# SIR JAMES LIGHTHILL AND HIS CONTRIBUTIONS TO SCIENCE

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## ABSTRACT

Michael James Lighthill born in 1924 is considered by many of his contemporaries to be one of the greatest applied mathematicians and fluid dynamicists of the twentieth century. His papers on jet noise theory written in the 1950s were the first on this topic and have become famous and are referenced extensively. He also did much important original work in many other areas including shock wave theory, biofluiddynamics, wave mechanics, oceanography, atmospheric dynamics, tropical cyclones, typhoons and hurricanes, and magnetohydrodynamics which has been partly overshadowed by his jet noise papers. In addition to his scientific achievements he held several important administrative posts, although at the same time continuing his scientific work. He was knighted in 1971 as Sir James Lighthill. This paper begins with some biographical details and continues with discussions of his major scientific contributions and some of his administrative achievements made during his career. Also some information about his interests in music and swimming is given in order to try to present a balanced picture of him as a person.

## INTRODUCTION

Those of us who are members of the International Institute of Acoustics and Vibration (IIAV) will know Sir James Lighthill as the charter IIAV President from the foundation of IIAV in 1995 and its first elected President after December 1997. Many will have heard his presidential lectures in 1996 and 1997. Most of us will be aware of his seminal work in aerodynamic noise theory and his famous velocity to the eighth power law. But many may not know about his earlier scientific achievements and his other contributions in so many different scientific areas. It is the purpose of this paper to present some less well known aspects of his life and scientific accomplishments. I will begin this paper, however, with a few general introductory comments about his career and his scientific approach to problems.

Michael James Lighthill was born in January 1924 in Paris. He attended Winchester College and at the age of only 15 was admitted to Cambridge University although he did not attend until he was 17. In 1943 he became involved in supersonic aerodynamics as part of the war effort. In 1946 after a brief period back at Cambridge he went to Manchester University where he was promoted in 1950 to Professor. In 1959 at the age of only 35 he became Director of the Royal Aircraft Establishment (RAE) at Farnborough. In 1965 he became the Royal Society Research Professor at Imperial College London and then in 1969 he went to Cambridge University as the Lucasian Professor. His last post was as Provost of University College London as which he served from 1979 to 1989.

He regarded every obstacle whether it was a mathematical or physical problem, learning a foreign language or piece of piano music, or attempting one of his famous "adventure swims" as simply a challenge to be overcome by his scientific intellect, physical endurance and strength.

His scientific papers are characterized by their lucidity and by the interdisciplinary perspective with which he views the physics of the problem under consideration. In his papers, Lighthill would normally study a physical problem breaking it into a number of clearly defined sub-problems, which he would approach with powerful mathematical tools. And if the mathematical tools did not exist he would invent his own. His books: "Introduction to Fourier Analysis", Cambridge, 1958 and "Higher Approximation in Aerodynamic Theory", Princeton, 1960 are early illustrations of his brilliance in these areas.

Sir James was also an able and energetic administrator as Director of the Royal Aircraft Establishment, Farnborough, 1959-1964 and Provost of University College, London, 1979-1989. Nor did his retirement in 1989 put a stop to his scientific enquiries and publications, which he continued extensively to the end. His scientific activities and achievements are very much linked to his academic and administrative positions during his career.

Lighthill wrote a large number of mathematical papers and books, and achieved so much in his career, that it is difficult to know how to write about his many achievements. Although I could have included sections on his contributions in different specific areas, I decided in the end to approach this paper in a chronological way. Thus I have mainly divided the paper into different periods of his life together with some general discussions of his scientific contributions made during those periods. I have also included some other sections concerning his swimming and other activities.

Of course a mere listing of his achievements can never really describe Sir James adequately. During the last few years when I came to know him quite well, my impression of him was of a person of boundless enthusiasm and curiosity about the physical world. Like the high-speed, high-altitude Concorde whose design problems he studied at RAE when he was director, his brain operated at a much higher speed and higher level or altitude than those of most of us mere 'mortals.' His scientific work was characterized by his approach of studying each chosen topic in depth so that he could know it better than even the experts and become very confident of his knowledge of the area. He also strongly believed that scientific research was of no real value unless it was shared with others in the scientific community. He was thus very interested to write up and publish all of his scientific work. His writing is characterized by its clarity. It always starts with a concise formulation of the problem, next the theoretical analysis and comparison with experiment or observation of the physical world, and then finally the conclusions.

There have been various obituaries and/or articles written about Sir James and his scientific contributions.[1-7] Some were written very soon after his death and are brief and some have minor inaccuracies. The obituary written by David Crighton, however, is extensive and very useful.[1]

## EARLY YEARS AND THE LIGHTHILL NAME

Lighthill's paternal grandfather, Christian Adolf Lichtenberg was born in Denmark in 1841. His maternal grandfather was a Yorkshire engineer named L. W. Holmes. The Lichtenberg family traced its origin back to Alsace. At the age of 21, Christian Lichtenberg emigrated to Liverpool, England in 1861. He began working for a beef importing company. He married the owner's daughter and moved to a senior position in the company and ultimately he became its manager. Several children were born and one of their children, Ernst Balzar Lichtenberg, became a mining engineer in England. Ernst found it difficult to get an engineering job in England during the First World War because of his German-sounding family name and the intense anti-German feeling at the time. Thus he decided to change his name from Lichtenberg to Lighthill and made the necessary announcement in the Times newspaper.[8,9] He took his family to France soon after the 1914-18 war ended, first managing a quarry in the Creuse area of France and then moving to Paris.

Michael James Lighthill was born on 23 January 1924 in the rue Michel-Ange, Auteuil in Paris. He was the youngest of the three children. He had an elder brother Olaf, and an elder sister, Patricia. Figure 1 shows the young James at 18 months while he was still living in France.

*Fig. 1 James Lighthill at the age of 18 months purposely going to the golf course.*

The Lighthill family moved back to England in 1927 and settled in North London living in a flat at the bottom of Highgate West Hill. James first attended Byron House, Highgate, a pre-preparatory school for children up to the age of 11, and was escorted there each day by his elder sister Patricia. According to Pat, his mathematical gifts were evident from the start. "When we first arrived at Highgate and before (James) started school, he amazed the local butcher by measuring every surface in the shop and writing the figures down in a little notebook."[8] Much of James' early education, in fact, came directly from his father. For his fourth birthday his father gave him an unusual gift for his age. As James was to say later: "Throughout my life I've extensively used the superb 11th Edition (1910) of the Encyclopedia Britannica, which I received as a 4th birthday present in 1928...." [9], and "My father had already retired at the earliest date I can remember, and gave me the best part of my education from three to eight, although I also attended kindergarten school. I learnt from him unusual amounts (for my age) of arithmetic, algebra and geometry, geology, astronomy and paleontology. When I was seven, an intelligence test established my mental age as fourteen, but I am sure that this was in great measure due to my father's instruction in so many things." [9]

James was thus quite a precocious child and usually was allowed to study at school along with children much older than himself.[10] When James was eight he became a boarder at Boxgrove School near Guildford. Figure 2 shows the young James at the age of eight. He was taught mathematics well at Boxgrove by Mr. Coombes and on the strength of his mathematical knowledge at the age of 12 he was placed seventh in the entrance examination to Winchester College winning a scholarship.[9]

*Fig. 2 James at Boxgrove School*

## WINCHESTER COLLEGE

When James Lighthill went to his high school, Winchester College, in 1936, as a scholar, he lived in the College (i.e. the school's oldest buildings where all the scholars lived.) He had several notable contemporaries, whom he got to know well: Hugh Sisam, Freeman J. Dyson and H. Christopher Longuet-Higgins. Some of the teachers had a strong influence on James Lighthill, especially Eric James in the humanities. C. V. Durrell's influence on James was mainly through his admirable books.[9]

James immediately became a firm friend of Freeman Dyson, another student of the same age. They both shared a passion for mathematics and for four years at Winchester they worked together almost constantly on mathematics ranging in topic far beyond that offered by the college curriculum.[11] Because they were so far ahead of many of the other students, they managed to persuade their teachers to allow them to study mainly on their own from books.[9,10,11] Their method was to read all of the mathematics books they could find in the college library, which had a remarkable collection, almost unknown to the college teachers. In addition they bought others.

James read *Principia Mathematica* by Whitehead and Russell at the age of 14, but the defining moment came soon after when James discovered the three dusty volumes of Camille Jordan's "*Cours d'Analyse*" and immediately recognized its immense value. Working through this book carefully, page by page, James and Freeman attained a deep understanding of the level that classical mathematics had reached during Jordan's period as lecturer in the Ecole Polytechnique of Paris in 1909.[9,11] "The physics teaching at Winchester was particularly good - conducted purely on the heuristic method. We had to weekly English Essays to write. We were examined on 14 plays by Shakespeare, two books of (Milton's) *Paradise Lost* and 'all the literature since 1800,' but we took no public examinations except the School Certificate."[9] Figure 3 shows James dressed formally at Winchester.

*Fig. 3 James dressed formally at Winchester College*

During their fourth year at Winchester, at the age of fifteen, both James Lighthill and Freeman Dyson took the entrance examination in December 1939 to Trinity College, Cambridge and won scholarships.

## A Period of Preparation and Self Study

Trinity College, however, would not allow James and his friend Freeman Dyson to go to Cambridge as undergraduates in September 1940, but instead held the scholarships open for them until October 1941. So their parents decided to keep them at Winchester for a fifth year. Although Freeman stayed and received some extra tutoring, James took matters into his own hands.

During the Christmas holidays at the end of 1940, James made contact with Storton Steen, a well known Cambridge algebraist and lecturer at Christ's College.[11] His knowledge and enthusiasm impressed Steen. Steen, together with Wilson, an applied mathematician at Trinity College, tried to get Lighthill and Dyson admitted in January 1941.

The sixteen-year old James' knowledge of and enthusiasm for mathematics can be gauged from his own words in a letter from St. Fabians, Newmarket to Freeman Dyson on December 28, 1940.

Dear Freeman:

"I had an interesting interview today with a man called Steen about which I thought I might tell you. He has done a lot of work on Hilbert space, continuous geometry and lattices. Continuous geometry is one in which any two spaces of the same dimension have in common a space of lower dimension: thus while in geometry two planes meet in a line, two lines in a point, you cannot go any further. In continuous geometry this is possible and a representation to prove constituency of axioms has been drawn from the theory of infinite matrices……. Lattices it seems are pseudo-rings, that is groups of entities closed with respect to double descriptive functions which behave like union and intersection in class-theory except for the distributive axiom, which is not assumed. The lattice then is a generalisation of the theory of propositions, classes, continuous geometry,…… , probability logic and quantum mechanics, etc. And he talked quite lot about some of these subjects, notably probability logic (which he said could be regarded in 2 ways) which seemed to correspond to taking the limit of a system with truth-values 0, 1/n, 2/n, ….., (n-1)/n and one with 0, 1, 2, … , n ….. About books he said that yes Hilbert-Beynays was the book to get but suggested no means of getting it - but I am seeing him at his house in Cambridge soon and I will see if I can borrow it. …….. I have got books for Xmas including the 3 Cambridge tracts (Rational Quartic, Conformal Representation, and Integral Bases) which look very good; "Differential Systems" by Thomas (Amer. Math. Soc.) which I have read a lot of and certainly says a lot of sound things; and Carnap's "Logical Syntax of Language" which I am also impressed with. My books from Foyle's (*a large book store in London*) have not yet come: I must write to them again soon….. Well I will write to you as soon as anything important happens. I shall be able to tell you more about Carnap, etc. then too. If you have any comments to make, do so. This letter has been very scrappy, but at any rate everything it says is true. Yours, James." [11]

The sixteen-year old James' voracious appetite for mathematics books was still unabated because in only three days on December 31, 1940 he was writing again from Newmarket to Freeman Dyson.

"Dear Freeman,

….. I am afraid that we have crossed letters. About your books I especially support Veblen, Lefschetz, and the 2 Dicksons and the various. But I have none of them at all. I hunted Cambridge for Veblen without success, but have got Moore's "Foundations of Point Set Theory" (30/-) (*i.e. 30 shillings*) which is very comprehensive tome and will take some reading. So don't bother about Young. I shouldn't get Frenkel myself but you may want to. What I should like to get is Littlewood "Theory of Group Characters" (Oxford, 1940) which I saw in Bowes and Bowes and which pleased me greatly but (*I was*) penniless. I also tried to get Quine but I did not want to order it without seeing it. If you ever you want an Amer. Math. Soc. Book, Bowes and Bowes have almost all of them. I do not understand how you hope to haggle for Baker but still. Carnap is trying to develop the syntax of his symbolic language within the language itself by a subtle "arithmetization" process as in Goedel's theorem. Steen is having a good time *(trying to get the two youngsters admitted to Trinity College in January 1941)* but nothing has definitely come out. Get Veblen especially. Yours, James.

…. Fresh news. Drama. Mr. Steen has 'phoned saying that he and M. Wilson agree now that nothing must be allowed to stop us going. You will know this by the time this reaches you. But do try as hard as you can to pull it through. It's a choice between January and October, between 3 years and 2 years at Cambridge before calling-up (*for the war effort*), between taking Part II in 1942 and 1943, between getting an assured research studentship before we are called up and not, between spending the next 9 months worth-while-ly and feeling frustrated in Winchester. Wherefore I deem it worth a little fuss and bother, and even exercise in ingenuity. M.J.L." [11]

But this was not successful, since Trinity College resisted the efforts of Steen and Wilson to get them admitted early and they had to wait until September 1941 for admission. James left Winchester in April 1941, but remained in Newmarket taking as he said a "long vacation" reading voraciously and supplying Freeman Dyson with books from the Cambridge bookshops. Dyson went back to Winchester where the College arranged for him to receive some private tuition from Daniel Pedoe (then a mathematics lecturer at University College Southampton.)[9,11]

## CAMBRIDGE UNIVERSITY

Arriving at Cambridge in 1941, Lighthill concentrated on pure mathematics (analysis, algebra, topology and so on) under the guidance of G. H. Hardy, J. E. Littlewood, P. A. M. Dirac and A. S. Besicovitch. The rule was then that, because of the war, no student could have more than two years' university education. So knowing that they were already at an advanced stage in their mathematical studies and that they would not get a chance later, he, together with Dyson, only attended the Part III *(i.e. postgraduate)* lectures.[9,10]

There were very few postgraduate students at these lectures because most of the students had had to leave to take part in the war effort. (Lighthill would say later: "We were pushed out after two years because of the War"). He also did very little applied mathematics (only mugging it up before the examinations.)[12] Most of the applied mathematics faculty had also had to leave to take part in the war effort. Lighthill and Dyson found that they were two out of only four or five, at the most, students in the postgraduate classes so that they had the greatest mathematicians as teachers almost to themselves.[9] James Lighthill took the Preliminary (exam) in 1942 and Parts II and III of the Mathematical Tripos in 1943 obtaining a First Class honours, and a Distinction in Part III. Lighthill had covered the subject matter in pure mathematics before going to Cambridge, although in applied mathematics he was very weak, even on leaving. He had only found the hydrodynamics sufficiently interesting to read it up for the Part II examinations. It was quite possible then, however, to obtain a First on ones knowledge of pure mathematics alone.[9]

Lighthill always said that he learned most from Hardy and Littlewood who were great mathematical analysts and outstanding lecturers and easily the major influences on his life at Cambridge, although he admitted that he was also influenced by Besicovitch, Dirac, Eddington, Hodge, Newman, and Steen whose lectures he also attended.[9,10] Lighthill preferred *pure* mathematics in those days. "My preference for *pure* mathematics at this time was due principally to the personal magnetism of Hardy and Littlewood. I need hardly say how much the sound training in (mathematical) *analysis* which I received from them helped my later work in Applied Mathematics."[9]

Lighthill's mathematical studies and his bachelor's degree at Cambridge were finished in only two years in 1943 because of the wartime regulations. When Lighthill graduated, the war with Germany was still going on and James was sent to the National Physical Laboratories (NPL) in Teddington. Besicovitch sent a letter to Sydney Goldstein at NPL agreeing to 'lend the services' of James during the war, but with the plea: "Please do not ruin him," meaning "Please do not turn him into an applied mathematician!" Later Sydney Goldstein was very proud of the fact that he *had* most effectively 'ruined' James.[12]

It was through his interest in music that James met his wife Nancy Alice Dumaresq in 1942. She was also a mathematics student and an amateur cellist and they performed together in a chamber music group. In one recital Nancy joined him in a performance of

Mozart's Piano Quartet in G Minor at Cambridge. Like James, Nancy also had to join the war effort on graduation in 1942 and she was sent to the Royal Aircraft Establishment at Farnborough (RAE). Although James tried to join her, a year later, in September 1943 at the RAE, the authorities sent him to NPL instead.

## NATIONAL PHYSICAL LABORATORIES

For the remainder of the Second World War, Lighthill worked on supersonic and hypersonic aerodynamics, first as Junior Scientific Officer, then as Scientific Officer, in the Aerodynamics Division of the National Physical Laboratories (NPL) which had several very good wind tunnels. Sydney Goldstein, an applied mathematician was also at the NPL at the time and directed James' work. From Goldstein, James was to learn (almost like a postgraduate student) the research method, fluid dynamics and the philosophy of theoretical science. And Goldstein was to take up his 'tutoring' again from 1946-50 when they were together at Manchester University. James could not have wanted for a better tutor. For the first year at NPL he was under Goldstein's direction almost continuously, but in the second year he had more independence. James was very appreciative of his interaction with Sydney Goldstein at NPL and at Manchester subsequently and was to write later "(Sydney Goldstein) was the principal formative influence in my career as a fluid dynamicist."[9,10]

James felt very frustrated at first at NPL, always having wanted to be a pure mathematician, but later he was to view this two-year interruption as much more stimulating than he had expected.[9,10] Since it was felt in 1943 that the war with Germany might go on for a long time and *supersonic* fighter aircraft would be needed, Goldstein asked Lighthill to study *supersonic* aerodynamics. Lighthill continued research on this topic continuously for the next two years until the end of the war. In these two years at NPL, while he was involved in the War Service, Lighthill's lifelong interest in the application of applied mathematics to fluid dynamics was first aroused. "The problems seemed *both* urgent *and* deeply exciting. Moreover, Goldstein introduced them to me in the most compelling and urgent way possible by having me read, first of all, the finest exposes of twentieth century aerodynamical knowledge. Actually the vast majority of these had emerged from the school created (in Gottingen) by Ludwig Prandtl - whose relationship to fluid dynamics parallels closely that of Einstein to other parts of Physics."[9]

Fortunately Lighthill's German was just good enough so that he could read these seminal papers in the original German.[9] So he began to study the published work in this area, much of which had been done by the German scientist Prandtl and his students Busemann and Ackeret (from Switzerland). A few of the other articles Lighthill studied were in English and written by another student of Prandtl, Theodore von Karman who by then was living in California and working at Caltech. The Italian scientist Crocco had done some other work that he studied at the time.

Lighthill's earliest work involved extending the work of Prandtl and his school in supersonic aerodynamics. From time to time he did of course collaborate with other NPL staff including (on aerofoil design) Brian Thwaites who had been a contemporary of his at Winchester and later was to become President of the Institute of Mathematics and its Applications (IMA) after Lighthill.

As Lighthill has described, his researches for the next few years involved *subsonic*, and *supersonic* aerodynamics.[9,10] *Subsonic* aerodynamics involves the study of flow at low Mach numbers which can be modeled mathematically with the use of Laplace's equation. But it also involves the study of boundary layers and other phenomena. On the other hand, *supersonic* aerodynamics requires the use of hyperbolic equations in the mathematical models.

A few years later Lighthill also was to study *transonic* aerodynamics, an interesting and more difficult field than subsonic or supersonic aerodynamics. Transonic aerodynamics requires the use of equations of a mixed type. Starting in 1946 Lighthill did pioneering work and invented a new method of solution for transonic problems that involved *hodograph* transformations, which could be used to map a problem into a different problem that then could be solved.[10]

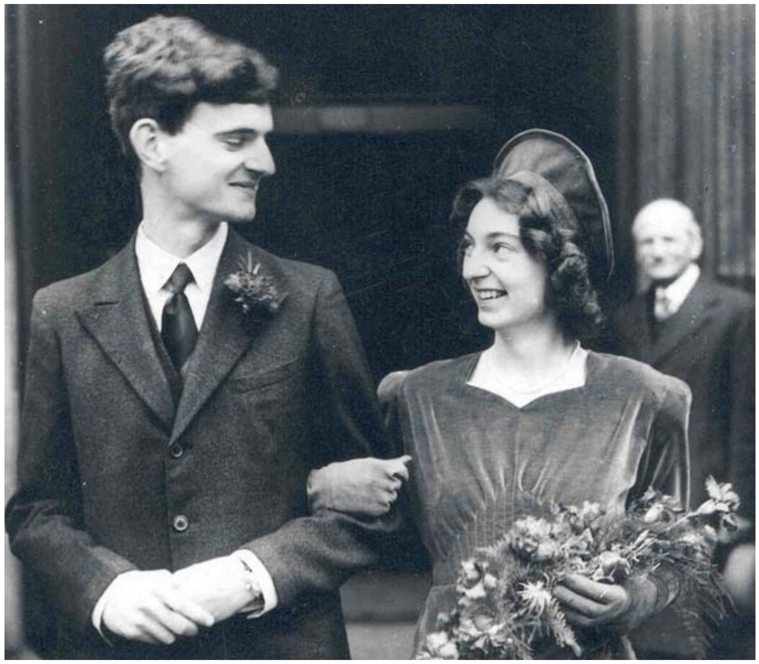
It was at the NPL that Lighthill first began to develop ideas on what supersonic aircraft might look like in the future. And it was at the NPL that he published his first paper in January 1944 just before his twentieth birthday. His five papers on supersonic aerofoil theory published as NPL reports and memoranda during 1944-45 give us some idea about his work at NPL, but we can get further ideas from some of the letters he wrote to Freeman Dyson at the time. From these we can deduce that James was actually enjoying his life studying fluid dynamics. But it would take him a little longer to completely accept his 'conversion' from pure mathematics to applied mathematics and his future career in fluid dynamics.

January 6, 1945

Dear Freeman,

..... My new method of aerofoil design is also going well. I have made one very revolutionary shape, like an ace of spades: - If you suck at the points marked (to get rid of the boundary layer), you should be able to get any value of lift coefficient from minus 3 to plus 3, with a low value of drag. Unfortunately people say that it will be impossible to get designers to use quite such a novel shape, so I am bringing out a rather thinner, but still pretty ambitious version to be tested in the wind tunnel. .... I may be transferred to Cambridge soon (still working under the Ministry of Aircraft Production of course). If this happens, we (Nancy and himself) will buy a house there and settle down straight away. ... Afterwards when I am finally released (*from wartime service*) I hope my aerodynamical researches will be accepted for a fellowship thesis. ...Yours ever, James." [11]

But then the war in Europe was coming finally to an end and sooner than had been anticipated. In 1945, with the war in Europe nearly over, James was married to Nancy on February 17, at Highgate Church. Freeman Dyson was the Best Man in the ceremony. Later Nancy and James were to have five children. Figure 4 shows James and Nancy on their wedding day.



*Fig, 4 James and Nancy outside St. Michael's church in Highgate, North London on their wedding day, 17th February, 1945.*

## CAMBRIDGE UNIVERSITY AGAIN

So with the war over, James Lighthill was very keen to get back into pure mathematics, feeling that it was the highest 'calling' to which he could aspire. He gathered together all of the papers and reports that he had written to date at NPL and submitted them to Trinity College in Cambridge with his application for a fellowship at the College. He was successful and in July 1945 he returned to Trinity College, as a research fellow for a six month period.[9] He concentrated on pure mathematics (conducting research in algebra and number theory) and spent six months trying to prove the theorem that there is an infinite number of pairs of prime numbers differing by two.[9,12] He did not succeed in this proof and I believe that this theorem still has not been proved.

At that time Lighthill began to receive letters about his previous NPL fluid dynamics work from Sydney Goldstein and the great fluid dynamicist G. I. Taylor. He found that his interests were gradually being drawn away from pure mathematics. James soon realized that Sydney Goldstein *had* "ruined" him and that in the future his interest and allegiance was to fluid dynamics and to applied mathematics rather than to pure.[9,12]

## MANCHESTER UNIVERSITY

In 1945 Sydney Goldstein accepted a position as Beyer Professor of Applied Mathematics at Manchester University. And in 1946 he persuaded Lighthill to accept a position at Manchester as a senior lecturer.

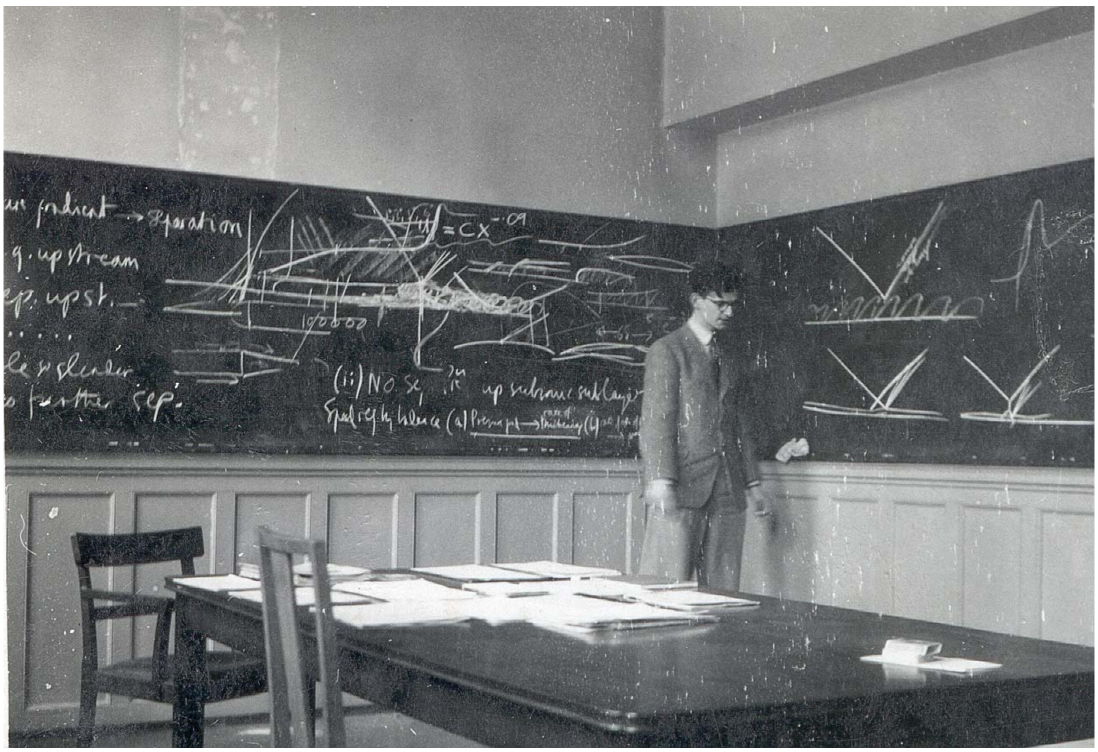


*Fig. 5 James Lighthill soon after his arrival at Manchester University. Note the writing and diagrams on the blackboard show that transonic flow and shock waves were the topic to be discussed.*

One of Lighthill's first projects was to study transonic aerodynamics and he tackled this using an elegant, but rather complicated mathematical approach, that he developed called the *hodograph* method (see Appendix A). Figure 5 shows James Lighthill at Manchester University not long after his arrival. James Lighthill wrote to Freeman Dyson about his position at Manchester University soon after he arrived there in an undated letter in the summer of 1946. This gives a good idea of his contentment with his early university life.

'Dear Freeman,

...... "The university is a bit more prosaic than Cambridge but treats its staff fairly well. There is no undergraduate supervision, which is a relief. 7 lectures are required per week on the average, but I give only 4 since I do some of Sydney Goldstein's research supervision for him. Both my courses are on mechanics: I always felt I might have to learn the subject in the end. Meanwhile I am compiling a work in many parts on the hodograph method in trans-sonic flow. ... We find Manchester a good place on the whole: our district is as near open country as we were in Cambridge and we have the Halle concerts, which are superbly played under Barbarolli: the Manchester Guardian is also rather a treat. The necessity of much bus-travelling is the chief drawback. ... There is a wonderful man here called Ferguson who is pushing the decimal value for pi far beyond Shank's value. He found a mistake in Shank's value which he has published: now he has reached the 690th decimal place and is still going strong. He does work for the university and is tabulating for me the set of hypergeometric functions, which arise in the hodograph theory. He lives for computing and stops in the evening, he says, only to long for next morning when he can start again. ... Yours ever, James" [11]

The Post-war University of Manchester at this time was forward thinking and a place of scientific change. It was headed by the brilliant vice-chancellor, John Stopford, and he together with Sydney Goldstein (the new Beyer chair of Applied Mathematics) and Max Newman, the new Fielder Professor of Pure Mathematics, set the goal of making Manchester into a great new modern scientific centre of pure and applied mathematics which could overtake and outstrip Cambridge.[9] The idea was to achieve this by a combination of: 1) streamlined decision making in staffing and curriculum matters, and ii) high ratios of research to teaching time for the academic staff. Goldstein used this philosophy in successfully recruiting Lighthill at the age of 22 as a senior lecturer using enticing 'vacation powers.'[9]

Goldstein made other judicious appointments at that time for the Applied Mathematics Department and for the newly formed Fluid Motion Laboratory. There was an air of excitement about and the faculty carried out many modernizations to the curriculum and experimental equipment and facilities at least ten years before any such improvements were implemented at Cambridge University. Lighthill and other faculty felt with some pride that the fluid mechanics traditions of Osborne Reynolds and Horace Lamb had been revived and enhanced.[9]

Lighthill's fame was beginning to grow and in May 1948 he was appointed as a member of the Fluid Motion Sub-Committee of the Aeronautical Research Council. At that time and later, meetings of the Fluid Motion Sub-Committee had an important influence on Lighthill. At the meetings he was to meet a number of important scientists including, several times, the great G. I. Taylor. At these meetings much scientific work was discussed including that of Lighthill and Lighthill received comment and advice from many scientists at the meetings including G. I. Taylor. Lighthill maintained many of his close aerodynamic contacts with other scientists not only G. I. Taylor but also the famous applied mathematician George Temple through his work on the Fluid Motion Sub-Committee. Many of the Committee members worked at the Royal Aircraft Establishment (RAE) at Farnborough. Besides involving Lighthill in numerous practical aerodynamics problems, Lighthill's work on the Committee demonstrated to him the importance of good scientific leadership.[9] It was his contact with Temple and his work on Generalised Functions that inspired Lighthill to write his own book on this subject: Introduction to Fourier Analysis and Generalised Functions, (Cambridge University Press, 1958.) Figure 6 shows Lighthill during the early 1960s in the middle of his Manchester period.

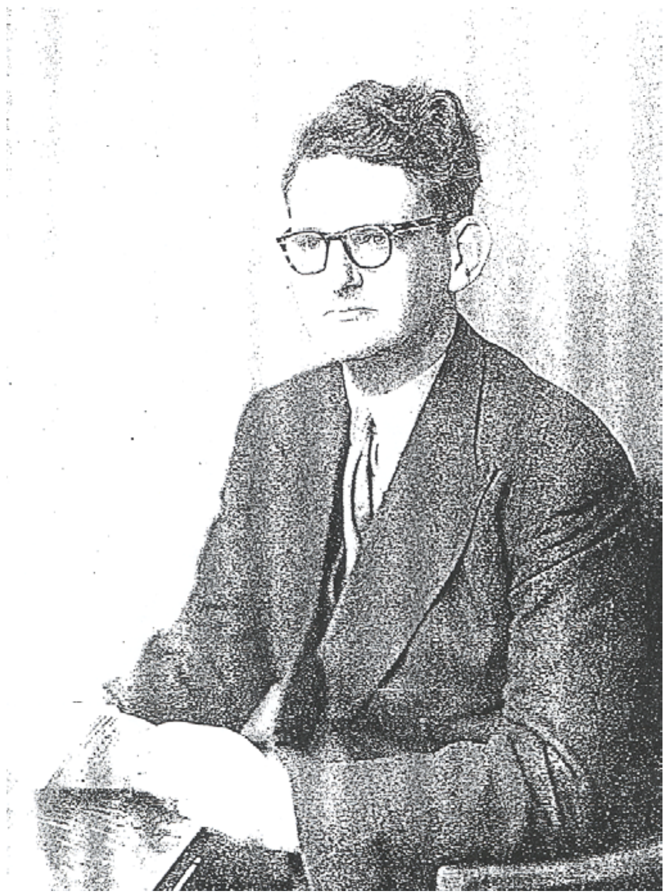


*Fig. 6 James Lighthill at Manchester University in the early 1960s*

In August 1948 at the Seventh International Congress of Theoretical and Applied Mechanics (ICTAM) in London he gave a General Lecture on "High Speed Flow of Gases." At the Congress, Lighthill met Theodore von Karman who was then organising the Princeton Series of 12 books on High Speed Aerodynamics and Jet Propulsion. Not long after this Lighthill was invited to write Section E (Higher Approximations) for Volume VI - General Theory of High Speed Aerodynamics. This work brought him further credit after its publication in 1954. In 1950, Lighthill was named Beyer Professor of Applied Mathematics succeeding Sydney Goldstein who had left to take up a position at the Technion University at Haifa in Israel.

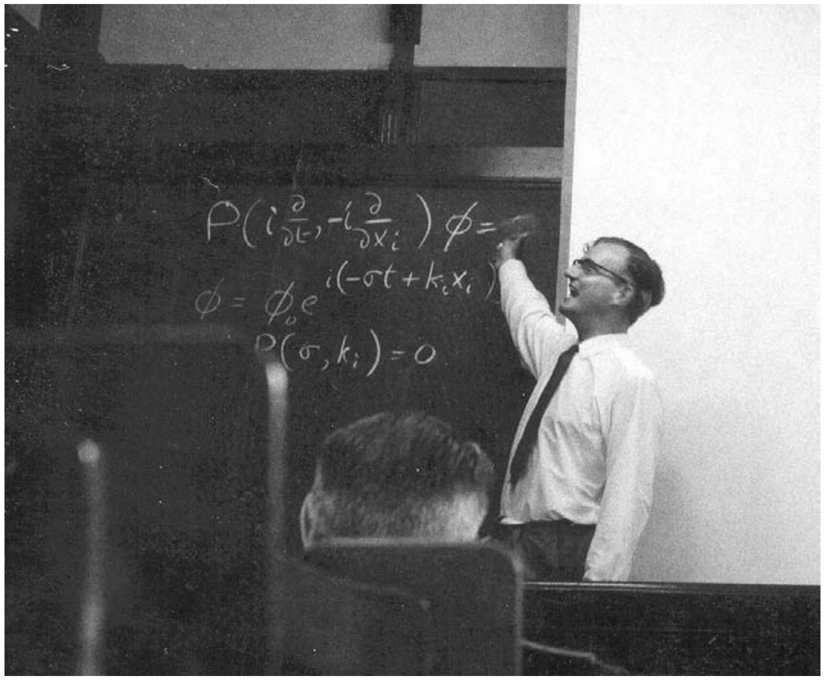



*Fig. 7 James Lighthill lecturing at Manchester University. Note that the topic of this lecture is the wave equation.*

Lighthill's 13 years at Manchester were some of the most fruitful and vigorous of his career. After Goldstein left Manchester, Lighthill continued to build up such a powerful fluid mechanics group that it had few, if any, rivals anywhere. This group had about 10 research students at any one time and used the first rate laboratory called the 'Fluids Motion Laboratory.' The Laboratory was well equipped with good supersonic wind tunnels, shock tubes and turbulence tunnels. It was ably directed by W. A. Muir (1946-52), P. R. Owen (1953-63) and then by N. H. Johannesen. There were additional research students associated with the Laboratory. Technicians were available to run the tunnels and the research team was able to run series of experiments from which theories could be developed and tested. Lighthill worked with many doctoral students and many of these were later to hold chairs at universities in the United Kingdom and overseas. (see Appendix B for a listing of the students who studied with him.) From 1953, undergraduate students entering in Mathematics, Physics and Engineering were able to elect for a course in Fluid Motion (as an integrated experience) which comprised about one third of their second year and two thirds of their third and final year coursework. The course made use of the well-equipped Fluid Motion Laboratory. Figure 7 shows James Lighthill lecturing at Manchester.

During his time in Manchester, Lighthill worked on high-speed fluid dynamics including reentry aerodynamics, magneto-hydrodynamics and diffraction of shock and blast waves. But he also initiated two new fields of study: *aeroacoustics* and *non-linear acoustics.* (See Appendix A).

The first, *aeroacoustics*, was evidenced by his now famous papers published by the Royal Society in 1952 and 1954 "On Sound Generated Aerodynamically - Parts I and II." [13,14] These papers contain his famous acoustical analogy. As Lighthill himself described them, these papers resulted from the "biggest challenge of his life" posed to him in 1949 by H. B. Irving who was then the British Government's Assistant Director of Scientific Research in Aeronautics.[9] Irving toured the country in 1949 vigorously trying to interest scientists and engineers in making scientific studies of jet noise and of empirical methods for its suppression.[17] Irving stated that England possessed good jet fighters but that there was a concern as to whether jet engines could ever be used on aircraft for civilian purposes. At that time existing jet engines were very noisy and any more powerful ones needed for commercial aircraft would presumably be intolerable for communities near to airports. In those days passenger jet aircraft were still only a dream. Nevertheless Irving felt that jet noise was an important problem that should be getting serious scientific study.

Lighthill began to consider the jet noise problem. He recognized that the turbulent mixing of the fluid issuing from the exhaust of a jet with the quiescent atmosphere is a complicated non-linear process both from physical and mathematical perspectives. But he realized that, far from the mixing region, the non-linear effects would have decayed and that *there* the sound propagation could therefore be treated as a *linear* process. Thus he rearranged the Navier Stokes Equations resulting in an inhomogeneous equation with the linear wave propagation terms on the left hand side and the non-linear terms on the right which he treated as acoustic source terms. He showed that the sources are *quadrupole* in nature. A fluctuating force acting on the fluid (such as that produced by a fan blade) produces a dipole source. But there is, of course, no net force acting on the fluid in turbulence, although there are stresses in the fluid caused by the turbulent mixing. Stresses are comprised of *equal and opposite forces* that act on a fluid element thus producing *equal and opposite dipoles*, which are *quadrupole* in nature. See Fig. 8 which

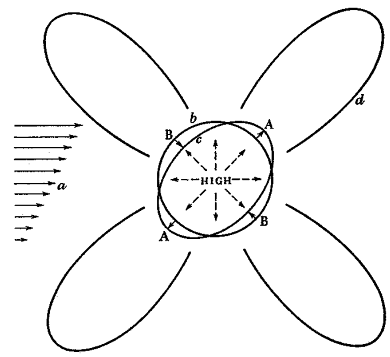



*Fig. 8 Quadrupole sources [14]*

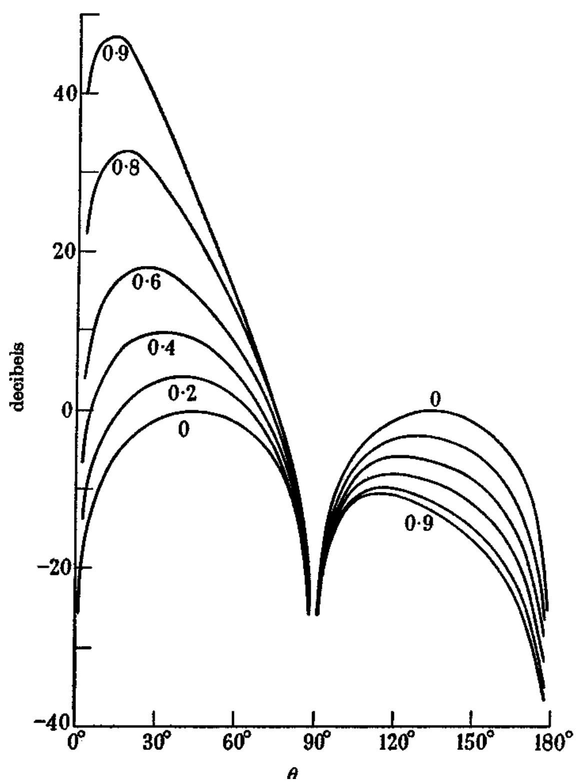



*Fig. 9 Effect of Mach number on the direction of the sound intensity distribution of a lateral quadrupole due to translation [13]*

is reprinted from the second of the two famous papers by Lighthill.[13] Figure 9 from the first of the two papers illustrates the effect of exit Mach number *M* on the directional sound intensity distribution due to a lateral quadrupole as a result of translation. The direction θ is measured from the direction of (jet) translation.

It is said that Lighthill developed the mathematical ideas for the first of these papers in only two weeks but for 16 months held off submitting it for publication until he had worked and reworked his results making the mathematical implications of more use in jet engine design.[1] Significantly being the seminal work in this field, this first paper has no references.[13] He was able to work quietly on the ideas for these papers during some of his long train journeys back and forth from Manchester to London to attend committee and other meetings in the capital.

Geoffrey Lilley recounts an interesting incident that happened in 1951 just before James Lighthill published the first of his two famous papers.[15] James had arranged a dinner party for 12 researchers who were working on experimental and theoretical aspects of jet noise generation and reduction.[15] James kept the group in fits of laughter throughout the dinner party in his inimitable way regaling them with outrageous stories such as on the sex life of the earthworm or of the stickleback. However, just as the 12 were leaving he presented them each with a preprint of his paper 'On Sound Generated Aerodynamically' with the comment that he "hoped that it would make good bedtime reading."[15] Geoffrey Lilley had been completely unaware of Lighthill's masterwork before and had come for the meeting next day with view graphs representing two years' of jet noise experiments and that *hitherto* did not contain any comparison whatsoever with any theory. That night after reading Lighthill's paper and spending a sleepless night, Lilley and his colleague Bob Westley redrew all of their view graphs which *now* showed excellent agreement between their experimental results and his theory. They presented these after James Lighthill's presentation of his new theory next morning. [15]

These two papers of Lighthill on aerodynamic sound generation [13,14] have received considerable citations in the literature and have remained, for over a half-century, the starting point for all subsequent studies in aerodynamic and jet noise. Of immediate and continuing practical importance in jet engine design, is Lighthill's finding that the acoustic power radiated from a jet is proportional to the eighth power of the exhaust velocity. This fact, together with their improved fuel efficiency, has been one of the main motivations for the move from pure jet engines to turbofan engines -- jet engines with higher bypass ratios (engines that move more air with lower exhaust velocities). Lighthill went on to give reviews of his jet noise theory in later years.[17,18] Figure 10 (from his Bakerian lecture) shows the excellent agreement between the total acoustic power of air jets and Lighthill's eighth power law.

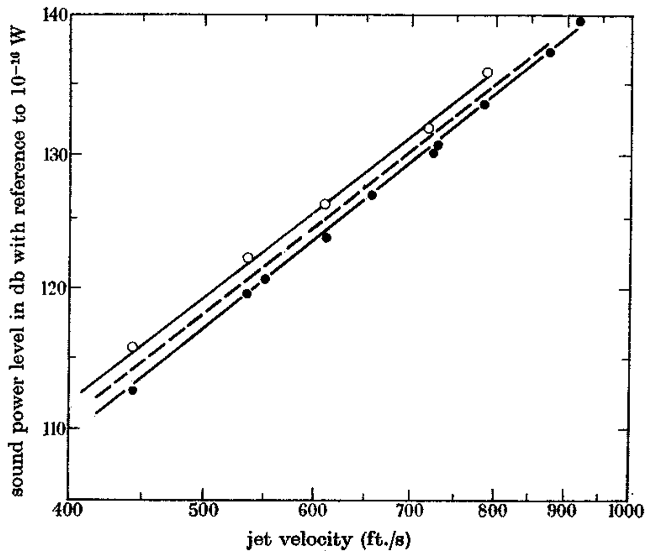



*Fig. 10 The acoustic power of air jets of half-inch diameter (Waterhouse and Berendt 1958). Equal diameter and thrusts. O, Cylindrical pipe; ♦, long radius nozzle; ---, Lighthill's eighth power law [17]*

The *second* field of study, *non-linear acoustics,* began in 1956 with Lighthill's 100-page article "Viscosity Effects in Sound Waves of Finite Amplitude" which was written to celebrate G. I Taylor's 70th birthday. In this survey article, he included, along with viscosity, all of the other physical effects that produce dissipation in intense sound waves.[16]

## THE ROYAL AIRCRAFT ESTABLISHMENT (RAE)

In 1959, at the age of only 35, Lighthill became Director of the Royal Aircraft Establishment (RAE) at Farnborough. When he learned of his appointment, Freeman Dyson wrote to him from California to congratulate him. Dyson added, however, that while he had no doubt that (Lighthill) would do a splendid job as a Director, he was sorry that he had taken on such a big administrative job at such a young age, because it would probably mean the end of his career as a creative scientist.[11] Lighthill's reaction was immediate and sharp. Writing on 4 September 1959 from the Department of Mathematics at Manchester University, he wrote:

"Dear Freeman,

Naturally I don't see my own affair the way you do. Having come to find directing 50 scientists a bit easy, I am looking forward to directing the lively team of 1000 scientists that are the core of Farnborough and are able to pursue their ideas with an annual budget of 12 million pounds. I shan't do this by committees, I'll have plenty *of people to sit on them. I shall do it by going round and finding out what the problems are and arguing people into finding the right solutions. The job is a mixture of science, which is one of the pleasures of life.... and human relations, which is another fascinating side of life. I think I can do it because my scientific record is enough to give all of the scientists under me confidence from having me on top..... Yours ever, James"* [11]

(Lighthill, in later life, was to describe this RAE situation as "a position I couldn't refuse… I would not have changed it for the world.") During this six-year period he directed the work of a staff of 8000, fully 1400 of whom were engineers and scientists. Although many were 20 years his senior, they, recognizing his scientific genius, accepted his leadership and during that time he built the RAE into one of the premier aeronautical research institutions in the world.[1] Figure 11 shows Lighthill during his time at the RAE. The main base of RAE was at Farnborough, but it also had an important airfield at Bedford together with large supersonic wind tunnels.[9]

Lighthill threw himself into the RAE Director position with considerable energy and gusto. "From the outset I devoted myself to acquiring an encyclopedic knowledge of everything going on (and this broadening of my knowledge base during 1959-64 influenced greatly my later researches.)"[9] Lighthill's son Michael described how his father, after accepting the RAE Directorship, insisted on receiving full details of the managerial staff and then succeeded in learning all the important details of every member. "I can remember clearly having to test him on the details of the charts that he had prepared for himself.[8] Lighthill helped the RAE to grow in both "scientific excellence" and "gifted scientific manpower" during the period he was Director, while keeping a strict financial control through a new financial system that he devised.[1,9]

As Director, Lighthill was involved in examining and approving the details of every report produced by the RAE.[1] During this period the RAE was working on among other topics: i) the aerodynamics of the Concorde's delta wing, ii) vertical take-off aircraft (VTOL) that would later become the Harrier, iii) all-weather automatic landing systems, iv) projected successor hypersonic passenger aircraft (which were not developed because of economic constraints), v) the development of communications satellites, and vi) the feasibility of using high altitude aircraft as launch platforms for spacecraft. He took a particularly keen interest in the first three topics. On delta wing and VTOL developments he collaborated with Handel Davies, Philip Hufton and Dietrich Kuchemann and with John Charnley he helped to foster the developments in automatic landing systems.[9]

During his time at RAE, Lighthill initiated and chaired a national committee on minimum-cost air transportation (where almost the first use of the term "air bus" was coined.) "RAE would (thus) be seen to argue strongly *for* high technology (Concorde) type aircraft *and* the low cost (Airbus)."[9] Also Lighthill took the RAE in two new directions *medicine* and *space*. "I cultivated relations with a neighbour (an institute near to the RAE) the Institute of Aviation Medicine (directed by Air Cdre W. Stewart), learning thereby many subtle ingredients needed for an effective engineering/medicine mix. Above all, I took (with George Burt) the steps to forge at RAE a powerful Space Department which continues today as a major UK centre for Space activity." [9]

Although Lighthill, at that time, did not really have the time to do any original scientific research work, he was able to use the results of various research teams and, with the good bibliographical services at his disposal, write rather long review articles. These first appeared as Director's memos. These articles were not just summaries of the work of others, but also incorporated his own views on the topics. Examples of his better reviews written then are his Bakerian Lecture given in 1961 and his Wright Brothers Lecture *on jet noise* that he delivered in the USA in 1963.[17,18]

A story may serve as an illustration of the level and speed of Lighthill's thinking. An important aerodynamicist at the RAE, C. H. E. Warren, noticed what he thought was an error in an equation in one of the director's memos. He brought this to Lighthill's attention. Lighthill pointed out that he had taken the equation in the memo from the 'Theory of Sound' by Lord Rayleigh and that it was most unlikely that Rayleigh was wrong. However, Warren persisted that the equation did not appear to adhere to Fermat's principle of least time. Lighthill promised that he would think about it, but that he was flying to the USA in two days' time. Indeed, directly on Lighthill's return from his trip, Warren received a letter from Lighthill written on several sheets of notepaper of the British Overseas Aircraft Corporation (BOAC). On the sheets Lighthill had worked out the whole problem (concerned with waves in a moving fluid) using phase velocity and group velocity vectors and had concluded that Warren was right and that both Rayleigh and he had been wrong before. [19]

Lighthill also found time, in 1963-64 during his RAE period for two outside activities. At that time the Fluid Motion Sub-Committee planned a major work to succeed their "Modern Developments in Fluid Dynamics." This work was finally published as "Laminar Boundary Layers" and Lighthill contributed chapters 1 and 2 to this work.[9] He also became dissatisfied with the attention that scientific societies were paying to applied mathematics and he helped to found the Institute of Mathematics and its Applications (IMA).[10] He later served as its first President from 1964-1966.

After six years at RAE Farnborough, Lighthill, although he had very much enjoyed his period at the RAE, started to long to do some more original scientific research. Moreover since he had then been working for 21 years in aviation and aeronautics he concluded that he did not want to spend the rest of his life solely in this area and that he would enjoy researching into some different areas. Thus in 1964 he accepted a position as the Royal Society research professor at Imperial College, London. He was convinced later that G. I. Taylor had facilitated this appointment and move. At that time he also became the Physical Secretary of the Royal Society.

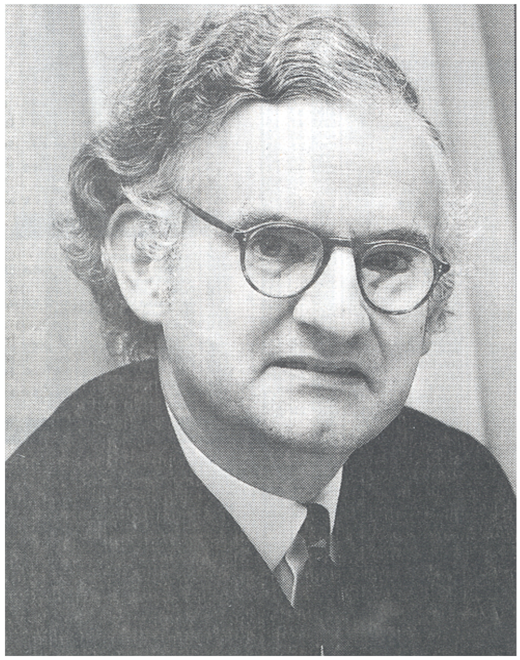


*Fig. 11 James Lighthill in 1971 soon after his appointment as Lucasian Professor at Cambridge University*

## IMPERIAL COLLEGE

During his time at Imperial College he continued his activities as the chairman and member of several scientific and technological committees with UK and international scientific and technological issues. However during the 1960s, the UK experienced only moderate economic growth and the UK government decided to scale back its expensive aerospace activities. With the exception of the Concorde, the UK government decided not to participate in most European aerospace projects. It has been suggested by some that after his time at RAE and after the UK government's decisions of the 1960s, James rarely spoke about aerospace any more. His immediate research work after his RAE period was devoted to work on *General Theories of Waves in Fluids* and was a continuation of his immediate pre-RAE studies. And this was the topic of his inaugural address as IMA President in November 1964. (See Appendix A.)

He also began to extend his investigations into finding mathematical explanations of biofluid-dynamics. These involved the flying of birds and insects, the swimming of fish and reptiles, blood flow, and wave propagation and acoustic energy flow in the cochlea. While still at Imperial College he wrote a major review of aquatic animal propulsion.[20]

Although Lighthill's contributions to the understanding of *external* biofluiddynamics are very important, perhaps his contributions to the understanding of *internal* biofluiddynamics have been even more important. He was to write important papers later on the *internal* workings of the human inner ear, but even more significant at this time were his efforts in 1965, along with Colin G. Caro, the clinician and physiologist then at St. Thomas hospital in London, to persuade Imperial College (IC) to create the Physiological Flow Studies Unit.[9,22] This Unit, with the IC Rector's encouragement and help, started its research in 1966 initially attached to the Department of Aeronautics. "From the outset it was an interdisciplinary Unit, designed to integrate contributions by doctors, physiologists, engineers and mathematicians (in ways that I had learned about at Farnborough) and it has continued to attracted able people in all of these disciplines."[9] The Physiological Flow Studies Unit is now attached to the Department of Biological and Medical Sciences and has gone on to make an international reputation particularly in studies of the response of artery walls to haemodynamic stresses, which is important in the understanding of atherosclerosis.[22]

Lighthill now had more time to be involved in a number of outside scientific meetings and other activities. In 1966, a meeting was held at La Jolla, California where he described an approach to oceanographic problems using a method based on vorticity principles. This interest in oceanography was probably inspired by a visit he made at that time to the National Institute of Oceanography.[9] In 1967 Lighthill organised a Royal Society Discussion Meeting on 'Nonlinear Dispersive Wave Theory' in which he was able to collaborate with Witham again. About this time after his 1965 appointment to the Natural Environment Research Council, Lighthill was appointed chair of its Oceanography and Fisheries Research Committee. This committee was responsible for coordinating programmes at the N.I.O and other N.E.R.C.-supported laboratories.[9]

In 1967, Lighthill's friend from California, D. M. Van Dyke, invited him to contribute an article to the first volume of the Annual Reviews of Fluid Mechanics on which he was just embarking. Van Dyke had been involved in supersonic aerodynamics research since the early 1950s, and Lighthill had first visited him in 1951. Lighthill took the opportunity to write a major survey article (without mathematics) on *Aquatic Animal Locomotion* and on this article he worked with James Gray and his colleague R. Bainbridge.[20] This was a subject that Gray had briefly introduced to Lighthill in 1960. Lighthill had the considerable resources of the London library collections, including those at Regents Park and South Kensington, for his first foray into this field.

Meanwhile, Manchester University commemorated the 1968 centenary of Osborne Reynolds' appointment to its Chair of Engineering by announcing a meeting at which Lighthill was invited to give an extended lecture on current knowledge on *Turbulence*. And later in 1968 the U.S. National committee for Fluid Mechanics Films asked Lighthill to come to Boston with J. E. Ffowcs Williams to make the film "Aerodynamic Sound Generation."

Lighthill's well-known interest in *Monsoon Dynamics* was initiated by his desire to give Indian Post-doctoral students studying with him at Imperial College problems relevant to the real needs of India. Dr. Dernnathan studying with Lighthill responded ably, but regrettably died soon after his return to Bangalore. However Lighthill published his first paper on this topic in 1969.[9]

## CAMBRIDGE UNIVERSITY AGAIN

In 1969 Lighthill became Lucasian Professor of Mathematics at Cambridge University where his immediate predecessor was Paul Dirac (who invented the Dirac delta function) and many years earlier it had been Isaac Newton. He stayed in this position for 10 years. Lighthill felt later that several scientists such as G. I. Taylor who served as electors had been influential in his appointment to this position. [9,10]

At Cambridge, again he lectured frequently and energetically to students. He also extended his research interests and areas further into acoustics and wave motion with studies on active control of sound, and oceanography. In addition he worked on and predictions of the propagation of tropical cyclones and monsoons and other topics.[1,10]

He also developed further his interest in physiological fluid dynamics and published several papers on this subject. The first was one of his extensive survey papers "Physiological Fluid Dynamics, published in the Journal of Fluid Mechanics" [23]. He continued his work on the swimming of fish. Figure 12 shows Lighthill's illustration of subdivisions of hydrodynamic theory relevant to animal locomotion.

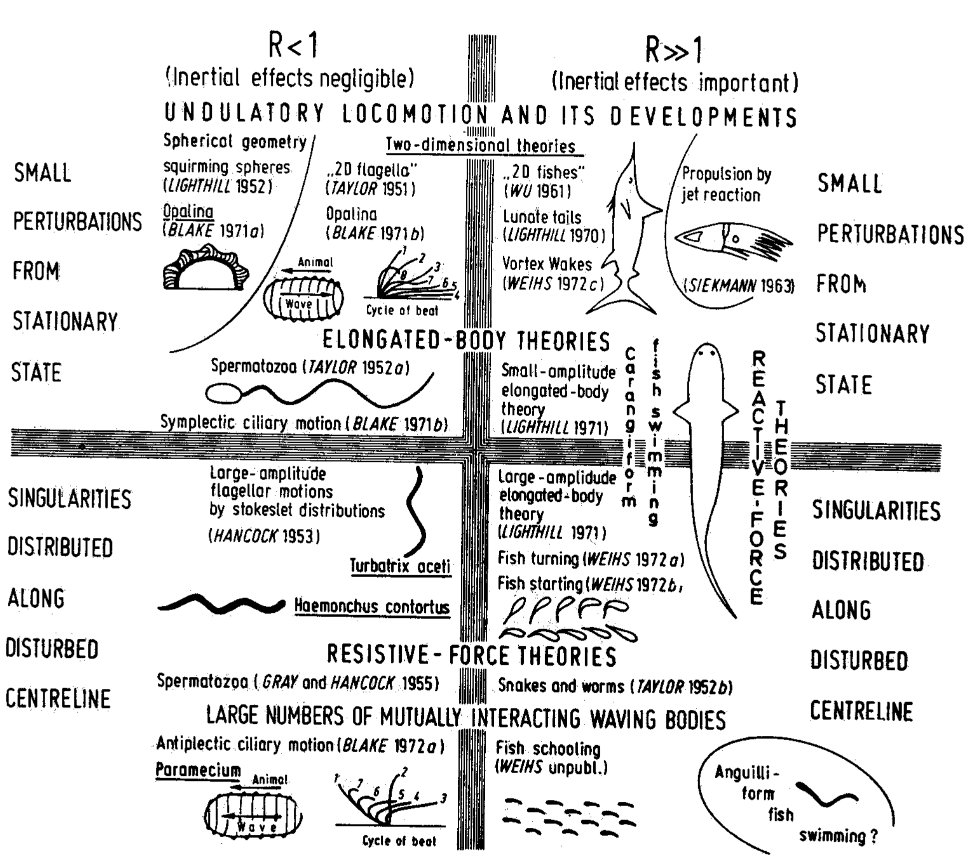



*Fig. 12 Subdivisions of hydrodynamic theory relevant to animal locomotion [24]*

He extended his elongated-body theory to more realistic shapes and more importantly to large amplitude body motions.[25,26] He also conducted a preliminary analysis of the lunate tail.[25] Figure 13 shows the lunate tail in six percomorph fish.

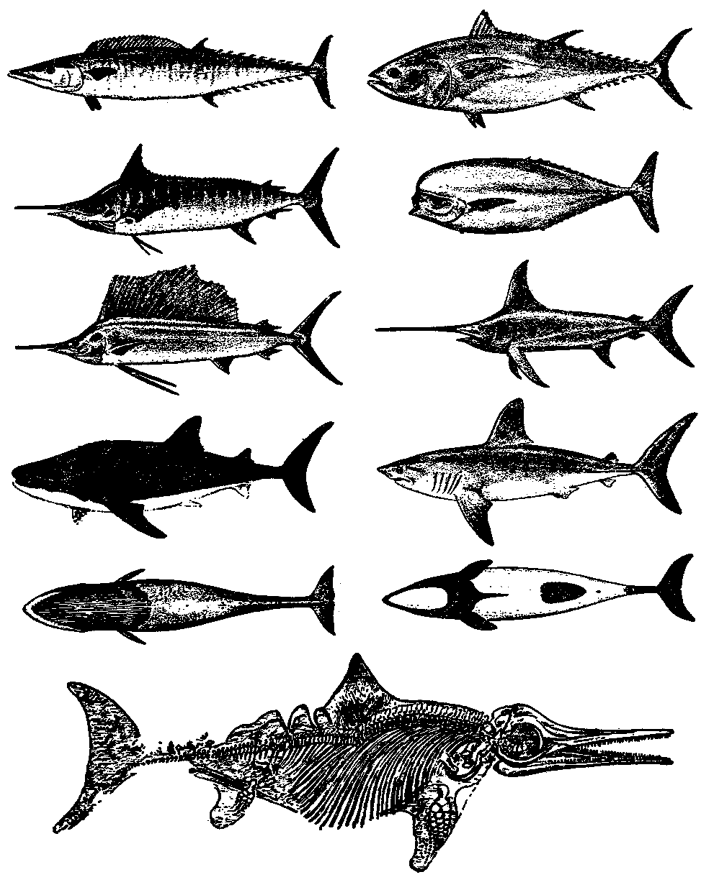


*Fig. 13 Illustrations of the lunate tail in six percomorph fish: Two sharks, two cetacean mammals and one reptile [24]*

Figure 14 shows Lighthill's model of the motion of the caudal fin to the right (left-hand diagram) and to the left (right-hand diagram) as a transverse wave reaches it with velocity *V*, while the fish moves forward at velocity *U.* Figure 15 shows a comparison between the motion of the fish fin and that of a bird wing.

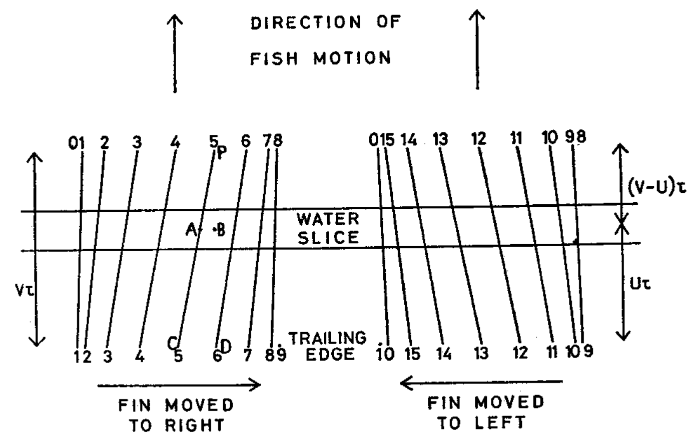



*Fig. 14 Lighthill's model of Caudal fin. The fin moves to the right (left-hand diagram) and then to the left (right-hand diagram) as a transverse wave reaches it at velocity V, while the fish moves forward at velocity U [24]*

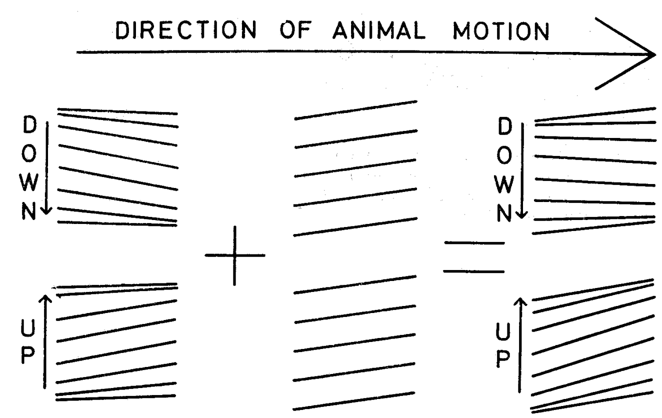



*Fig. 15 The left hand diagram shows vertical oscillations of carangiform type, obtained by rotating Figure 14 clockwise through 90 degrees. The middle diagram shows a weight-supporting regime with constant angle of attack, and the addition of the two in the right-hand diagram shows a typical bird-flight mode [24]*

Figure 16 shows the vortices cast off the trailing edge of a caudal-fin. As Fig. 17 shows, schools of fish may take advantage of the vortex pattern and resulting jet motion. Figure 17 suggests that a diamond pattern may be particularly helpful in reducing the overall power consumption of the school of fish. In between certain vortices as shown, fish will be dragged forward. There is some evidence that, at high speed, fish take up such diagonal lattice patterns and the question arises whether *passive* forces bring the pattern into existence or whether a very complicated control mechanism is needed to maintain the lattice pattern. [24]

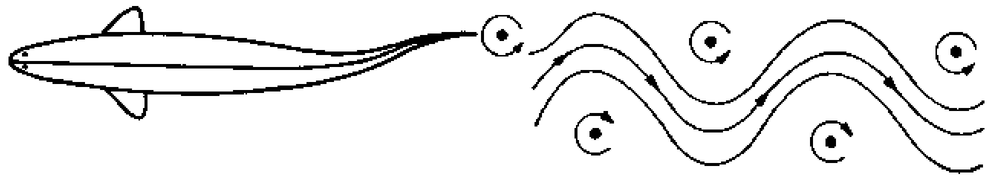


*Fig. 16 Vortices cast off by the trailing edge of a caudal-fin trailing edge as the fish moves forward to the left. Also shown is the jet-like streamline pattern induced by the vortices. The pattern was traced from streamlines obtained experimentally [24]*

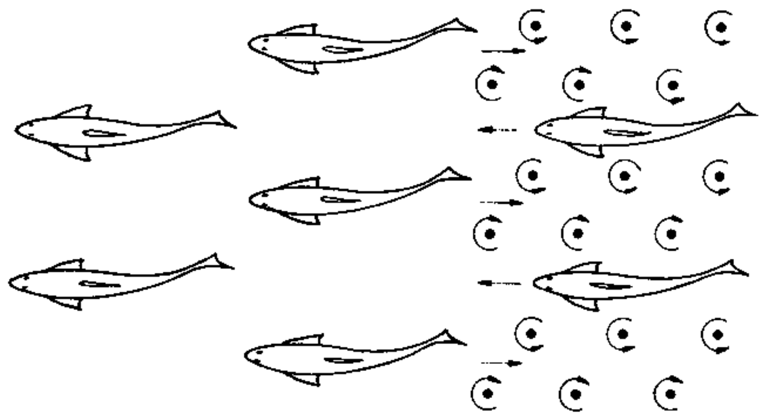


*Fig. 17 This shows vortices cast off by the caudal-fin trailing edges. These vortices induce a jet-like streamline pattern in between fish swimming in formation. The momentum carried by the 'jet' is of course related to the thrust produced by the fish propulsion system. The diamond-shaped pattern of schools of fish is observed when they are traveling fast and it thought they save energy by using a diamond formation [24]*

Soon after Lighthill's return to Cambridge, he agreed with Cambridge University Press on a book project on "Waves in Fluids." But when he had completed 220 pages of what would eventually be the 500 page book, he had to put it aside because he had become so intensely engrossed in a new topic of research: biofluiddynamics. (He was to return to his Fluids book four years later, early in 1976, and he would complete it quite quickly before the end of that year.) [9]

Lighthill's new research topic that aroused his intense interest came from his interaction with a new zoologist T. Weis-Fogh, a Dane who had succeeded Sir James Gray as

Professor of Zoology. Weis-Fogh was an expert on insect flight and had recently observed and explained the mechanism of the hovering flight of small insects. This has become known as the *clap and fling mechanism.* Large insects fly rather like small versions of birds. Whereas, as Weis-Fogh had discovered, small insects 'clap' their wings and then fling them apart. They clap their wings behind their backs, once per wing beat, then they fling their two wings open about the common trailing edge. The air rushes into the gap and this begins a circulation about each wing. They then pull them entirely apart completing the circulation and thus producing lift almost instantaneously. As Lighthill explained, with this mechanism there is no need to wait for the action of viscosity as is necessary for the starting vortex mechanism used with wings in normal aeronautics.[10]

Lighthill immediately became enthralled with this new (to him) mechanism of flight. He became engrossed on explaining it mathematically. Lighthill had the ideal aeronautical background for the task and it was easy for him to move from the subject of "swimming" to the similar, but more difficult subject of "flying," and his collaboration with Weis-Fogh began to blossom.[9] The 'celebrated' fruit fly Drosophila virilis and some other similar insects use this mechanism about 200 times a second. Lighthill explained the fluid dynamics of the hovering flight of the Drosophila and similar insects not just in qualitative terms but using a rigorous mathematical treatment.[9, 27] Figure 18 shows the morphology of Encarsia formosa. Weis-Fogh was able to take slow-motion pictures of the Encarsia formosa at over 7,000 frames per second in hovering flight. Figure 19 shows tracings taken from such slow motion frames. Encarsia succeeds in making about 400 wing beat cycles (as shown in Fig. 19) each second. Figure 20 from Weis-Fogh [28] shows his interpretation of the 'fling' mechanism in Encarsia formosa.

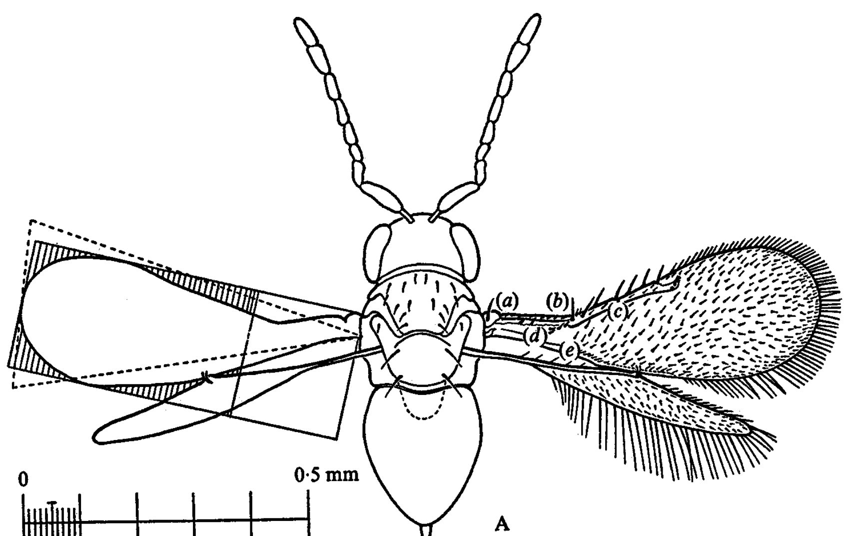


*Fig. 18 The morphology of Encarsia formosa [24]*

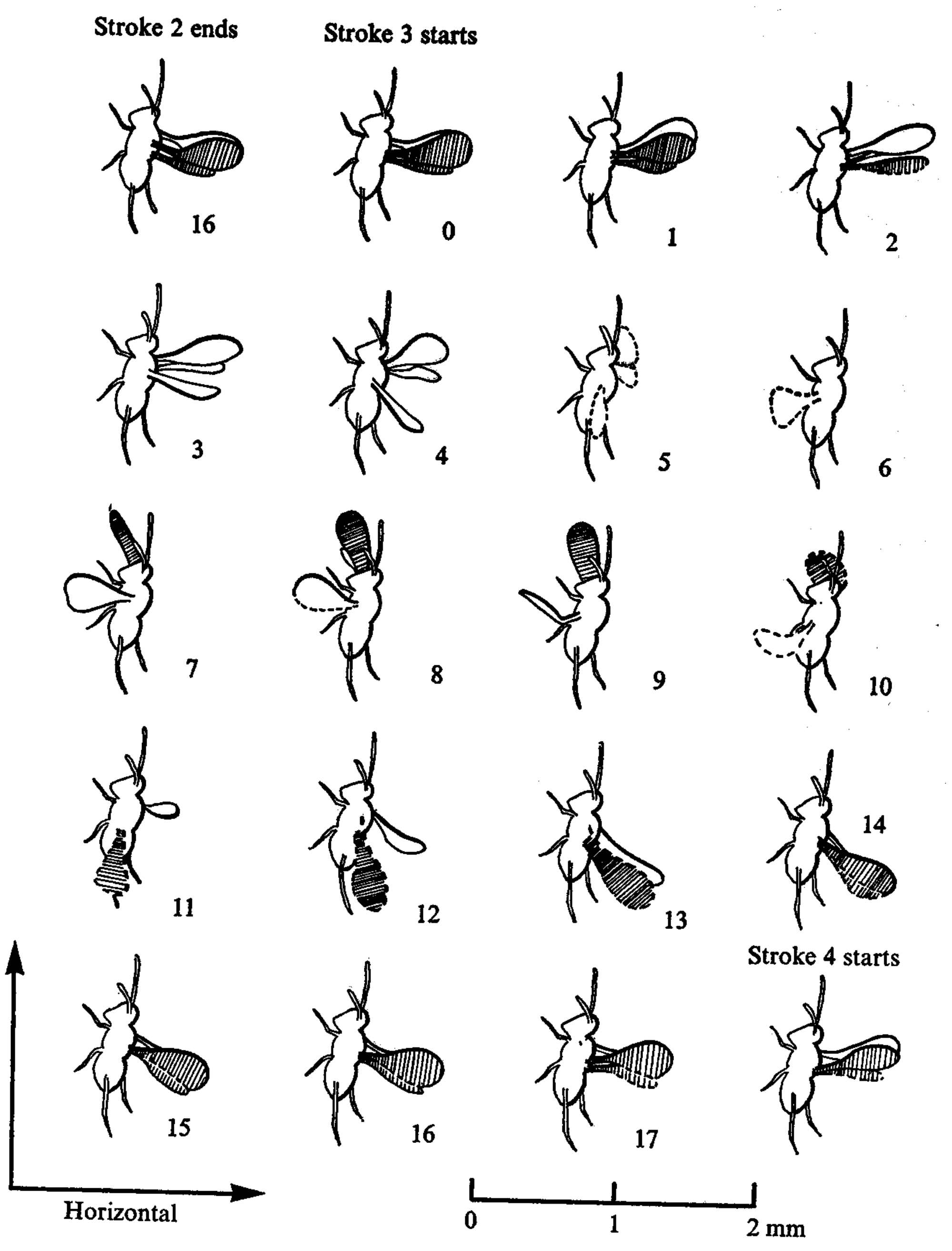



*Fig. 19 Tracings from successive frames from slow-motion photography by Weis-Fogh (1973) of the flight of Encarsia formosa in hovering flight [24,28]*

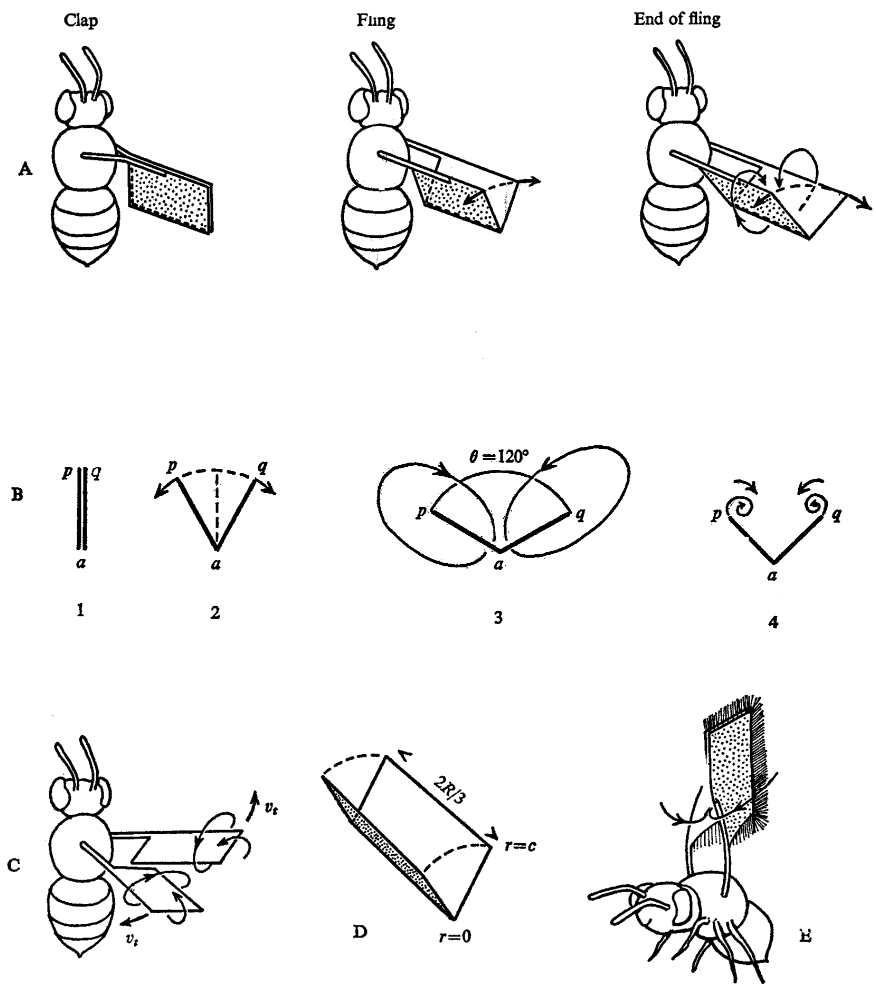



*Fig. 20 Fling Mechanism in Encarsia formosa [24,28]*

Lighthill's mathematical analysis is too extensive to repeat here. Perhaps one or two figures and some discussion in words will suffice. As Lighthill explains, the mechanism that Encarsia uses could work even in an inviscid fluid and assuming two-dimensional motion starting from rest. Kelvin's theorem states that the circulation round a body must vanish. However the theorem does not exclude the possibility that if the body breaks apart into two pieces that there may then be equal and opposite circulations around them, each suitable for generating the lift required in the two pieces' subsequent motions. [27] Figure 21 illustrates Lighthill's schematic of the initial fling process in Encarsia formosa.

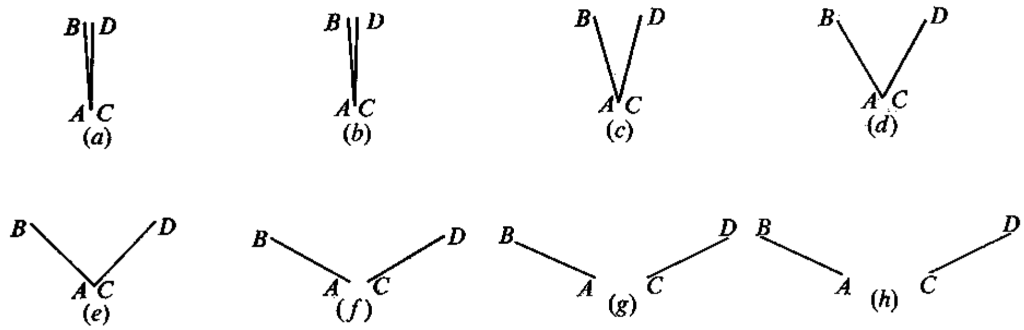



*Fig. 21 This shows Lighthill's schematic of the initial stages of the fling process [24]*

As Lighthill states, Encarsia formosa is not able to move its wings completely through the full angle of 180$^o$ so as to perform the true 'clap and fling' *twice* per beat; instead the wings can move only through about 130$^o$. Encarsia does, however, complete a 'clap and fling' at the end of one wing beat and makes at the other extreme a broadly similar 'flip' motion (with the same total magnitude of complete wing angular movement) without bringing the two wings together. This latter motion is harder to analyse. It is quite probable that the combination of beats may produce results not too different from what the 'ideal' motion would achieve.[27]

Lighthill collaborated with Weis-Fogh on creating a series of interdisciplinary meetings on Animal Locomotion. The first meeting was held in 1973 at Duke University, where K. Schmidt-Nielsen coordinated it. The second meeting was held at Caltech in 1974 to which Lighthill contributed a survey paper on "Aerodynamic Aspects of Animal Flight." Then in September 1975, Lighthill collaborated with Weis-Fogh in jointly organising an IUTAM/IUPAB Symposium "Scale Effects in Animal Locomotion" at Cambridge University. The Proceedings of the Symposium were edited by one of the Cambridge Department of Applied Mathematics and Physics (DAMPT) faculty, T.J. Pedley.

At Cambridge Lighthill was able to continue building a good research group that studied bird flight. The group was interdisciplinary including zoologists, mathematicians and engineers. They conducted some experiments and extended the theoretical knowledge of bird flight. Lighthill also made good contacts with the Society of Applied Mathematics (SIAM) in the USA. SIAM invited him to give a week-long series of lectures at the Rensselaer Polytechnic Institute (RPI) in 1973. His 1973 lecture series was later to be developed into his book "Mathematical Biofluiddynamics," SIAM, Philadelphia, 1975.[24] This is indeed a book with a really original scope. It contains Lighthill's ideas to that date concerning animal locomotion through the surrounding fluid media (water and air) which he termed *external* biofluiddynamics, and heat and mass transport by fluid flow systems within an animal, or *internal* biofluiddynamics. Some of the chapters were originally given as special lectures previously at RPI and elsewhere, but they are blended together and written in a masterful way so characteristic of Lighthill's writing.[24]

SIAM again invited Lighthill to RPI in 1975 to give the John von Neumann lecture. For this lecture, Lighthill carried out a comprehensive survey "Flagellar Hydrodynamics." However, soon after, with the sudden death of Weis-Fogh in December 1975, Cambridge gradually started to become "less special" for Lighthill and he felt that it might be more attractive to "move on" to something else and then also he began to want to "run something again" as he had at the RAE.[9]

Before leaving Cambridge Lighthill did, however, find time and energy to complete his magnum opus "Waves in Fluids" which he had put aside in 1972, when he began collaborating intensively with Weis-Fogh. This book "Waves in Fluids", published by Cambridge University Press in 1978, contains comprehensive discussions on wave motion in fluids including acoustics, oceanography, water waves, internal waves in the atmosphere, and atmospheric science, etc.

This Fluids work suggested several other lines of enquiry to Lighthill including cochlear mechanics (first introduced to him by D. A. Laming) and ocean engineering and he carried out several other researches on these topics. He also organised together with one of his prior Cambridge post-docs, M.P. Singh, an important IUTAM symposium on Monsoon Dynamics held in New Delhi in 1977. During the Symposium, the foreign scientists attending persuaded the Government of India to start university research centres devoted to Atmospheric Sciences. In the event, such centres were set up in New Delhi (headed by M.P. Singh) and Bangalore (headed by R. Narasinha) providing much useful information and advice to the Government of India on weather forecasting. Lighthill continued to remain in touch with these centres for the rest of his life. [9]

## SIR JAMES AT UNIVERSITY COLLEGE

In 1979 Lighthill accepted an administrative position as Provost of University College London. As chief administrator he threw himself into his new position with vigour. He led, as he had at the RAE Farnborough earlier, by totally immersing himself in the "business" of the College, that is its scholarship and its educational practices. He contributed to both of these aspects of the College life. He energetically developed new areas at the college in biotechnology and life sciences. University College (UCL) had about 10,000 students during Sir James' tenure as Provost. It had a strong medical school and good science, engineering and humanities and social sciences research efforts. He was very proud of the fact that during his tenure the research support overtook that of Cambridge University, although not that of Oxford University. He was also pleased that he helped to arrange a merger between the University College Medical School and the nearby Middlesex Hospital Medical School forming the University College Middlesex School of Medicine.[10]

As Sir James has described, he had two great role models in demonstrating academic leadership in his position as Provost: the previous vice-chancellor of Manchester University, John Stopford, and the Rector of Imperial College, London, Patrick Linstead.[9] His approach to his position was as follows. "..the head of an institution: a) needs to acquire detailed knowledge of all that institution's activities; and b) must have frequent informal meetings with all key management staff; yet c) should (at least if he is highly numerate) cultivate his closest relationship with the institution's Chief Accountant - since all policy must make sense in financial terms."[9] To achieve his academic leadership goals with this approach, he proceeded as follows. To fulfil requirement (a) he wrote letters to all of the academic staff asking them to inform him of their innovations. In addition he made a point of visiting all of the departments. Thus he "probed" all of UCL's excellences extensively. This task was facilitated by his wide knowledge of engineering and sciences (including biomedical) and because of his considerable familiarity with the arts and humanistic studies. His requirement (b) was met initially with two sets of meetings (without minutes) with the UCL vice-provosts and administrative officers each week, and with the vice-provosts and deans every three weeks. In this way everyone became informed about issues of importance. Later Lighthill added regular meetings with Student Union officers which helped very much to improve academic staff/student harmony.[9] Requirement (c) was met by having frequent meetings, which led to a good rapport with the chief accountant as at the RAE.

Lighthill thought that (in order to encourage the best from the academic staff), it was very important to raise morale. The measures just described were an important means to this end, but in addition he felt it essential that he could also describe the work of his colleagues to the outside world. He thus became sufficiently knowledgeable about the work of his academic colleagues so that he was able to follow each inaugural lecture that they would give by his "summary" of their work. In addition he made an affirmation (as Provost) in October 1979 that the work of all the UCL academic units was *outstanding* in a move to preserve all of them against the then current threats. Lighthill knew that this affirmation was accurate in all but a few cases and he resolved (privately) then rapidly to "make it true" even in such exceptional cases by "an intelligent use of the atmosphere of rationalisation then current in London." This involved carefully merging some units of University College with other units of colleges or hospitals in London.[9]

In addition Sir James was involved in fund raising for the College and he was instrumental in improving the representation of women in senior academic staff positions at the College. While he was Provost he helped eliminate male prejudice from the faculty selection committees and he saw the number of women full professors reach 15 with six of these being Heads of Department. His administrative duties curtailed his detailed research studies, but they did not prevent his continuation of his scientific work and publications. He continued to publish widely including <u>An Informal Introduction to Theoretical Fluid Mechanics</u>, (Oxford University Press, 1986.) During his time at University College London, Sir James became interested in the human inner ear and its ability to discriminate the pitch or frequency of sound. He approached this mater from a wave mechanics point of view. With this approach he demonstrated that the ability of the hair cells in the cochlea to sense sounds of different frequencies, in relation to the distance from the oval window at the entrance of the cochlea, is associated with a phenomenon of critical layer absorption of the elasto-acoustic waves set up in the cochlea. [29-32]

## RETIREMENT YEARS

After retirement in 1989, Lighthill became Honorary Research fellow at University College and he continued his very active involvement in scientific work to the end. He continued his written publications and also an extensive involvement with the work of many scientific societies. In 1995 he helped to found the new **International Institute of Acoustics and Vibration (IIAV).** "I helped to initiate the IIAV, an international interdisciplinary body having individual members devoted to areas of study... in acoustics and the mechanics of solids and fluids." He acted as founding President of IIAV and first elected President from December 1997. Figure 22 shows Sir James Lighthill together with Professor David Newland, Dr. Hanno Heller and Professor Malcolm Crocker at the Fourth International Congress on Sound and Vibration, St. Petersburg, Russia in June 1996.

*Fig. 22 Sir James Lighthill and IIAV colleagues at the Fourth International Congress on Sound and Vibration, St. Petersburg, Russia, June 1996. From left to right: Professor David Newland, IIAV Vice-president; Sir James Lighthill, IIAV President; Dr. Hanno Heller, IIAV Vice-president; and Professor Malcolm Crocker, IIAV Executive Director*

Figure 23 shows Sir James Lighthill chairing a Board of Directors meeting at the Fifth International Congress on Sound and Vibration in Adelaide, Australia in December 1997.

*Fig. 23 Sir James Lighthill chairs IIAV Board of Directors meeting at the Fifth International Congress on Sound and Vibration in Adelaide, Australia, December 1997*

He contributed two articles to the new refereed journal of **IIAV**, the **International Journal of Acoustics and Vibration (IJAV).** He continued to present many keynote papers including those at IIAV congresses on "Hearing and the Cochlea" at the Fourth International Congress on Sound and Vibration, St. Petersburg, Russia, 1996, "A Century of Shock Wave Dynamics" at the Fifth Congress in Adelaide, Australia in 1997 and a planned "Fifty Years of Aeroacoustics" at the Sixth Congress in Copenhagen in 1999. He gave the closing general lecture at the 19$^{th}$ International Congress of Theoretical and Applied Mechanics (ICTAM) Kyoto, Japan in 1996 on "Typhoons, Hurricanes and Fluid Mechanics." Figure 24 shows Sir James Lighthill giving his presidential keynote paper at the Fourth International Congress on Sound and Vibration St. Petersburg, Russia, in 1996.

*Fig. 24 Sir James Lighthill giving his keynote paper on "Hearing and the Cochlea" at the Fourth IIAV Congress in St. Petersburg, Russia in June 1996*

Sir James was an accomplished lecturer and often was asked to be the lead-off or keynote speaker ("opening bat" as he liked to call himself) because conference organizers knew that he could guarantee a packed house with his profound scientific knowledge, erudition and flamboyant style and because he would be sure to entertain and delight the audience with his lecture and his knowledge of many languages.[1] He was famous for his gestures and physical movements during his lectures whether he was demonstrating sound radiation from monopoles, dipoles and quadrupoles, the flight of insects or birds, and the inrush of moist air and its subsequent rapid rise at the eye-wall of a tropical cyclone (from sea level to the stratosphere base).

Sir James, although sharing authorship of some of his papers with his colleagues, rarely allowed his name to be added to papers written by his students.

## HONOURS AND AWARDS

Sir James Lighthill received many honours and awards. He was elected as Fellow of the Royal Society in 1953 at the age of 29 and received the gold medals of the Royal Society in 1964 and Royal Aeronautical Society in 1965. He was posthumously awarded the Copley medal of the Royal Society, its highest honour. He served on several UK governmental scientific advisory bodies. Queen Elizabeth II knighted him as "Sir James Lighthill" in 1971. Figure 25 shows Sir James outside Buckingham Palace in 1971.

*Fig. 25 James Lighthill outside Buckingham Palace in 1971 collecting his knighthood. With him are his wife Nancy and son and daughter, Michael and Christine*

He received 24 honorary doctorates from universities in England, France, Germany, Portugal, Russia, Ukraine and the United States of America. He was an honorary foreign member of 11 learned societies in France, Italy, India, The Netherlands, Russia and the USA. He was President of the **International Union of Theoretical and Applied Mechanics (IUTAM)** from 1984-1988. (See Appendix D for a listing of his honours.) Figure 26 shows Sir James Lighthill during the ceremony for the award of honorary doctorate in St. Petersburg, Russia in June 1996.

*Fig. 26 Sir James Lighthill during the ceremony for the award of honorary doctorate by the Baltic State Technical University in St. Petersburg, Russia in June 1996*

*Fig. 27 Sir James Lighthill receiving the Theordorsen Medal from Lee Beech at NASA Langley in 1993*

## COLLECTED PAPERS

His complete works "Collected Papers of Sir James Lighthill", Oxford University Press, was published in four volumes published in 1997. The majority of his published papers were included. (See the review in the December 1997 issue of IJAV.) In reading these collected papers one is made even more aware of Lighthill's mathematical powers and the breadth of his scientific knowledge and physical understanding in so many scientific fields. One is also struck by the similarities that can be observed with Lord Rayleigh's mathematical versatility, physical understanding and some aspects of his scientific career.

The first volume of the "Collected Papers of Sir James Lighthill" contains papers on the first and main topic of his study during the first 15 years of his career*: the theoretical foundations of high-speed flows including re-entry aerodynamics*. His work in this area was of course at first necessitated by his assignment to study the possibilities of supersonic flight during the war effort in England in 1943. But his interest in this area continued for an extended period of time. His work on *supersonic* and *hypersonic* aerodynamics during the first 15 years of his career produced significant innovative contributions. For example his use of the *hodograph* method to study the flow past solid boundaries allowed non-linear phenomena to be analyzed using linear equations and made possible advances in compressible flow aerodynamics. The hodograph method has not been used so much lately because of its difficulty. His *method of strained coordinates* has become a useful tool to analyze certain classes of singular perturbation problems. Many problems in supersonic aerodynamics have been made amenable to analysis using his *slender body theory.*

Volume II includes Lighthill's papers on the aerodynamics of bodies in inviscid incompressible flows with or without viscosity. The results of these studies are applicable to situations where the viscous effects are assumed to be confined to a thin boundary layer around the body. This volume also contains his contributions to boundary layer theory throughout the whole subsonic to supersonic speed range. Two particularly important papers are included: i) his study of supersonic boundary layers and upstream influence, and ii) boundary layers in fluctuating streams. Lastly Volume II also includes Lighthill's papers on chaos and chaotic motions; one of these papers contains an illuminating study of Osborne Reynolds' pioneering work on turbulence and also a review of turbulence research up to 1968.

Volume III contains all of Lighthill's papers on waves in fluids. The first two papers included are the famous papers dating from 1952 and 1954 and already extensively discussed here. Other papers include those on: wavelike ocean-current patterns, kinematic wave theory and its application to flood conditions in long rivers, road traffic flow, and loading on offshore structures.

Volume IV contains all of Lighthill's papers on internal and external biofluiddynamics. The papers included range from surveys, studies and theoretical models of the propulsion of aquatic animals, from small organisms to large fish. Also described are his papers on insect and bird flight. In addition this volume includes studies of internal biofluidmechanics from the flow of red blood corpuscles in the capillaries to the flow of acoustic energy in the cochlea.

## SIR JAMES AND LANGUAGES

Sir James Lighthill was conversant in several languages including French, German, Portuguese and Russian. In these languages he could give after-dinner speeches, scientific lectures and read novels. In French he read all of the famous works of Balzac, Duras, Gide, Stendahl, and Zola; in Portuguese he read those of Dinis, Queiroz and Amado (from Brazil); while in Russian he read those of Dostoevsky, Goncharov, Gorky, Sholokhov, Solzhenitsyn and Tolstoy. In addition he had a reasonable knowledge of Italian and Spanish. He also read some works in Spanish including the Latin American authors: Donoso and Marquez. In English he continued to enjoy the novels of Austen, the Brontes, Bruckner, Byatt, Dickens, Eliot, Hardy, Huxley, Murdoch, Seth, Trollope, and Woolf.

He recalled that his interest in languages began quite early. During the time he was waiting to go to Trinity College in 1940 he was able to spend some time learning languages.[9,10] Later, before leading a delegation during a three-week visit to the Soviet Union to tour aircraft establishments in the 1960s he dedicated his efforts to learning Russian and mastered it in a few months. It is said that initially he learned sufficient Russian in about six weeks for his visit by reading translations of Russian literature into English. Because he knew the Russian literature quite well and by putting both the Russian and English versions, side by side, he was able to get a working knowledge.[1] During the visit to the Soviet Union he gave a technical lecture in Russian on aeronautics and was able to answer questions in Russian with ease. Later he was fluent enough to be able to give after-dinner speeches in Russian.[1] ("Sir James spoke to us in Russian. He recited some Pushkin poetry. His Russian is very good!") He learned Portuguese faster, however, and he is said to have mastered it in three weeks.[1] ("Before I go (to Portugal) I read one or two novels to brush up.")

## STORIES ABOUT SIR JAMES

Stories about Sir James abound. Although the exact details of some stories are unverifiable, it does not make them less indicative of his character and humanity. During his time at Winchester with Freeman Dyson, the two boys were particularly precocious at mathematics and geometry. Cordelia James recalled that during the Second World War she would take the younger Winchester students (Collegers) to a Harvest Camp at Hurstbourn Priory. Their meals were in the village hall and she made a rota of boys to sweep up afterwards. Whenever it was Lighthill and Dyson's turn, they would divide the floor precisely into squares and isosceles triangles to the nearest inch (or centimetre) so that both had exactly the same floor area to sweep. And when they were 'stooking' (putting up the sheaves of wheat to dry), one said to the other reprovingly "Have you never seen a single cruciform basilica?"[33]

David Larman recalls an incident when he went to the University of Sussex in the UK as a young lecturer. The Head of Mathematics at Sussex was Professor Bernard Scott who had been one of the examiners for the Cambridge Open Scholarships in the early 1940s. Bernard Scott told David Larman that one year two students had obtained almost perfect scores on his examination paper. He was very upset by this. However, when he went to the examiners meeting he found that the same thing had happened on all of the other examination papers. One of the two students was Michael James Lighthill and the other was Freeman Dyson (who later went on to Princeton to become the Professor succeeding Einstein.)

As a young man, James Lighthill suddenly realised that since he was born in France, even though his parents were British and he was resident in England, he would be regarded as a French citizen by the French government. It thus became evident that unless he took some urgent action, he would become liable for compulsory military service in France. Thus he and his family became involved in masses of correspondence and the filling in of a number of forms and their submission to the authorities. Eventually James received a letter setting forth his British citizenship which he preserved to the end in his wallet. [8]

Freeman Dyson recounts an incident when in the summer of 1944 he and James were taking a long walk through Kensington Gardens in the middle of London. The V1 bombardment of London was at its height. Every few minutes there would be the noise of another "buzz-bomb" sounding rather like the pop-pop-pop of a small motorcycle. Then there would be a silence followed by an explosion and the sound of falling masonry. They calculated that the chance of being hurt by a flying bomb was approximately equal to the chance that someone playing a hundred-yard approach shot at golf would hit the ball into the hole without its bouncing.[11] Each time they heard an explosion without it hitting them they knew that the person with the mashie golf-club had missed again. The next morning Dyson tried to telephone to James' family home in Highgate to arrange another meeting, he heard only an out of order signal. So he traveled on the underground train system to Highgate next day. When he arrived, he found James raking over the rubble, trying to salvage and rescue his precious mathematics books. The house was demolished but fortunately no one was hurt. So much for mathematics and statistics theory! [11]

In 1959 when Lighthill was the Beyer Professor at Manchester University he was dismayed to find that the Irish Mail express train did not stop at Crewe as he had expected. He managed to convince a guard on duty that he was lightly loaded with only a briefcase and could easily jump out and close the door behind him, as he did successfully when the train went through Chester at 15 kilometres per hour. But British Railways (BR) took the matter seriously (perhaps concerned that the guard might have been bribed to slow the train down as it went through Chester). After an enquiry, BR fined Professor Lighthill one pound sterling!

Lighthill is said to have successfully defended himself against speeding charges on more than one occasion by explaining to the magistrate in court that as Lucasian Professor, he had a duty to the environment and the laws of mechanics not to waste energy by applying the brakes on any downhill stretch of road![1]

## SWIMMING AND OTHER HOBBIES

Sir James listed his leisure interests as music and swimming. He took both of these pursuits very seriously, but he did however have other hobbies mostly consisting of Chess, Bridge, Backgammon, Bezique, the Times crossword (which he finished almost every day) and long walks.[8] Figure 28 shows Sir James playing monopoly with his mother.

*Fig. 28 James playing Monopoly with his mother (Marjorie) in the 1930s*

A favourite pastime was chess, which he learned at an early age playing with his sister Pat and his father. Figure 29 shows James playing chess with his sister Pat

*Fig. 29 James playing Chess with his sister Pat*

He used to have fierce Chess battles with his father. However his father gave up when the blindfolded James beat him. He also liked to play chess with his children particularly his son Michael whom he could initially beat even with the handicap of his queen and queen's rook. Later when Michael reached ten the handicap had to be reduced to just his queen for him to have the chance to continue to win.[8]

His mother first taught him the piano, and then later he had lessons from Mrs. Ethel Hobday (who when a young girl had studied with Johannes Brahms in Vienna!)[9] James Lighthill became an accomplished pianist. On vacations from Winchester he would play piano duets with his mother. They played a piano version of Beethoven's symphonies with great enthusiasm sometimes driving James' father to retreat to another room, especially at the beginning of the Fifth symphony. James continued his interest in music and the piano throughout his life. For about 40 years (1942-1982) he regularly took the piano part in chamber music with his wife Nancy who took the cello part. They often played with others (on violin, viola, double bass or clarinet) and sometimes in public. Their repertoire included the main classical chamber works that contained piano and cello: beginning in 1942 with Mozart's G minor Quartet and Dvorjak's Quintet. Later they were to play among other piano quartets and quintets including those of Brahms, Frank, Faure, Frank, Schubert and Schumann and piano trios by Beethoven and Brahms. When his wife Nancy had given up her physically demanding cello in her 60s and he was Provost at University College London (UCL) he would give piano recitals each year - sometimes in public at the UCL Music Club.[9] In 1997 he played the piano accompaniment for some songs by Richard Strauss, in the Netherlands, at the birthday of his friend Professor Weingarten, his friend. Figure 30 shows Sir James playing a duet for piano and violin in Canada.

*Fig. 30 James Lighthill playing a duet with his grandson Nicholas during a visit to Canada a few years ago*

But swimming was almost a passion. He swam regularly. " Throughout the entire year I swim for (three to five miles) each week (at the Parliament Hill swimming ponds in London, although in indoor pools from mid-November to mid-March) just to keep fit."[9,10] When opportunities presented themselves either in his summer vacations or during his travels all around the world he would undertake "adventure swims" often in rough conditions. "I embarked on this hobby at age 40 - possibly influenced by the confident views of RAE test pilots to the effect that, if you can understand scientifically what may occur, you can safely perform feats which for someone else would be hazardous!"[9] "Because I have a deep understanding of both tidal currents and waves, I have enjoyed and continued to enjoy (say, once a year) some specially challenging swim that requires use of that understanding. I have a reliable stroke (Old English Backstroke) which I can keep up all day (if necessary) at 2.5 km/hr in waters above 13 C; (at lower temperatures I can only do shorter swims of, say half an hour.)."[9]

He would plan each swim down to the last detail starting several months ahead. Beginning in January of each year, he would discuss with his wife Nancy where they would spend their summer holiday. Once the place was chosen, then they calculated when to go by determining the position of the Moon in August and September. With this basic information, the holiday travel and accommodation was reserved and James would start work on further detailed study of the currents and tides. On arrival on the island (his summer holidays were almost always spent on islands), he would often spend several more days (sometimes seven to ten) concentrating on smaller swims on parts of the final route before he would take the complete "adventure swim."[8] Figure 31 shows James swimming with his son Michael in the mid-1960s.

*Fig. 31 James Lighthill with his son Michael swimming at Port Nouvelle in the mid-1960s*

There were many swims of which he was proud. He swam around many of the Scilly Isles, Sark, Alderney, Lundy, Caldey, Comino, the Needles in the Isle of Wight, Herm, Jethou, and Ramsay Island. He swam around Stromboli when it was erupting and is said to have counted 13 eruptions during his swim. He noted that the water on one side of the island was significantly warmer because of the lava that was entering it. He also made several other swims involving strong currents across straits of water (between islands or between an island and the mainland), such as those involving the Calf of Man (to the South of the Isle of Man), between two islands in the Azores (Faial to Pico), the round trip between St. Mary's and St. Agnes (in the Scilly Isles) and the St. Michael Island off the South coast of Wales.[8, 9,]

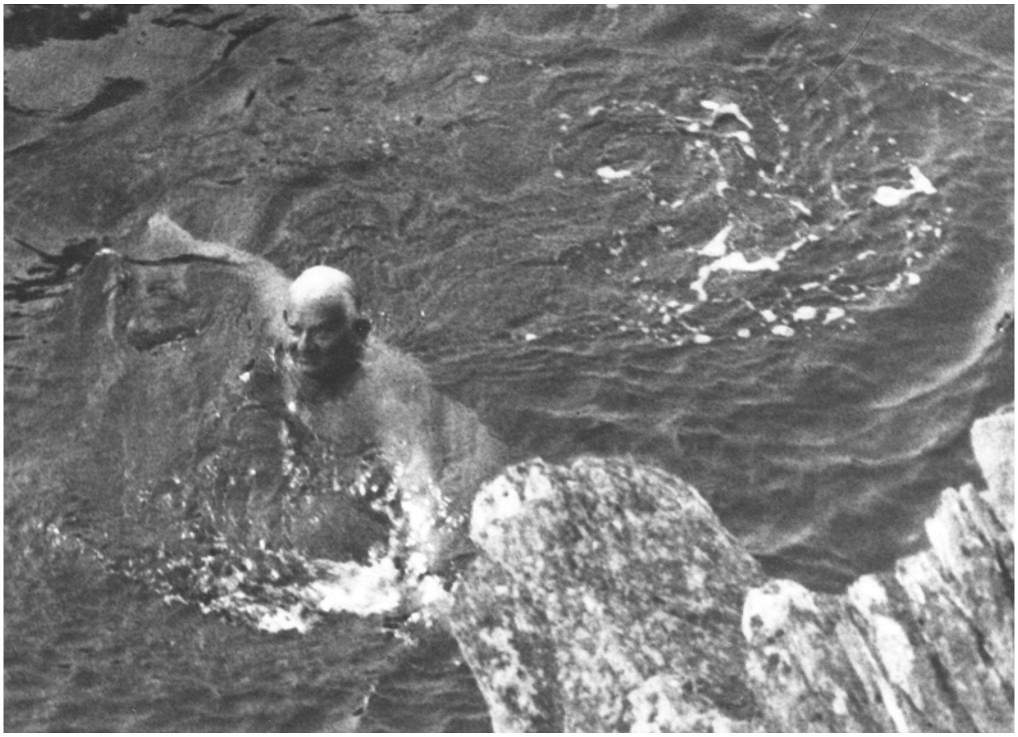


*Fig. 32 Sir James Lighthill completing a difficult swim around the island off the south coast of the Isle of Man*

He became the first to swim around the island of Sark (one of the Channel Islands between England and France) in nine hours using his favorite back stroke (arms and legs alternately in unison).[34,35] He repeated this feat five more times. He did not really count this first time in 1971, since he stopped half way on the beach for a picnic lunch with his wife Nancy, sister Pat and son Michael.[8,35,36]

*Fig. 33 James Lighthill on one of his swims around Sark*

One of his swims around Sark was during a south-westerly gale which was the one that caused a disaster during the Fastnet sailing boat race in which many ships capsized. He recounted that during his adventure swims, at all times, he had to use his knowledge of wave mechanics and tides to enable him to determine the correct direction in which to swim. He had to add up vectorially his own swimming velocity with the current velocity and the wave drift caused by the powerful ocean waves in order to find the right direction. [36]

*Fig. 34 Sir James Lighthill during his successful swim around Alderney.*

*Fig. 35 Sir James Lighthill during his swim around Lundy*

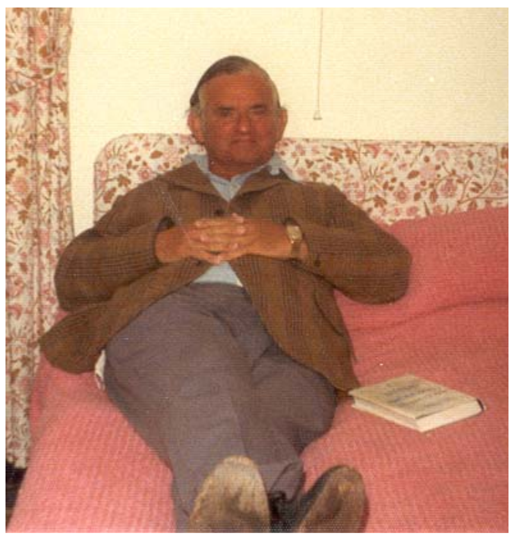


*Fig. 36 Sir James Lighthill after his swim around Lundy*

Lighthill said that he had a sort of pleasurable feeling about fluids. His interest in flight was stimulated not only by aircraft, but also by birds, bats and insects. But also his great interest in the ocean - ocean waves, ocean currents, and ocean tides increased this feeling. He had a fellow feeling for the swimming animals that would sometimes accompany him: seals, dolphins and even once a shark. Sir James was once chased out of a cave he was exploring by sea in Sark by an annoyed sea lion! [8]

On July 17 1998 on another attempt to swim around Sark, in inclement weather with strong winds he died of mitral valve failure near the end of his nine-hour swim. He was at the height of his intellectual powers.

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## Appendix A. Principal Areas of Research of Sir James Lighthill

The following listing shows the principal lines of research that Sir James Lighthill pursued.[9] It is noticed that he would often return to a research topic later in life and in some cases undertake some more basic research; in other cases he would write a summary or review paper. These are mostly the periods of his life when he devoted his research interests and journal and book publication efforts to the topics shown. Rarely did James Lighthill allow his name to be added to papers published by his students.

**1.** Theory of inviscid flow at supersonic speeds, 1943-4, 1947-52, and 1956
**2.** A method of two-dimensional aerodynamic design, 1944-5
**3.** The hodograph method in compressible flow theory, 1946-7
**4.** A technique for rendering approximate solutions to physical problems uniformly valid, 1949-51 and 1961
**5.** The diffraction of blast, 1948-49
**6.** Shock wave-Boundary-layer interaction, 1949-52
**7.** Heat transfer, 1948-52 and 1954
**8.** Turbulence and Sound, 1950-53, 1955, 1961-62, 1966, 1968, 1991-93.
**9.** River waves - and a "traffic" analogy 1954-56
**10.** Viscosity effects in sound waves of finite amplitude, 1954-55
**11.** Three-dimensional disturbances to shear flows 1955-58
**12.** Dynamics of a disassociating gas 1956-59
**13.** Fourier analysis and generalized functions (his book on Fourier Analysis) 1957 and 1993

**14.** Fundamentals of fluid dynamics 1957-59 and his book of Fluid Dynamics 1983-85.
**15.** General theories of waves in fluids 1958-60 and including work on book on Waves in Fluids 1964-67, and 1989-94
**16.** Fluid dynamics of animal location, i) Aerial 1973-75 and 1992, ii) Aquatic 1960-77 and 1988-94, and iii) Microbiological 1975 and 1992-95
**17.** Physiological fluid dynamics 1966-71 and his book on Animal Biofluid-dynamics 1973-74 , 1978-83 and 1989-92
**18.** Ocean science, 1962, 1968-69, 1970-79, 1990-93

## Appendix B. Students who worked with Sir James Lighthill

Among the students who studied with Sir James Lighthill are the following: [9]

**At Manchester**

**1.** G. B. Witham, who later became Professor at Caltech in the USA and is known for his work on nonlinear propagation of waves.
**2.** F. A. Goldsworthy, who became a professor at Leeds University in the UK.
**3.** S. N. Curle who was a faculty member at Southampton University and also Professor at St. Andrews in Scotland before his early death.
**4.** M. R. Abbot who wrote a hydrodynamics thesis on the River Severn and later became a hydraulic engineer in Denmark.
**5.** G. J. Hancock who, after some pioneering works in microbiological biofluid-dynamics, became Professor of Aeronautics at Queen Mary College, London.
**6.** E. J. Varley made analyses of non-linear waves in stratified shear flows and is now Professor at Lehigh in the USA.
**7.** E. Cumberbatch successfully analysed wave "slamming" forces, and is now Professor at Claremount, California, USA.
**8.** J. H. Gerard conducted jet-noise experiments, and then joined the Fluid Motion Laboratory (FML) staff at Manchester University.
**9.** I. M. Hall after conducting analyses of disturbed shear flows also joined the FML staff at Manchester University.
**10.** N. C. Freeman after conducting hypersonic studies, became Professor at the Engineering Department of the University of Liverpool.
**11.** N. Riley studied the theory of unsteady aerodynamics and has become Professor at the University of East Anglia.

**At Imperial College**

**12.** M. S. Howe conducted studies in general wave theory and aeroacoustics and now is Professor in the Department of Mechanical Engineering at Boston University, USA

**13.** D. J. McConalogue carried out computational fluid dynamics for flows in curved tubes (e.g. the arch of the aorta) and later became Professor at Queen's University, Canada

**At Cambridge**

**14.** J. R. Blake conducted research in microbiological and other fluid dynamics and is now Professor at Birmingham University.
**15.** M. A. Swinbanks conducted research into active noise control and has now become an acoustical consultant.
**16.** A. J. Mead conducted research into general control theory, and has become Professor at the University of Western Australia.
**17.** P. E. Rapp conducted research into the analysis of shorter biorhythms and is now Professor at the Medical College of Philadelphia.
**18.** M. J. Simon conducted research into the theory of the energy of ocean waves and is now a lecturer at the Department of mathematics at the University of Manchester.
**19.** J. M. V. Rayner analyzed the aerodynamics of bird flight and is now a Professor at the Zoology Department of Bristol University.
**20.** R. W. Blake specialised on the research into the swimming of fish that swim without bending their bodies and is now a Professor of Zoology at the University of British Columbia, Canada.
**21.** J. J. L. Higdon conducted research into microbiological biofluid-dynamics and later became an engineer.

## Appendix C. Research, Teaching and Administrative Positions of Sir James Lighthill

**1943-45.** Junior Scientific Officer (later Scientific Officer) at the National Physical Laboratories (Aeronautics Division)
**1945-49.** Research Fellow of Trinity College, Cambridge. (Resident only from 1945-46)
**1946-50.** Senior Lecturer in Mathematics, University of Manchester
**1950-59.** Beyer Professor of Applied Mathematics, University of Manchester
**1959-64.** Director of Royal Aircraft Establishment, Farnborough
**1964-69.** Royal Society Research Professor, Imperial College, London
**1964-66.** (First) President of the Institute of Mathematics and its Applications
**1965-69.** Physical Secretary of the Royal Society
**1969-79.** Lucasian Professor of Mathematics, University of Cambridge
**1971-74.** President International Commission on Mathematical Instruction
**1979-89.** Provost of University College London (UCL)
**1984-88.** President, International Union of Theoretical and Applied Mathematics (IUTAM)
**1989-98.** Honorary Research Fellow, UCL, Department of Applied Mathematics

**1990-95.** Chairman, Special Committee on the International Decade for Natural Disaster of the International Council of Scientific Unions
**1995-98.** Founding President (1995-97) and from 1997-98 (first) elected President of the International Institute of Acoustics and Vibration (IIAV)

## Appendix D. Honours and awards

Sir James had many honours and awards. This lists the principal ones.[9,10,11]

**October 1945**. Elected to Fellowship under title A in Trinity College, Cambridge

**May 1948.** Appointed a member of the Fluid Motion Sub-Committee of the Aeronautical Research Council.

**August 1948.** Gave a General Lecture "High speed flow of gases" to the 7th International Congress of Theoretical and Applied Mechanics (ICTAM) London

**May 1952.** Appointed Chairman of the Fluid Motion Sub-Committee, and Member of the Aerodynamics Committee, Aeronautical Research Council.

**April 1972.** Gave General Lecture "Aquatic Animal Locomotion" at the 13th International Congress of Theoretical and Applied Mechanics ICTAM (Moscow)

**August 1996.** Gave General Lecture "Typhoons, Hurricanes and Fluid Mechanics" at the 13th International Congress of Theoretical and Applied Mechanics ICTAM (Kyoto)

**Fellowship** of Royal Aeronautical Society (RAeS), 1961 and

**Fellowship** of the Institute of Mathematics and its Applications (IMA) 1964

**Honorary Fellowships** in RAeS and IMA, also in Institution of Chemical Engineers, Institution of Electrical Engineers, and in the Institute of Acoustics; and in the USA in the American Institute of Aeronautics and Astronautics and the American Society of Mechanical Engineers.

**Foreign Honorary Memberships in Academies:** US National Academy of Science, US national academy of engineering, American Academy of arts and Sciences, American Philosophical Society, Acedemie des Sciences (Paris), Accademia delle Science di Torino, Russian Academy of Sciences, Indian National Science Academy, and Indian National Academy of Sciences

**Knighted 1971** as Sir James Lighthill

**Honorary Doctorates:** Liverpool 1961, Leicester 1965, Strathclyde, 1966, Essex 1967, Princeton 1967, East Anglia 1968, Manchester 1968, Bath 1969, St. Andrews 1969, Surrey 1969, Cranfield 1974, Paris 1975, Aachen 1975, Rensselaer 1980, Leeds 1983, Brown 1984, Southern California 1984, Lisbon 1986, Rehovoti 1987, London 1993, Kiev 1994, Compiegne 1994, St. Petersburg 1996.

**Royal Society**, Royal medal 1964;

**Royal Aeronautical Society**, Gold medal, 1964;

**Institute of Mathematics and Applications**, Gold medal, 1982.

**Harvey Prize** of the Israel Institute of Technology, 1981

**Chairman**, Academic Advisory Committee, University of Surrey, 1964

**Member**, Geddes Committee into the Shipbuilding industry, 1966

**Member**, Natural Environment Research Council and Chairman of its Oceanography and Fisheries Research Committee, 1965-70. (Later member of the Fisheries Research and Development Board.)

**Member** (part-time) of the Post Office Board, 1972-74

**Member**, Advisory board for the Research councils, 1980-86

**Associate Editorship** of the Journal of Fluid Mechanics, 1956-79

**Royal Society Lectureships**: Bakerian (1961) and Humphry Davy (1991)

**Wilbur Wright Memorial Lecture** (UK, 1960)

**Wright Brothers Lecture** (USA, 1962)

**John von Neumann Lecture** (USA, 1975)

**Rayleigh Lecture**, (ASME, USA, 1989)