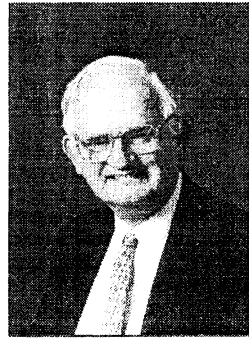




Sir James Lighthill and modern fluid mechanics

A memorial tribute

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Sir James Lighthill
(1924-1998)

“...as Sir Cyril Hinshelwood has observed... fluid dynamicists were divided into hydraulic engineers who observed things that could not be explained and mathematicians who explained things that could not observed.”

James Lighthill

Abstract

This memorial tribute commemorates Sir James Lighthill the man and the mathematical scientist. A brief biographical information is presented with my personal reminiscences. He is one of the most brilliant and influential applied mathematicians of the twentieth century. By any standards, his legacy of research and publications of six books and one hundred fifty papers in fluid mechanics and applied mathematics will remain forever as a remarkable example of scholarly work.

1. Brief biographical sketch and career

Sir James Lighthill was born on January 23, 1924 in Paris, France. After a rigorous education at Winchester College with an outstanding record, he entered the Trinity College, Cambridge in 1941 to pursue a B.A. degree in Mathematics. He successfully completed his B.A. degree in two years, and



then joined British National Physical Laboratory (NPL) as Junior Scientific Officer at Aerodynamics Division in 1943, and soon became a Senior Scientific Officer at NPL. Before he became twenty in 1944, Sir James [1] published his first paper on two-dimensional supersonic airfoil theory in the Aeronautical Research Committee Report and Memorandum (ARCRM). Because of his outstanding research work at NPL, he was awarded a prestigious Research Fellowship at Trinity College in 1945. After spending a year at his 'Alma Mater', Lighthill joined the University of Manchester as Senior Lecturer in Mathematics at the age of twenty-two. Within a short period of time, he succeeded Sydney Goldstein in the Beyer Professor of Applied Mathematics at Manchester at the age of twenty-six. This was almost an extraordinary accomplishment in the United Kingdom in those days. His thirteen years stay at Manchester was very productive and rewarding in his life in terms of research, publications and supervision of doctoral students — many of them are now well known in applied mathematics. Highly respected by his applied mathematics peers, he was instrumental in organizing a strong research group in fluid mechanics and applied mathematics in England. Above all, he created an enduring cordial atmosphere of mutual support and encouragement for fluid dynamics research at the highest level.

In 1952, Lighthill was elected Fellow of Royal Society of London at the age of twenty nine for his pioneering research on sound generated aerodynamically. He was awarded the Bronze Medal of the Royal Aeronautical Society for his outstanding contributions to aerodynamics in 1955. Lighthill left Manchester in 1959 to join the extremely prestigious position of Director of the Royal Aircraft Establishment (RAE) at Farnborough. However, even as Director of RAE, he was actively involved in research and development of aerodynamics of the slender delta wing for aircraft, spacecraft, and performance of high speed jet aircraft and missiles.

In 1964, Sir James was selected for the position of Royal Society Research Professor at the Imperial College of Science and Technology at London. In a new and conducive academic atmosphere at Imperial College, he had the usual responsibility of teaching, research and guiding many promising young researchers. At Imperial, he delivered three courses of lectures on Nonlinear Waves, Geophysical Fluid Dynamics and Blood Flow in Arteries during 1965-67. In addition to his many outstanding papers and presentations on these topics, he got involved in the development of strong research in mathematical biofluid dynamics. Under his unique leadership, a new *Institute of Mathematics and Its Application* was established in the United Kingdom in 1965, and he became the first President of this newly created institute. During 1963-1965, he was awarded the Royal Society Medal and Gold Medal from the Royal Aeronautical Society, and Timoshenko Medal from the American Society of Mechanical Engineers for his outstanding research contributions.

From Imperial College, Lighthill returned to Cambridge in 1969 to succeed Paul Dirac as the Lucasian Professor of Applied Mathematics. This is probably the most prestigious Mathematics Chair in the United Kingdom as



this Chair was formerly held by Sir Isaac Newton. Lighthill was justifiably proud to tell people that his predecessor in the Lucasian Chair was Newton. Within the next two years of his stay in Cambridge, Queen Elizabeth presented him a Knighthood as Sir James Lighthill. Among his many other honors were Bakerian Lecture in 1961, the 48th Wilbur Wright Memorial Lecture in 1960, Wright Brothers Lectures in the United States in 1962, The Symons Memorial Lecture in 1969, John von Neumann Lecture in the United States in 1975, American Institute of Aeronautics and Astronautics (AIAA) Aeroacoustics Award in 1976. During his stay in Cambridge from 1969 to 1979, Sir James vigorously continued his teaching and research on acoustics, more and more wave propagation, geophysical fluid dynamics, biofluid mechanics, ocean and atmospheric dynamics with special reference to prediction of monsoons and tropical cyclones.

In 1979, Sir James left Cambridge to serve in the position of Provost of the University College London (UCL). Due to his enormous wisdom and communication skills, and strength of character, he remained in that administrative position until his formal retirement in 1989. Even though he was very busy with administrative duties and responsibilities, Lighthill still maintained his scientific research in areas such as extraction of wave energy, dynamical systems, and biomechanics of the human auditory system.

His professional activities included service as President of the International Union of Theoretical and Applied Mechanics, as Member of the Advisory Board for the Research Council, 1980-1986, as Member of Natural Environment Research Council and Chairman of its Oceanography and Fisheries Research Committee, 1965-1970, as Member of Geddes Committee of Inquiry into Shipbuilding Industry, President of the International Commission on Mathematical Instruction (ICMI), 1971-1975, and as Member of the Advisory Council on Research and Development, 1978-1981. As President of ICMI which was then a sub-commission of the International Mathematical Union (IMU), Lighthill has had great influence on mathematics education at the international level. In order to promote mathematics teaching (Lighthill, [2]) at all levels and to upgrade mathematics education all over the world, Lighthill helped organize a number of symposia that include 'New topics in applicable mathematics in Secondary Schools' in Luxembourg in 1973, and 'Mathematics and Language' in Kenya in 1974. His philosophy of mathematics education can be best described by citing his own quotation from his Presidential address [3] at Exeter in 1973. "Let go *beyond mere use* of the concrete example as an aid to understanding or of reference to utility as an aid to widening the circle of those in whom interest is aroused. There is a still more important prize to be won: a prize concerned with a *deeper* integration of mathematics into the total education of the individual.

I want to suggest that educators may have most benefited their pupils when they have succeeded in giving them a feel for what is involved in the *process of applying mathematics*. ... Computers may be of great value in problem-solving, but apparently the human brain alone is able to tackle the subtler aspects of creating an effective correspondence between the mathe-



mathematical world and the world of experiment and observation.”

In addition, Sir James delivered many special lectures including the Inaugural Frederic Constable Lecture in 1980, and the Rayleigh Lecture in the United States in 1989. No doubt, he has made some important contributions to the British higher educational system and science policy. Among his many degrees, honors and awards, he received a Gold Medal from the Institute of Mathematics and Its Applications in 1982, and the Harvey Prize of the Israel Institute of Technology in 1981. He also received twenty four honorary degrees from many different universities including Princeton, Brown, and Kiev. In recognition of his notable research contributions to fluid mechanics and applied mathematics, he was elected to twelve learned societies including the U.S. National Academy of Sciences, Russian Academy of Sciences, and the Indian National Science Academy.

After his formal retirement from the University College London in 1989, he was appointed Emeritus Scientist by the College. He continued his research, publications and presentations. He accepted the Royal Society Lectureship to deliver the Humphry Davy Lecture in 1991 and the Inaugural Perkins Memorial Lecture in 1995. In the same year, Sir James and Lady Nancy visited the University of Central Florida (UCF) for a week during October to deliver three lectures on fluid mechanics as part of the Distinguished Lecture Series in Mathematics at UCF. In 1993, he received the ICASE/LARC Theodorsen Lectureship Award. In November 1996, Sir James and Lady Nancy came to Florida State University at Tallahassee to attend the International Symposium on Theoretical and Computational Fluid Mechanics which was organized in honor of Sir James Lighthill to celebrate his monumental contributions to fluid mechanics, applied mathematics and the mathematical community of the world. After the Symposium, they returned to England. Sir James remained at the University College London until his death on July 17, 1998 after completing a nine-hour swim around the island of Sark against high tides and strong winds. The 1998 Copley Medal of the Royal Society (the highest award of the Royal Society) has been awarded posthumously to Sir James.

2. Personal reminiscences

Perhaps it is appropriate to record here my personal relationship and association with Sir James Lighthill. Before I came to England, I heard his name as one of the great applied mathematicians, and read his famous book *Introduction to Fourier Analysis and Generalized Functions* and some research papers in order to prepare myself for pursuing research in fluid dynamics at Imperial College London. After joining the Imperial College as a postgraduate student, I first came into contact with him in the Fall of 1965. During the next two years of my stay at Imperial College, I had the rare opportunity of attending his three courses of lectures on nonlinear waves, geophysical fluid dynamics, and blood flow in arteries. All of his



three courses of lectures were primarily based on his own research notes, research papers either already published or under preparation at that time in Imperial College. All of these lectures dealt with remarkably new mathematical and physical ideas, results and predictions. I thoroughly enjoyed and learned a great deal from his lectures, and immediately decided to work on linear and nonlinear water waves for my Ph.D. dissertation. Sir James' unlimited enthusiasm, great challenge and interest in teaching and research will remain a lifelong memory with me and my other classmates at Imperial College. As I had stated earlier, his influence on me can, in fact, be traced back to my postgraduate days at the University of Calcutta well before I first met with him at Imperial College.

Sir James was an extremely dynamic and inspiring teacher in the classroom. Indeed, he was my most favorite teacher in my student days in London and Cambridge. Also what I do remember is the excitement generated by his lectures, but most importantly his numerous examples of applications intended to deepen our understanding of the mathematical theory with physical insight. During my stay at Imperial College, I had many opportunities to discuss my research problems with Sir James Lighthill and other members of his group.

During this period of twenty years, 1969-1989, I visited Cambridge for a year and then Oxford for six months to conduct research in applied mathematics. When I was at the Department of Applied Mathematics and Theoretical Physics in Cambridge. I again had the opportunity to attend some of his lectures and discuss research problems with him. During my stay in Oxford in 1980, I went to the University College London to discuss my research problems on nonlinear diffraction of water waves based on his famous 1979 paper on "Waves and Hydrodynamic Loading." Subsequently, Rahman and I wrote a paper (see Debnath and Rahman [4]) on "A Theory of Nonlinear Waveloading on Offshore Structures" in 1981, and then a chapter on "Nonlinear Diffraction of Water Waves" for my book [5] entitled *Nonlinear Water Waves* published in 1994. He was also noted for his leisure interests in swimming, languages, and music throughout his life. He was much attracted by the beauty of nature, particularly of oceans and ocean waves. He always loved to swim. On numerous occasions, he completed swimming around islands in the English Channel against strong currents and high winds in several hours. His favorite hobby of swimming led him to formulate the standard model of fish swimming based on body undulations.

At my personal invitation, Sir James Lighthill and Lady Nancy Lighthill visited our department in the Fall of 1995. During this week long visit at Central Florida, he delivered three lectures on hurricane dynamics, bacterial biofluid dynamics, and some aspects of aeroacoustic of extreme-speed jets. As usual, these lectures were loaded with many new, important and interesting ideas and results, and have stimulated interest in applied mathematical research. During this visit to Orlando, we had the opportunity to discuss many issues of mutual interest including research topics, the future of applied mathematics research, education and training in the U.K. and



in the U.S.A. One day, I escorted both James and Nancy on a sightseeing tour at Walt Disney World in Orlando and it seemed to me they enjoyed the tour. However, I enjoyed their company for a week and was impressed with their high levels of thinking with grace, good humor and friendliness. We had an ample but great time and this time we became good friends and were free to discuss many topics of diverse interests including past stories of our stay in London, Cambridge, and Oxford.

After their return to London, I have had regular correspondence with him. In each of his many letters written to me, he signed his first name in the end. It is my pleasure to record here his friendliness and kind invitation to participate in the International Symposium organized in honor of Sir James at Tallahassee, Florida in November 1996. Unfortunately, I missed this unique opportunity of attending this symposium to pay a special tribute to my favorite professor and friend due to my prior commitment to visit India as Fulbright Professor from July to December of 1996. After my return from India, I resumed correspondences with him and was delighted to see his *Collected Works* edited by Hussaini [6] in four volumes published by Oxford University Press in 1997. My last letter to him was in late June or early July in 1998 with a special proposal for publishing a book entitled *Sir James Lighthill*. Unfortunately, I did not receive any response to this letter, possibly due to his sudden death in July. I was deeply disturbed by this shocking news of his death. There is absolutely no doubt that this is a great loss for the entire mathematical as well as scientific community of the world. Personally, I lost a great teacher, and a great friend to whom I would remain grateful for his help and encouragement in my life. Indeed, I was fortunate to come in contact with such a great applied mathematician in both personal and professional levels. So my desire as well as interest in writing this memorial tribute commemorating Sir James Lighthill the man and the mathematical scientist is founded solely on my deep respect and admiration for this great man and renowned applied mathematician whom I had the opportunity of knowing very well.

3. Significant research contributions

Even a glance at the chronological list of his research papers and books appended to *Collected Papers of Sir James Lighthill* [6] will show that his whole life was packed with research and publication activities. His creativity was simply phenomenal, and his deep involvement in teaching, academic and professional service was enormous, and has many ramifications. He made major contributions in many areas which include aerodynamics, fluid dynamics, waves in fluids, biofluid mechanics, geophysical fluid dynamics, boundary layer theory, magnetohydrodynamics, atmospheric and ocean dynamics. In each of these areas, he made major and unique contributions with new mathematical results and profound physical significance. His mathematical research always dealt with vivid imagination that responded to the



1983 quotation of V. I. Arnold: "In every mathematical investigation, the question will arise whether we can apply our mathematical results to the real world."

Lighthill's [7] pioneering work on sound generated aerodynamically appeared in the *Proceedings of the Royal Society of London* in 1952. This work along with his many other papers on high-speed aerodynamics, how flows generate sound, and the theory of jet noise are considered as classic, and led to a new branch of fluid mechanics which is called *aeroacoustics*, and has immense industrial and technological importance. Indeed, he is considered as the founder of the modern theory and applications of aeroacoustics that basically deals with the mutual interaction of sound with fluid flows and turbulence as a source of sound. He was probably the first applied mathematician who developed the whole of modern aeroacoustics from unified mathematical and physical viewpoints.

In 1960, Sir James Lighthill's [8] deep and profound paper provided an elegant mathematical theory with physical interpretation of magnetohydrodynamic waves and other anisotropic wave motions. He developed a new method for finding the asymptotic behavior of a solution at large distances (as $r \rightarrow \infty$). In his 1964 inaugural lecture [9] as the first President of the Institute of Mathematics and Its Applications, Sir James discussed a wide range of different aspects of the theory of group velocity. In this paper, he obtained a new formula of the theory of group velocity in three dimensions. He also developed the method of stationary phase in three dimensions for a problem of forced wave motion due to a steady source of fixed frequency ω_0 with a compact support.

In the area of linear and nonlinear waves in fluids, Lighthill [10] made many significant contributions during 1954-1989. During his stay at Imperial College, Sir James [11] first published his first paper entitled "Contributions to the Theory of Waves in Nonlinear Dispersive Systems" in the *Journal of the Institute of Mathematics and Its Applications* in 1965. He not only began to work on nonlinear wave propagation, but he provided outstanding leadership in organizing the first "Discussion Meeting on Nonlinear Theory of Wave Propagation in Dispersive Systems" in May 1966 and publishing a special volume **A 299** [12] of the *Proceedings of the Royal Society*.

At Imperial Lighthill worked extensively on geophysical fluid dynamics and biofluid dynamics. His 1967 remarkable paper [13] deals with a unified approach to many kinds of dispersive waves that can be excited in a non-rotating, rotating and/or stratified fluid including the atmosphere and the oceans. In 1969, he published his work [14] on "Dynamic Response of the Indian Ocean to Onset of the Southwest Monsoon." Remarkably, his linearized theory of unsteady wind-driven currents in a horizontally stratified ocean with applications to the northern part of the Indian Ocean was fairly general so that it can be applied to other oceanic models. He also discussed barotropic response, baroclinic wave propagation, and baroclinic response to monsoon onset in an equatorial ocean in some detail. Subsequently,



he wrote a few articles on monsoon dynamics and made several presentations on hurricane dynamics and tropical cyclones. From his extensive study and research in flood waves, monsoon dynamics, and hurricane dynamics, Lighthill became seriously interested in all kinds of natural hazards that include floods, hurricanes, cyclones, tornadoes, earthquakes, thunderstorms, underwater explosions, landslides, and volcanic eruptions. These hazards are the most common and frequently observed to have catastrophic effects on life, economic, coastal and marine resources. During the last three decades, Sir James showed a tremendous increase in interest in the dynamics of oceans and atmosphere with special reference to waves and currents caused by hurricanes, tropical cyclones, underwater explosions and earthquakes. He became more and more involved in developing protective measures to save life, economic, coastal and marine resources from natural hazards. During the last several years of his life, he served as Chairman of the Special Committee on the International Decade for Natural Disaster Reduction of the International Council of Scientific Unions and traveled and lectured world-wide. His deep concern and active interest in reduction of all natural hazards and of wasteful use of energy reveal the unique character of this man.

The whole volume IV of *Collected Papers of Sir James* [6] contains all of his fifteen papers on external biofluid dynamics, and five articles on internal biofluid dynamics. The former is concerned with animal locomotion through surrounding fluid media (water and air), as animal's flight in air or animal's swimming through water, while the latter deals with fluid motions within an animal as in the study of circulation and respiration. He formulated the fundamental features of what has become the standard model of fish swimming. His first book on *Mathematical Biofluidynamics* [15] published by SIAM in 1975 covers a fuller account of both external and internal biofluid dynamics. His 1975 John von Neumann Lecture on Flagellar Hydrodynamics represents his significant work in mathematical biofluid dynamics of microorganisms with flagella and related organisms. He also developed mathematical methods required for the study of flagellar hydrodynamics.

In his famous paper [16] on "The Recently Recognized Failure of Predictability in Newtonian Dynamics" which appeared in the *Proceedings of the Royal Society of London* in 1986, Sir James Lighthill vigorously argued against the belief that dynamical systems governed by Newton's laws of motion *do not* necessarily exhibit the predictability property. As a firm believer of Newtonian dynamics, Sir James' statement of public apology is an enlightenment to read: "Here I have to pause, and to speak once again on behalf of the broad global fraternity of practitioners of mechanics. We are all deeply conscious today that the enthusiasm of our forebears for the marvelous achievements of Newtonian mechanics led them to make generalizations in this area of predictability which, indeed, we may have generally tended to believe before 1960, but which we now recognize were false. We collectively wish to apologize for having misled the general educated public by spreading ideas about the determinism of systems satisfying Newton's



laws of motion that, after 1960, were to be proved incorrect. In this lecture, I am trying to make belated amends by explaining both the very different picture that we now discern, and the reasons for it having been uncovered so late.”

4. Concluding Remarks

It is hoped that enough has been discussed to give some definite impression of Sir James Lighthill's professional life and career as well as of the range, power and depth of his great applied mathematical work in different areas of modern fluid dynamics. Sir James' whole career was totally dedicated to the pursuit of fundamental scientific discovery and dissemination of knowledge of diverse areas of fluid mechanics and applied mathematics. He was one of the most brilliant and influential fluid dynamists of this century. His research and publications have stimulated enormous interest among researchers in the academic as well as industrial community for further exploration and development of challenging problems in the fields of aerodynamics, aeroacoustics, waves in fluids, boundary layer theory, biofluid dynamics, atmospheric and ocean sciences. As a lifelong devotee of fluid dynamics, he expressed his genuine excitement for the subject in his 1962 lecture at the Fluid Dynamics Division of the American Physical Society by declaring: “It needs categorically to be reaffirmed that the continuum mechanics of a fluid innocent of electric field has as vital and exciting a present and future as any other branch of physical science.” As editor of *Collected Papers of Sir James Lighthill*, M. Yousuff Hussaini [6] states the following in his General Introduction: “For more than half a century, his contributions spanned the fields of aeronautics, astrophysics, atmospheric and oceanographic sciences, and biofluid dynamics. But Lighthill is distinguished not just by the diversity and excellence of his technical contributions; his unique vision and perspicacity are evident in the groundbreaking, original work in every field he touched. In certain areas of aerodynamics and biofluid dynamics — such as wave propagation, aeroacoustics, and animal motion — his first articles were seminal and remain virtually the last word on the subject.”

Sir James Lighthill was undoubtedly one of the most brilliant and influential fluid dynamists of the twentieth century. He revolutionized applied mathematics with his remarkable contributions to modern fluid dynamics. There is no doubt at all about Lighthill's profound and everlasting impact on mathematical sciences and the scientific community of the world. His lifelong concern for quality mathematics instruction at national and international levels, and for inevitable loss by natural hazards reveals the unique character of this man. He will be remembered forever not only for his great scientific achievements, but also his unique contribution to the welfare of the human race. In many ways, Sir James Lighthill was the epitome of the applied mathematical community.



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