also very simply analysed. Sound waves in a moving medium form the subject of a survey paper (28), although only two sections are concerned with ray-tracing.

Internal gravity waves in a stratified fluid are particularly interesting, from a ray-tracing perspective because, when the fluid is stationary, the group velocity is perpendicular to the phase velocity, i.e. parallel to the wave crests (see (34)). This non-intuitive result was confirmed experimentally by Mowbray & Rarity (1967), whose photographs are reproduced in both Lighthill's (34) and Whitham's (1974) books.

A further atmospheric or oceanic application of linear ray-tracing theory was made by Lighthill (22), in the context of rotating fluids, to study Rossby waves generated by a steady or time-dependent source in a wind. (Rossby waves arise in the oceans or atmosphere as a result of the variation of the vertical component of the Earth's angular velocity with latitude.) The results of the theory reveal significant differences between the wave patterns produced in easterly and westerly winds.

The reason for studying waves in rotating fluids of course stems from the desire to understand the complicated flow phenomena in the atmosphere and oceans. Geophysical fluid dynamics had been developing rapidly as an important and interesting research field since the mid-1950s, and when he returned to academia from the RAE Lighthill made several contributions. In addition to the pure wave theory discussed above, Lighthill (21) wrote a survey of the dynamics of rotating fluids. The first half of the survey discusses large-scale motions, in both thin layers of rotating fluids (such as the atmosphere or ocean) and 'fat' bodies of fluid such as laboratory tanks, entirely from the point of view of vorticity. As in many of the substantial papers published by Lighthill in the mid-1960s, this one did not discuss new phenomena or develop any intrinsically new theories, although it did bring together several disparate strands of the subject in a masterly way and totally changed many practitioners' views of their own subject.

The brief section in (21) on wind-driven ocean currents was followed up by a major 47-page paper (24) on the dynamic response of the Indian Ocean to the onset of the South-west Monsoon. This was more like the pre-RAE Lighthill, in which he first explains at (great) length the practical problem that needs solution, in this case the mechanism by which the Somali current is regenerated every Northern summer when the prevailing wind changes direction and blows from the southwest, and then he provides all the details of a theory to solve the problem. His proposed mechanism proves to be consistent with the observed one-month time-scale for development of the current, which is contrasted with the time-scale of decades predicted by a similar theory for a mid-latitude ocean such as the North Atlantic (Veronis & Stommel 1956). This Rossby-wave mechanism has since become part of our understanding of tropical ocean dynamics and its role in El Niño, for example.

The linear, ray-tracing theory for high-frequency dispersive waves breaks down at caustics. These are curves separating regions of complicated behaviour, for example those covered by two families of rays, from regions of simple behaviour, for example with no waves. In a homogeneous system, in particular, caustics are made up of points at which two rays come together. In a dispersive medium, linear theory can usually be used to smooth out the inconsistency of ray theory, but in practice the wave amplitude often becomes large and the linear theory may be inapplicable. In any case, it is essential to know how the predictions of
linear theory will be affected when the amplitude is no longer infinitesimal. Once more, Whitham paved the way with his derivation of the (nonlinear) wave propagation equations in a slowly varying medium from a variational principle involving an averaged Lagrangian. Lighthill (20) performed some typically intricate calculations with Whitham’s equations, but they are so complicated that even he eventually recommends experiments as the best way of seeing what really happens next.

Lighthill’s other major contribution to the theory of nonlinear dispersive waves was the organization in 1967 of a Royal Society Discussion Meeting on the topic. This contained significant surveys, containing original contributions, from many distinguished wave experts, including Benjamin (on the Benjamin–Feir side-band instability of uniform wave trains) and Whitham (reviewing his variational approach to wave propagation). Lighthill’s own paper was concerned with working out in detail various consequences of Whitham’s theory, including a modification of Benjamin’s theory that improves its agreement with experiment.

Lighthill wrote several other papers on topics in wave theory—for example on wave generation by wind, on wave-energy devices, and on the wave loading of offshore structures—but after the succession of substantial papers in the mid-1960s there is no doubt that his major effort in the field was the writing of the book Waves in fluids, which was eventually published in 1978. It was closely related to a course for final-year undergraduates that he gave at Cambridge for several years in the 1970s and was divided into four main chapters: (i) the three-dimensional propagation of linear sound waves; (ii) one-dimensional non-dispersive waves in tubes or channels, incorporating sound waves, shallow water waves and pressure waves in elastic tubes, and including Riemann’s theory for nonlinear waves leading to shock or jump formation; (iii) water waves, as a simple introduction to dispersive waves and group velocity; and (iv) internal waves in stratified (and moving) fluids, given a great exposure partly because of their intrinsic interest but primarily as a vehicle for the exposition of group velocity (by Fourier analysis) and of ray-tracing for linear waves, as described above. The epilogue introduces a variety of other waves in fluids and makes brief mention of the effect of nonlinearity on dispersion.

The style of the book is predictably Lighthillian. Although the subject is intrinsically highly mathematical, everything is explained physically, in words, with as little mathematics as possible. It is probable that many students who are well-trained mathematically but are unaccustomed to either physical thinking or long sentences do not find this an easy way to learn about wave theory and prefer Whitham’s (1974) book instead. However, students with less mathematics, in engineering or physics departments and certainly students who are simultaneously taking a course on the mathematical theory, find the approach extremely illuminating. When asked if he thought Waves in fluids would be found useful in the future, Lighthill replied that Lord Rayleigh’s Theory of sound was still a mine of information and understanding 100 years after its publication, and he did rather see himself as a modern Lord Rayleigh. Why not?

**Biological fluid dynamics**

During the 15 years that he spent at Imperial College and Cambridge, Lighthill totally transformed the study of biological fluid dynamics. He wrote major reviews of aquatic animal propulsion (25) and animal flight (30, 33) as well as low-Reynolds-number flagellar hydrodynamics (32). Each of these is characterized by an exhaustive survey of the animal kingdom to make sure that all actual modes of locomotion are covered by the preliminary fluid-
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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 both demonstrate his mastery of the relevant taxonomic terminology and make his fluid-dynamical audience feel at home by incorporating standard terms from aeronautics, for example. In addition he gave dramatic, large-scale demonstrations of the body movements exhibited by the animals in question. (There was one famous occasion when, in a Polish bar in 1969, he lay on the floor to give a remarkably realistic impression of a swimming seal.) He himself concurrently made major advances in fluid-dynamical analysis in all three areas.

For fish swimming he extended his elongated-body theory to increasingly realistic shapes and to large-amplitude body motions (26, 27), although in fact a momentum argument shows that the thrust can still be calculated from essentially the same formula as at small amplitude. The main weaknesses of the theory, which are not very important for fast forward swimming in a straight line at approximately constant speed, are that it ignores the effect of the vortex wake on the pressure distribution over the fish body and that the flow over the body does not satisfy the correct 'Kutta' condition at the trailing edge. Only recently have these deficiencies been partly rectified. Also in his 1971 paper, Lighthill gave a preliminary analysis of the lunate tail. Both large-amplitude elongated-body theory and lunate tail analysis were taken further by visitors to Cambridge in the early 1970s (notably D. Weis, M. Chopra and T. Kambe). Lighthill himself returned to fish swimming after he had retired from University College London, through a series of four papers on 'Balistiform and gymnnotiform locomotion', one of them with a former zoology student, R. W. Blake (36). More recently he gave a fascinating analysis of how a herring can control the motion of its head to enable its lateral-line neuromasts to sense pressure differences, across the head, of external origin without being swamped by self-generated pressures (37).

In the context of flight, Lighthill used his encyclopaedic knowledge of aerodynamics to inform his major reviews (30, 33) and initiate several new avenues of research. The most novel stemmed from his collaboration with the then Professor of Zoology at Cambridge, T. Weis-Fogh, and led to an elegant analysis (and some dramatic impersonations) of a newly observed mode of lift generation in small hovering insects, the clap-and-fling (29). But he also had many new ideas for the 'normal' flight of birds, bats and large insects, and these were put into effect by a PhD student, J. M. V. Rayner, who subsequently took the ideas much further.

Despite his pivotal contributions to external, or zoological, fluid dynamics, it is arguable that Lighthill's most significant contribution to the field came in internal, or physiological, fluid dynamics. Moreover, this was not through his publications but through his administrative vision. In the middle 1960s he joined forces with C. G. Caro, a clinician and physiologist 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 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 atherosclerosis.

Lighthill's own contributions to physiological fluid dynamics were restricted to two papers in the JFM. One of these was another of his inimitable surveys; the other was a model for the motion of a red blood cell along a narrow capillary (23). Here he assumed that the elastically deformed cell was a tight fit in the vessel so that lubrication theory could be used for the layer of plasma between the cell and the vessel wall. The analysis for large values of the
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dimensionless parameter representing the ratio of viscous to elastic forces (which he called \( L \), for some reason) involved the intricate matching of six differently scaled regions. Unfortunately, and most unusually, this paper had two major weaknesses. One was that the model chosen for cell (and vessel wall) elasticity—a linear relation between pressure and displacement—is so far removed from biological reality as to be highly misleading. The other, more egregious, weakness was an actual fluid-mechanical error: Lighthill omitted the contribution to the force balance on the cell from the pressure in the lubrication layer, which is really of the same order of magnitude as the contribution from shear stress. He was hugely embarrassed when this error was pointed out to him by Richard Skalak, and the paper was suppressed from his collected works.

In the 1970s Lighthill’s own contributions to physiological fluid dynamics consisted of a few chapters in his 1975 book *Mathematical biofluiddynamics* (31). Most of the chapters in that book were reprints of his earlier papers, but the chapter on the propagation of the pressure pulse in arteries, in particular, was specially written and is an extremely clear, simple and yet thorough analysis of pulse wave dynamics.

Shortly before leaving Cambridge for University College London in 1979, Lighthill teamed up with an experimental psychologist, Donald Laming, to investigate the function of the inner ear. For several years thereafter, when his time was dominated by administration, this topic formed the main focus of his research. His principal contribution was the demonstration 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 (35).

**University College London**

Ten years in Cambridge were enough for the Lighthills, and James was missing the much wider influence that he had been able to exert as the leader of a large organization, so in 1979 he was happy to be appointed as Provost of University College London (UCL). Here he was both extremely successful in enhancing UCL’s already outstanding academic strength and enormously popular. He got to know every professor, and many other members of staff, personally, and was famous for being able to summarize a colleague’s research in a few minutes, more clearly and compellingly than the colleague could himself or herself, after hearing about it only once, and in humanities or biomedical science as much as physical science. The formidable memory really came into its own here. He also made it a high priority to encourage women academics to fulfil their potential and he regarded it as a major achievement that the number of women in senior academic positions at UCL increased dramatically (from 4 professors to 15, for example) while he was Provost. The administrative load at UCL was heavy, and Lighthill was (for once) unable to devote much time to personal research, but other aspects of life were not excluded altogether. Among the more enduring memories are concerts of the UCL Chamber Music Society in which Lighthill performed, often as soloist, at least once a year. These continued well after his official retirement in 1989, when James and Nancy shared an office in the Mathematics Department at UCL, James being an Honorary Research Fellow (once more ‘being able to devote myself to full-time research’).

Throughout his career Lighthill had a major influence on many important scientific committees and societies. He was a member of the Fluid Motion Sub-Committee of the Aero-
nautics Research Council from 1948 until he went to Farnborough (and was Chairman from 1952). In 1959 Lighthill was responsible for initiating a series of annual conferences called the British Theoretical Mechanics Colloquia, of which the first was (of course) held in Manchester. These colloquia rapidly became the main forums for British applied mathematicians, and indeed are now called the British Applied Mathematics Colloquia (BAMC). Lighthill gave the last of his many invited lectures at the BAMC in 1998, entitled 'A century of shock-wave dynamics'. He also campaigned for the founding of the (British) Institute of Mathematics and its Applications, a professional and learned society fulfilling the role of an engineering institution but for mathematicians, and was its first President (1964–66); he was Physical Secretary and Vice-President of The Royal Society (1965–69); President of the International Commission on Mathematical Instruction (1971–74); President of the International Union of Theoretical and Applied Mechanics (1984–88); Chairman, International Council of Scientific Unions Special Committee on the International Decade for Natural Disaster Relief (1990–95). Lighthill was a source of advice and inspiration for many international bodies. He had a particularly strong influence in India, where he encouraged the Indian Institute of Technology (IIT) in Delhi to host international Winter Schools, first on Physiological Fluid Dynamics in 1975, and then, more significantly, on Monsoon Dynamics in 1977. He helped the IIT set up the Centre for Atmospheric Science, and the result is an unusually well-focused research effort on fluid dynamics of genuine Indian importance. A number of Indian scientists benefited greatly from one- or two-year spells working with Lighthill in England.

He chaired committees of The Royal Society and other bodies on various topics including postgraduate training in the UK (1968 and 1969); the future of telecommunications (1978); and most famously (or notoriously) on artificial intelligence, where he came down in firm support of the view that research in such a topic would be a waste of time and money (Science Research Council 1973). He served on the Post Office Board for two years (1972–74) at the time when long-distance telephone direct dialling was introduced into Britain, accompanied by an impenetrable national system of different-length area codes. (He was once in a conversation with other senior academics when one of them (David Crighton, F.R.S.) asked 'What idiot dreamed up this crazy system?'. James said 'I did'.) He was Chairman of the Oceanography and Fisheries Research Committee of the new Natural Environment Research Council from 1965 to 1970, and this enabled him to coordinate the programmes of laboratories such as the National Institute of Oceanography and the fisheries research laboratories at Lowestoft and Aberdeen, as well as to stimulate his own geophysically oriented research.

Of lasting importance for fluid dynamics was the fact that James was one of the founding Associate Editors of the *JFM*, despite having a very different approach to that subject (and many others) from George Batchelor, the founder and Editor. His style was idiosyncratic but effective. As an author this writer well remembers receiving a long letter the day after he had submitted a paper, which read something like, 'My Dear Tim, The referees [plural] are absolutely delighted with your new paper and I am very happy to accept it. However, it might be slightly improved if you alter sections 3 and 4 along the following lines…', whence followed a substantial remodelling of virtually the whole paper.

Lighthill received many honours, of which important British ones were Fellowship of The Royal Society in 1953, Fellowship of the Royal Aeronautical Society in 1961, the Royal Medal of The Royal Society in 1964, a knighthood in 1971, and the Copley Medal of The Royal Society, posthumously, in 1998 (the letter informing him of this award reached his home on
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The hugely prolific corpus of totally original work produced by Lighthill in the late 1940s and the 1950s is enough to justify his designation as one of the greatest applied mathematical scientists there has been, certainly in fluid dynamics. As indicated above, he was for a time the dominant personality in the theory of supersonic aerodynamics, the theory of perturbations to boundary layers, aeroacoustics, shock wave theory, nonlinear acoustics, and biological fluid dynamics. He made lasting influential contributions to the general theory of waves in fluids, to the description of fluid flows from the point of view of vorticity, to the development of powerful mathematical methods, both exact (Fourier analysis) and asymptotic, and to many smaller corners of fluid dynamics.

However, the nature of his contribution changed after he left Manchester for the RAE, and not only because of his large administrative burden both then and thereafter. Most of his later contributions involved fewer original ideas and were more a process of synthesis, of other people's work as well as his own (notably Whitham's, in the waves context), in papers that were not explicitly of a survey character as well as those that were. Even in the analysis of fish swimming, which one associates with his great biological period from the mid-1960s onwards, all the main original ideas appeared in the brief 1960 JFM paper. Presumably this change in emphasis, familiar in the work of many scientists and mathematicians, comes in part from the increased bureaucracy of senior academic life, in part from the increased external activity brought about by fame, and in major part from the desire to have a wider influence, to initiate more research, both through an increasing number of colleagues and students and through the writing of widely accessible reviews. However, although the consequent influence can, as with Lighthill, be enormous and of tremendous value to others, the really sharp, original thrusts of entirely new discoveries tend to become somewhat blunted.

The topics of Lighthill's research naturally changed with time, although it is remarkable that he published almost nothing on aeronautics or even aeroacoustics after leaving Farnborough in 1964 (possibly in response to the British government's niggardly treatment of the RAE and of aerospace research in general). However, his principles did not change: the need to explain one's results physically, in words, to the 'user'; the need to see things oneself from all possible viewpoints (equations, words and pictures); the need in collaborative research to engage fully with one's collaborators (whether biologists or meteorologists or engineers) and their experiments to develop a full understanding of what is important to them; and the desire to share his profound belief in the significance of fluid mechanics in many aspects of our world.
SWIMMING

No account of James's life can be complete without reference to his principal form of physical recreation: swimming. Many of the anecdotes that relatives, friends and acquaintances recall most vividly concern his swims, such as the time he was arrested for swimming in a restricted area of Puget Sound, or the time he was accompanied for several minutes by a basking shark while swimming round Lundy Island in the Bristol Channel, or the time in the early 1980s when he was forced to abandon a swim round Ramsey Island off the southwest corner of Wales because the waves and currents were stronger than he had expected—he clambered ashore over some abrasive barnacle-covered rocks, and was striding across the island to the side nearest the mainland when he met the owner of the island, who was somewhat taken aback to meet a very large man, wearing only sneakers and bathing trunks and covered in blood, walking across his private property. The owner offered to call the coastguard to take James back to Nancy on the beach but he declined, re-entered the sea and returned to Nancy and the cans of Guinness with which he liked to restore himself after long swims. The man called the coastguard anyway.

Every year from the age of 40 James would embark on an 'adventure swim', if possible round an island. Planning would begin months ahead with a study of the tides and tidal currents round the island concerned, so that the best dates for the holiday could be determined and the best swimming strategy worked out. Probably the most exciting island was Stromboli, while the volcano was erupting, but James's favourite was Sark, in the Channel Islands (where the tides are extremely high). He was the first person ever to swim round Sark, at the age of 49, and he successfully repeated the feat five times. On a calm day the swim would take him about six hours using the unusual but effective stroke that he called 'old English backstroke' (a sort of back-butterfly with breast-stroke leg motions). On 17 July 1998 he had almost completed the swim once more, having been in the water nine hours (the sea was a bit rough), when his mitral valve ruptured and he died. Given the choice, he would probably have chosen this way to go, eventually, though he would not have wished to cause the distress that his immediate family have experienced.

ACKNOWLEDGEMENTS

I am very grateful to Lady Lightihill for access to James's personal papers, to The Royal Society for access to James's personal record, to Freeman Dyson, F.R.S., for permission to quote from his and James's correspondence and to all those colleagues and friends of James's who sent me memories and anecdotes that have moulded my own appreciation of him. Most of Lightihill's published papers are reproduced in the four volumes of collected works, edited by Y. Hussaini and published by Oxford University Press in 1997.

A longer, more technical version of this memoir, entitled 'James Lighthill and his contributions to fluid mechanics', has been published in Annual Review of Fluid Mechanics 33, 1-41 (2001).

The frontispiece photograph was taken in 1967 by M.J. Wallace, and is reproduced with permission.

REFERENCES TO OTHER AUTHORS

Michael James Lighthill


BIBLIOGRAPHY

The following publications are those referred to directly in the text. A full bibliography appears on the accompanying microfiche (used by permission of Oxford University Press, Inc.). A photocopy is available from The Royal Society's Library at cost.


On waves generated in dispersive systems by travelling forcing effects, with applications to the dynamics of rotating fluids. *J. Fluid Mech.* 27, 725–752.


Aerodynamic aspects of animal flight. Fifth Fluid Science Lecture Arranged by the British Hydromechanics Research Association. (30 pages.)

*Mathematical biofluiddynamics.* Philadelphia: SIAM.


*Waves in fluids.* Cambridge University Press.


Estimates of pressure differences across the head of a swimming clupeid fish. *Phil. Trans. R. Soc. Lond. B* 341, 125–140.