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MATHEMATICAL ANALYSIS IN ENGINEERING

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How to Use the Basic Tools

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To My Parents and My Wife

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Preface

This book originated from a one-semester course on introductory engineering mathematics taught at MIT over the past ten years primarily to first-year graduate students in engineering. While all students in my class have gone through standard calculus and ordinary differential equations in their undergraduate years, many still feel more awe than confidence and enthusiasm toward applied mathematics. Upon entering graduate school they need a quick and friendly exposure to the elementary techniques of partial differential equations for studying other advanced subjects and the existing literature, and for analyzing original problems. For them a popular first step is to take a course in advanced calculus, which is usually taught to large classes. To cater to a large audience with diverse backgrounds, an author or instructor tends to concentrate on mathematical principles and techniques. Applications to physics and engineering are often kept at an elementary level so that little effort is needed to set up the examples before, or interpret them after, finding the solutions. In some branches of engineering, students get further exposure to and practice in theoretical analysis in many other courses in their own fields. However, in other branches such reinforcements are less emphasized; all too often practical problems are dealt with by tentative arguments undeservingly called the *Engineering Approach.*

In engineering endeavors rooted in physical sciences, deep understanding and precise analysis cannot usually be achieved without the help of mathematics. In this book I attempt to emphasize the art of applying some of the most basic techniques of applied mathematics in the three essential phases of engineering research: formulation of the problem, solution of the problem, and analysis of the solution for its physical meaning. There are several classic books that treat all these aspects of applications in an emphatic manner. *Mathematical Methods in Engineering* by Th. v. Kármán and M.A. Biot (1944) is certainly a pioneer of this kind; it discusses a certain class of engineering problems quite thoroughly before mathematical techniques are introduced to solve them. The same spirit has been admirably extended in *Mathematics Applied to Deterministic Problems in the Natural Sciences* by C.C. Lin and L.A. Segal (1988). On a more advanced level, the celebrated two-volume treatise, *Methods for Theoretical Physics* by P.M. Morse and H. Feshbach (1953), is another; it is comprehensive in scope and depth and contains a vast number of detailed analyses of nontrivial examples, most of which are of great relevance to engineering. In the past few decades new applications as well as new analytical techniques have evolved; however, the overwhelming majority of texts on the level of this book have, in my view, been written with greater emphasis on the mathematical techniques; engineering applications do not receive a large enough share of the spotlight. In order that fewer students will repeat my own earlier frustrations in learning how to use mathematics, this book is intended to foster practical skills for examining problems quantitatively and qualitatively, and, in the long run, for carrying out numerical tasks wisely.

Guided by the philosophy stated above, I have tried in most cases to motivate first the need for mathematical topics, by introducing physical examples. The mathematics is then presented in an informal manner with a view to putting even the most reluctant student at ease. Physical examples are selected primarily from applied mechanics, a field central to many branches of engineering and applied science. While the majority of examples are designed for classroom discussions requiring no more than two lectures per example, a few lengthier ones are also included, with a view to illustrating how to juxtapose skills introduced in different parts of this book. The complexity, and the juxtaposition, are also meant to give the students a glimpse of what awaits them outside the walls of a lecture hall. These longer sections, marked by asterisks, are more suitable for assigned reading than for lectures; they can be used as reference materials or, in the language of business schools, as *case studies.* To deal with many problems that cannot be solved exactly, a quick survey of perturbation methods, which are often treated in a more advanced course, is included here. I believe that the art of making approximations should be learned as early as possible. Finally, a chapter on symbolic computation is introduced as a tool to increase the power of perturbation analysis by transferring the inevitable tedium to the computer. This chapter has occasionally been included in my own lectures but can be used for self-study. While there are still important omissions, enough material is here for a two-semester course with three hours of lectures per week. The exercises are not large in number, but many can be reasonably demanding. At MIT I typically cover two-thirds of this book in one semester with four hours of lectures per week. Except for Chapters 11 and 12, the book can also be used by undergraduate seniors in various engineering disciplines related to mechanics, and in geophysical sciences.

Finally, I hope this book will entice more theoretical engineers to engage in the teaching of applied mathematics. To them mathematics is not an end in itself, but a tool to fulfill the larger mission of solving practical problems. From them a student can learn to sort out essential ingredients in formulating a new problem, select effective mathematical ammunition, guess the outcome before solving the problem, and extract physical implications of the solution incisively. In short, how to get the most with the least – the way the *Engineering Approach* ought to be!

Acknowledgments

Since most of the mathematical substance discussed in this text is classical, I have made extensive use of existing books on applied mathematics. In particular, the texts by Kármán and Biot, Morse and Feshbach, and Koshlyakov, Smirnov and Gliner have influenced my own style and choice of subjects. I am greatly indebted to Professor Theodore Y.-T. Wu and Dr. Arthur E. Mynett for materials on Riemann–Hilbert problems. The chapter on Computer Algebra is based on the joint contribution by Dr. Mamoun Naciri, Professor Ko-Fei Liu, and Professor Tetsu Hara. I am fortunate to have received generous help from Professor Pin Tong and Professor Hung Cheng, whose critical comments improved the accuracy of many parts of this book. All the drawings were produced with the computer artistry of Dott. Paolo Sammarco and Dott. Carlo Procaccini. Mrs. Karen Blair-Joss typeset much of the first draft.

Once again, my wife, Caroline, took part in the demanding task of editing the text, in addition to helping with the typesetting. Her insistence on directness of expression helped clarify time and again what I wished to convey. I also thank the editors of Cambridge University Press and Rosenlaui Publishing Services for their meticulous attention to detail.

Part of the writing was done during my visit to the Institute of Applied Mechanics, National Taiwan University, in 1993. The hospitality of Professor Yih-Hsing Pao and his colleagues at this young and dynamic institute is as unforgettable as my student days on the same campus, long ago.