The Bioengineer's Bookshelf

Mechanics and Thermodynamics of Biomembranes, by E. A. EVANS and R. SKALAK, 254 pp, $34.95, CRC Press, Boca Raton, Fla., 1980. Available as one bound volume, or as *CRC Critical Reviews in Bioengineering*, Vol. 3, issues 3 and 4, 1979.

One of the most exciting and rapidly growing areas of research in cell biology today is the structure and function (mechanical and chemical) of cell membranes. Numerous review articles and texts have appeared in the past ten years on the ultrastructure and transport function of biomembranes, but there has been no unifying text outlining the new developments in the continuum mechanics of biomembranes in this same period. This book by Drs. Evans and Skalak is a very welcome and much needed addition to the field. It provides at the same time an excellent tutorial introduction for engineering and physical scientists interested in a continuum mechanical and thermodynamic description of biomembrane systems and a valuable reference text for advanced researchers in the field. Two particular strengths of the presentation are that it ties together the mechanical concepts of deformation, rate of deformation and force resultants with thermodynamic concepts that provide constitutive relations for the material properties of membranes and then relates this theoretical framework to an impressive array of biological membrane experiments that are described in some detail in the last third of the book.

The first three introductory sections assume no specialized knowledge of membrane mechanics on the part of the reader. These sections systematically develop the governing relations for the deformation and rate of deformation of a thin surface material with averaged properties in the thickness dimension and examines the conditions of mechanical equilibrium on a surface element. The theoretical development assumes that mechanical properties in the thickness direction change discontinuously on a molecular scale whereas properties in the plane of the membrane can be treated as an isotropic continuum. This is a reasonable hypothesis for the red cell membrane and many simple lipid-protein bilayers.

Section IV first presents the mathematical theory of reversible and irreversible membrane work and then relates this thermodynamic description to elastic and viscous membrane processes. Multilayered systems are then treated and the concept of membrane bending stress introduced by allowing chemical forces to produce different interfacial energies in the coupling between the layers. The theoretical formulations for viscoelastic, thermoelastic, creep and viscoplastic behavior are then presented.

One of the outstanding parts of the book is section V, where a host of biological membrane experiments are described to illustrate the application of the theoretical models. These experiments include: membrane area dilation under tension, elastic deformation under fluid shearing stress, membrane bending stress due to osmotic swelling, temperature effects on membrane elastic, viscous and compressibility properties, time dependent recovery and viscoelastic response of red cells to extensional deformation and permanent plastic extension of red cell membranes once the yield stress is exceeded.

Both of the authors have devoted most of their research to the study of red cell membranes where the assumption of isotropy in the plane of the membrane is reasonable. The exclusion of other biomembranes, except for simple amphiphilic bilayers, is the most important shortcoming of the present book. Ultrastructural studies have shown that most cells with nuclei have specialized internal structures of intramembranous particles in the plane of the membrane which are of particular importance in endocytosis, exocytosis, vesicular transport or in the interaction between cells in the formation of various cell junctions. One would like to see these more difficult problems discussed in a general introduction and some thought given in the conclusion as to how the present planar isotropic theory might have to be modified to take account of either the spatial inhomogeneity in the plane of the membrane or of the molecular force fields that arise in the interaction between cell surfaces. One must stand before you can walk, and walk before you can run. Similarly, this book is an exceptionally good beginning, with much to be mastered before we can tackle the difficult and exciting problems that lie ahead.

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The Fluid Mechanics of Large Blood Vessels, by T. J. PEDLEY, 446 pp., $48.50, Cambridge University Press, Cambridge, New York, Melbourne, 1980.

I first saw a prepublication copy of this book on March 27, 1980 when Dr. Tim Pedley and I both attended the Conference on Fluid Mechanics in Aachen, Germany to celebrate the inauguration of the reconstructed building of the famous Aerodynamisches Institute. I was at once impressed by the book's richness of material and depth of treatment. I was allowed to keep it overnight, but I was not able to read it extensively because I had to prepare my lecture to be presented the following day. Hence, I was delighted when my copy finally arrived. Reading it at leisure, I find it meets all my expectations.

This book is concerned with large blood vessels (the heart, arteries, and veins). The chapter headings are:

1 Physiological Introduction
2 Propagation of the Pressure Pulse
3 Flow Patterns and Wall Shear Stress in Arteries
  I. Straight Tubes
4 II. Curved Tubes
5 III. Branches Tubes and Flow Instability
6 Flow in Collapsible Tubes
Appendix: Analysis of a Hot-Film Anemometer

The major historical outline of the subject is given in the Preface. The history of this book is mentioned there too. For example, it is stated that the first draft of this monograph was completed in December 1976, and, together with the review article "Pulmonary Fluid Dynamics" (*Annual Review of Fluid Mechanics*, Vol. 9, 1977, pp. 229–274), was awarded the Adam Prize of the University of Cambridge for for 1975–76. The author did not say when the last draft was delivered to the printer, but the references list contains some entries of 1979 papers.

Chapter 1 gives a brief account of the anatomy and physiology of large blood vessels, with clear explanations of the experimental methods and of the need for mathematical analysis. The active contraction of muscle is considered briefly, the literature is reveiwed, but neither the heartbeat, nor the action of the vascular smooth muscle is analyzed. The entire book is focused on the passive aspects of the circulation. The large blood vessel is treated as an elastic (sometimes viscoelastic) body. The left heart is regarded only as a source of blood flow, providing a certain flow rate into the aorta, and a pressure at its entrance; and the right heart is just a sink for the vena cava. But there is a nice discussion of the action of heart valves and the left ventricular ejection.

One of my graduate students, Lew Waldman, working on the coupling of the heart muscle mechanics and the blood flow in the lung, found Pedley's remarks on these pages extremely helpful.

Chapter 2 gives a concise and comprehensive exposition of one of the most thoroughly worked-out areas of cardiovascular fluid mechanics, the propagation of the arterial pressure pulse. The one-dimensional theory is presented first, treating the vessel as a straight, uniform, elastic tube, and the blood as an inviscid, homogeneous, incompressible fluid. An outstanding feature is the analysis of nonlinear effects on pp. 79–87. Following this a two-dimensional linearized theory for a uniform tube and viscous fluid is presented. The motion is assumed to be axisymmetric. The theory follows the tradition of Womersley, Atabek, Anliker and others. Through the two-dimensional analysis it is possible to examine the effect of longitudinal tethering (constraints on axial motion of the wall due to tissues external to the vessel). For physiological pressure pulse the formulas of wave speed, flow rate, and shear stress derived for the one-dimensional theory can be modified relatively easily according to the two-dimensional theory.

Following this, a linear theory of the effects of taper and branchings is developed as outlined by Lighthill in his 1975 book, *Mathematical Biofluid Dynamics*. Finally, a method to analyze nonlinear phenomenon in an arterial pathway that is not necessarily slowly varying is outlined.

The next three chapters (3–5), pp. 126–300, are concerned with flow patterns and wall shear stress in arteries. They form the core of this book, and have two purposes: 1) to explain arterial velocity profiles in detail, and 2) to make predictions of the detailed distribution of wall shear stress, which is related to the rate of mass transport across artery walls and hence (presumably) to atherogenesis. Chapter 3 starts with an explanation of why it is so difficult to measure wall shear stress in vivo, then goes on to analyze the unsteady entry flow (with flow reversal) in a straight tube. This analysis is continued in Chapter 4 for curved tubes, and in Chapter 5 for branched tubes. Chapter 5 concludes with a discussion of flow instability in arteries.

These three chapters contain a great deal of the author's original work. The analysis is difficult because one has to deal with quantities varying in three-dimensional space as a function of time. The major tools used here are the matched expansions. The main topics discussed can be seen from the successive section headings: 3.1 The difficulty of measuring wall shear stress; 3.2 Entry flow in a straight tube; 4.1 Fully developed steady flow; 4.2 Fully developed oscillatory flow; 4.3 Fully developed unsteady flow starting from rest; 4.4 Entry flow with a flat entry profile (in both 4.3 and 4.4, first uniform curvature, then slowly varying curvature); 4.4.3 Experiments; 4.5 Steady entry flow with a parabolic entry profile; 5.1 Flow in symmetric bifurcations; 5.2 Flow in asymmetric bifurcations; 5.3 The instability of flow in the aorta.

I will not discuss the details of these investigations, because they lie outside the areas of my own research and I do not have intimate knowledge about the details. I will invite some persons with greater expertise in this area to write another review. In fact, it will be a policy of this journal not to limit each book to a single review. In a field as broad and diversified as bioengineering, it will often happen that a reader can have expertise only in one part of a book. Furthermore, opinions of more than one person will be more useful to the readers than that of a single reviewer.

Chapter 6 is devoted to the analysis of flow in collapsible tubes. This subject has many applications. The author first describes the experiments by Conrad, Holt, and Katz, et al. (1969), then elaborates on the mechanisms of Korotkoff sound which are heard in the measurement of arterial blood pressure when a cuff is inflated around a limb. The ensuing analysis is particularly relevant to the Korotkoff sound problem. Theoretical results are taken from a paper by Wild, Pedley, and Riley *Journal of Fluid Mechanics*, Vol. 81, (1977, pp. 273–94). A tube of elliptical cross section is analyzed. Lubrication theory is used to determine the local pressure gradient and flow relationship. The cross section of the tube is assumed to remain elliptical and slowly varying in axial direction. The analytical results are applied to a collapsible tube with a specified pressure-cross-sectional-area relationship, and the self-excited oscillations are analyzed by a lumped-parameter.

This analysis is unique among the recent flurry of papers on the subject of flow in collapsible tubes in that it uses the lubrication theory to derive the fluid forces. It is one of the simplest analysis that does not use one-dimensional approximation. The approach is analytical. Other authors have used numerical methods, finite elements, etc. There are new experiments also. As the author points out, there are still many unresolved questions.

Finally, there is a self-contained appendix in which the unsteady response of a hot-film anemometer, widely used for blood velocity measurement, is analyzed in detail.

This book is an important addition to the biomechanics literature. It contains good fluid mechanics.

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