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Fluid Dynamics in Biology

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CONTEMPORARY MATHEMATICS

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Fluid Dynamics in Biology

Proceedings of an
AMS-IMS-SIAM Joint Summer Research Conference
held July 6–12, 1991 with support from
the National Science Foundation
and NASA Headquarters

A. Y. Cheer
C. P. van Dam
Editors

American Mathematical Society
Providence, Rhode Island

An AMS-IMS-SIAM Joint Summer Research Conference on Biofluiddynamics was held July 6–12, 1991 at the University of Washington, Seattle, Washington with support from the National Science Foundation, Grant No. DMS-8918200 (2nd year), and NASA Headquarters.

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Preface

This volume contains most of the papers that were presented at the Conference on Biofluiddynamics, which was held July 6–12, 1991 at the University of Washington, Seattle. This Conference was part of the Joint Summer Research Conferences sponsored by the American Mathematical Society (AMS), the Institute of Mathematical Statistics (IMS), and the Society of Industrial and Applied Mathematics (SIAM) and supported by the National Science Foundation and the NASA Headquarters.

The Conference was organized to provide biologists, engineers, mathematicians, and physiologists a forum to discuss problems of mutual interest leading to effective collaboration on research projects with an emphasis on problems involving fluid flows in biology. The Conference opened with an overview of external flows given by Sir James Lighthill, whose contributions have been instrumental in establishing and building up the field of biofluiddynamics. The numerous papers that followed illuminated the richness in the field of biofluiddynamics from the viewpoints of both the fluid dynamicist and the biologist. Furthermore, they highlighted a number of problems in fluid dynamics which have been suggested by biologists but remained largely unexplored. This has been in part due to the difficulty in addressing biological problems which often involve large systems of nonlinear differential equations applied to complex geometries. However, recent advances in the field of computational fluid dynamics, such as the availability of supercomputers and the ability to handle complex geometries by splicing together multiple grids (i.e. Chimera Scheme), have expanded the opportunities for solving fluid flow problems in biology. Such developments have spawned increased interest in many research problems in biology including the mechanisms of blood and air flow in humans, the ecology of the oceans, and animal swimming and flight. We hope that the papers presented here convey in part the breadth of ideas and the stimulating exchange which occurred during the Conference.

The papers in the Conference were divided into those concerned with either external or internal flow problems and each of these divisions was subdivided into those concerned with low or high Reynolds numbers. One day of the Conference was devoted to each of these four categories. The papers in this volume appear in the same order as they were presented at the Conference.

The Editors would like to acknowledge the assistance of their fellow Organizing Committee members. Prof. S. A. Berger (U. C. Berkeley), Dr. D. Kwak (NASA Ames Research Center), and Dr. A. Mayo (IBM T. J. Watson Research Center). We would also like to thank Prof. T. Daniels for helping extensively with local preparations of the Conference at the University of Washington, Sir James Lighthill and Prof. S. A. Berger for leading the roundtable discussion, and Ms. Carole Kohanski at the AMS for taking care of the many details involved in putting the Conference together. We appreciate the help of Mr. L. Popish for editing the volume, Mr. J. Wagner for organizing the typesetting of the papers, Mr. J. Takakuwa for helpful suggestions on all aspects of the Conference and the volume, the authors of the papers and Ms. Donna Harmon at the AMS for putting together the volume for publication. Finally, we would like to thank Prof. J. Keizer (Director), C. Mikashus, and L. Scribner at the Institute of Theoretical Dynamics for their assistance and support.

A. Y. Cheer
C. P. van Dam
University of California, Davis
June 1992

Sir James Lighthill

Sir James Lighthill was educated at Winchester and Trinity College, Cambridge. He was Beyer Professor of Applied Mathematics at Manchester University from 1950 to 1959, succeeding Sydney Goldstein in that post. For the next five years (1959–1964) he served as director of the Royal Aircraft Establishment, where he directed the research and development of the Concorde supersonic transport. He was then appointed Royal Society Research Professor, a position he held at Imperial College. It was during this period, 1964 to 1969, that he began his work on biofluiddynamics, in association with Dr. Colin Caro. Dr. Caro was head of the Physiological Flow Studies Unit, a pioneering collaboration of medical, physical, and mathematical scientists.

In 1969 Sir James was elected to one of the world's renowned academic positions, Lucasian Professor of Mathematics at Cambridge University, in the tercentenary of the appointment of Sir Isaac Newton to this chair. In 1979 he resigned the Lucasian professorship to assume the provostship of University College, London, the position from which he has recently retired.

Official recognition of Lighthill's distinguished contributions to science and public service came when he was knighted in 1972. He is also the recipient of more than a dozen honorary doctorates from universities around the world and was one of the youngest members ever elected to the Royal Society, from which he received the Royal Medal. He has been elected to honorary memberships in the scientific and learned academies and societies of many nations, including the National Academy of Sciences and National Academy of Engineering in the United States, the Academie des Sciences in France, and the Koninklijke Akademie van Wetenschappen in the Netherlands. Sir James has received numerous other awards from a wide range of scientific, engineering, and mathematical societies, including the Gold Medal of the Royal Astronautical Society, the Timoshenko Medal of the American Society of Mechanical Engineers, and the von Neumann Lectureship of the Society for Industrial and Applied Mathematics, a testimony to the enormous breadth of his work. He is a founding member and was the first president of the Institute of Mathematics and its Applications.

Most areas of fluid mechanics and aerodynamics have been enormously enriched by the contributions of Sir James, including those of incompressible and compressible flows and inviscid and viscous flows at both low and high Reynolds and Mach numbers. In particular we note his early work on higher approximations in aerodynamics, on the design of airfoils, on the hodograph method for compressible flows, on the PLK method (now often called the method of strained coordinates), on aerodynamic noise (the modern theory of which begins with his work), on the ideal dissociating gas in hypersonic flows, on heat transfer, on nonlinear dispersing waves, and on viscous-inviscid interactions, which anticipated and led to modern triple-deck theory.

Biofluiddynamics, both external and internal, has benefited from Sir James's insights and contributions. In the former, he made seminal contributions to our understanding of aquatic animal propulsion, spanning the range from high to low Reynolds numbers, from the propulsion of fish and mammals to that of flagellated and ciliated microorganisms. His contributions to the study of animal flight include his analysis of lift generation in the hovering flight of insects by the Weihs-Fogh mechanism, which is named after the famed Cambridge zoologist and Sir James's close friend and collaborator. (No one ever forgets Sir James illustrating the "clap" and "fling" in a public lecture.) In internal biofluiddynamics he has done much to elucidate the role, in health and disease, that fluid mechanics plays in the flow of blood and air, as well as in other physiological flows. His lubrication theory of red blood cell flow in the capillaries continues to exert enormous influence on studies in this area. More recently, his studies of the cochlea have contributed greatly to our understanding of the remarkable frequency acuity of the human auditory system.

Sir James is not only a sublime researcher across the whole spectrum of fluid mechanics, but he has also shared his insights with us in a number of enormously influential monographs and texts. These include "Higher Approximations in Aerodynamics" (1954), in the *Princeton Series*; the "Hodograph Transformation", in *Modern Developments in Fluid Dynamics*: *High Speed Flow* (1953, L. Howarth, ed.); "Viscosity Effects in Sound Waves of Finite Amplitude," in *Surveys in Mechanics* (1956, G. I. Taylor Anniv. Vol.); his introductory chapters on "Real and Ideal Fluids" and "Boundary Layer Theory," in *Laminar Boundary Layers* (1963, L. Rosenhead, ed.); and the books *Fourier Analysis and Generalized Functions* (1958), *Mathematical Biofluiddynamics* (1975), and *Waves in Fluids* (1978).

Stanley A. Berger

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Fluid Dynamics in Biology
A. Y. Cheer and C. P. van Dam, Editors

This book contains nearly all the papers presented at the AMS-IMS-SIAM Joint Summer Research Conference on Biofluiddynamics, held in July 1991 at the University of Washington, Seattle. The lead paper, by Sir James Lighthill, presents a comprehensive review of external flows in biology. The other papers on external and internal flows illuminate developments in the protean field of biofluiddynamics from diverse viewpoints, reflecting the field's multidisciplinary nature. For this reason, the book will likely find a wide audience including mathematicians, biologists, engineers, physiologists, cardiologists, and oceanographers.

The papers highlight a number of problems that have remained largely unexplored due to the difficulty of addressing biological flow motions which are often governed by large systems of nonlinear differential equations and involve complex geometries. However, recent advances in computational fluid dynamics have expanded opportunities to solve such problems. These developments have increased interest in areas such as the mechanisms of blood and air flow in humans, the dynamic ecology of the oceans, animal swimming and flight, to name a few. This volume addresses many of these flow problems.

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