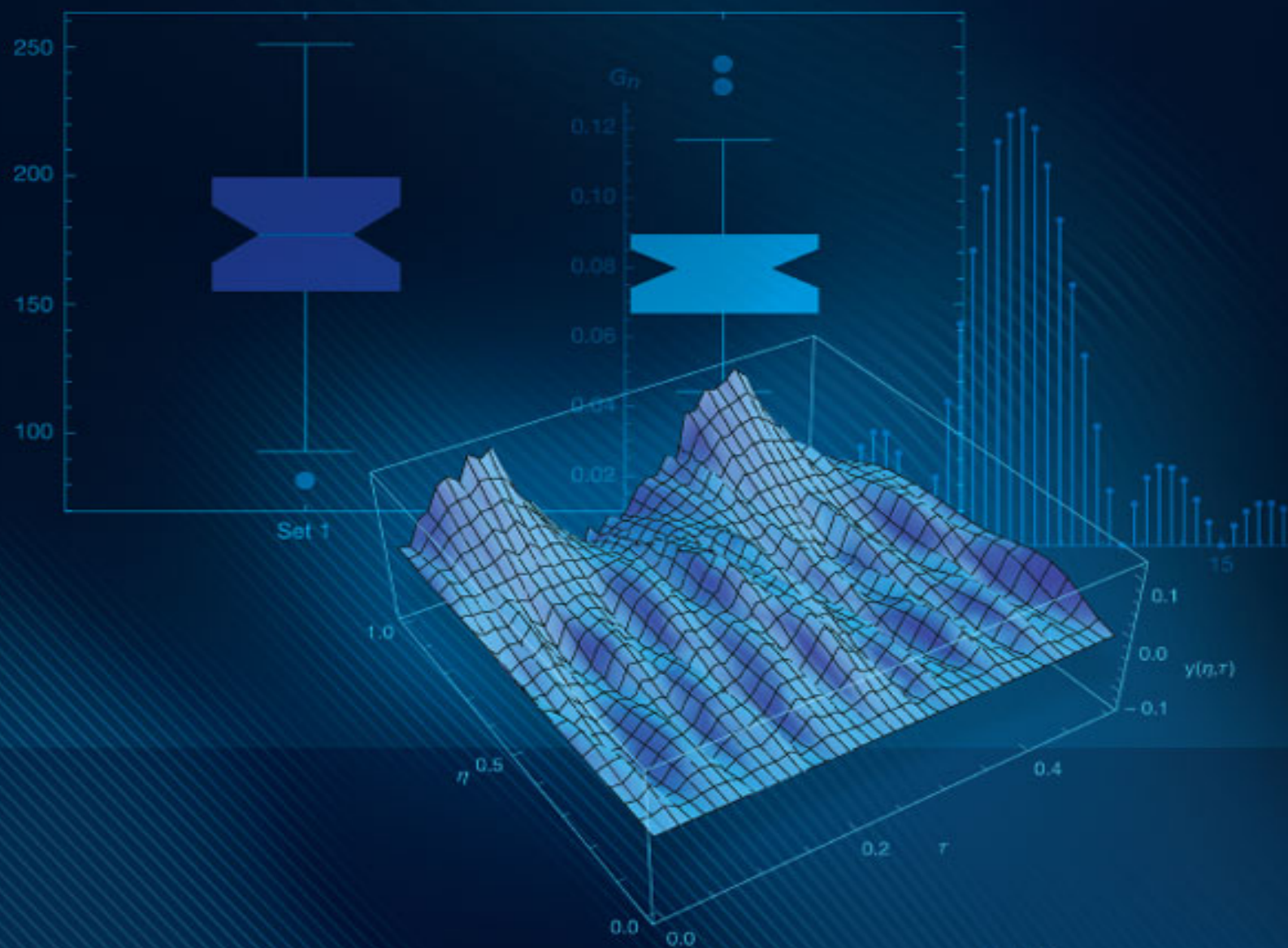


Edward B. Magrab

An Engineer's Guide to Mathematica®



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AN ENGINEER'S GUIDE TO MATHEMATICA[®]

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For
June Coleman Magrab

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Preface

The primary goal of this book is to help the reader attain the skills to create Mathematica programs that obtain symbolic and numerical solutions to a wide range of engineering topics, and to display the numerical results with annotated graphics.

Some of the features that make the most recent versions of Mathematica a powerful tool for solving a wide range of engineering applications are their recent introduction of new or expanded capabilities in differential equations, controls, signal processing, optimization, and statistics. These capabilities, coupled with its seamless integration of symbolic manipulations, engineering units, numerical calculations, and its diverse interactive graphics, provide engineers with another effective means of obtaining solutions to engineering problems.

The level of the book assumes that the reader has some fluency in engineering mathematics, can employ the engineering approach to problem solving, and has some experience in using mathematical models to predict the response of elements, devices, and systems. It should be suitable for undergraduate and graduate engineering students and for practicing engineers.

The book can be used in several ways: (1) to learn Mathematica; (2) as a companion to engineering texts; and (3) as a reference for obtaining numerical and symbolic solutions to a wide range of engineering topics involving ordinary and partial differential equations, optimization, eigenvalue determination, statistics, and so on.

The following aids have been used to make it easier to navigate the book's material. Different fonts are used to

make the Mathematica commands and the computer code distinguishable from text. In addition, since Greek letters and subscripts can be used in variable names, almost all programs have been coded to match the equations being programmed, thereby making portions of the code more readable. In the first chapter, the use of templates is illustrated so that one can easily create variables with Greek letters and with subscripts. Lastly, since Mathematica is fundamentally different from computer languages usually employed by engineers, the introductory material attempts to make this transition as smooth as possible.

In many of the chapters, tables are used extensively to illustrate families of commands and the effects that different options have on their output. From these tables, the reader can determine at a glance which command and which options can be used to satisfy the current objective. The order of the material is introduced in such a way that the complexity of the examples can be increased as one progresses through the chapters. Thus, the examples range from the ordinary to the challenging. Many of the examples are taken from a wide range of engineering topics. To supplement the material presented in this book, many specific references are made throughout the text to Mathematica's *Documentation Center*, which provide numerous guides and tutorials on topical collections of commands.

The book has two interrelated parts. The first part consists of seven chapters, which introduce the fundamentals of Mathematica's syntax and a subset of commands useful in solving engineering problems. The second part makes extensive use of the material in these seven chapters to show how, in a straightforward manner, one can obtain numerical solutions in a wide range of engineering specialties: vibrations, fluid mechanics and aerodynamics,

heat transfer, controls and signal processing, optimization, structures, and engineering statistics. In this part of the book, the vast majority of the solutions are presented as interactive graphics from which one can explore the results parametrically.

In Chapter 1, the basic syntax of Mathematica is introduced and it is shown how to intermingle symbolic and numerical calculations, how to use elementary mathematical functions and constants, and how to create and manipulate complex numbers. Several notational programming constructs are both illustrated and tabulated and examples are given on how to attach physical units to numerical and symbolic quantities. The basic structure of the notebook interface and its customization are presented. In addition, the various templates that can be used to simplify the integration of Greek letters, superscripts and subscripts, and other mathematical symbols into the programming process, and the commands that represent many basic mathematical functions and mathematical constants are illustrated.

In Chapter 2, the commands that can be used to create lists are discussed in detail and their special construction to form vectors and matrices composed of numerical and/or symbolic elements that are commonly employed to obtain solutions engineering applications are introduced. The use of vectors and matrices is discussed in two distinctly different types of applications: to perform operations on an element-by-element basis or to use them as entities in linear algebra operations.

In Chapter 3, ways to create functions, exercise program control, and perform repetitive operations are discussed. The concept of local and global variables is introduced and its implications with respect to programming are illustrated.

In Chapter 4, two types of symbolic manipulations are illustrated. The first is the simplification and manipulation of symbolic expressions to attain a compact form of the result. The second is to perform a mathematical operation on a symbolic expression. The mathematical operations considered are: differentiation, integration, limit, solutions to ordinary and partial differential equations, power series expansion, and the Laplace transform.

In Chapter 5, several Mathematica functions that have a wide range of uses in obtaining numerical solutions to engineering applications are presented: integration, solution to linear and nonlinear ordinary and partial differential equations, solution of equations, determination of the roots of transcendental equations, determining the minimum or maximum of a function, fitting curves and functions to data, and obtaining the discrete Fourier transform.

In Chapter 6, a broad range of 2D and 3D plotting functions are introduced and illustrated using numerous tables and examples from engineering topics. It is shown how to display discrete data values and values obtained from analytical expressions in different ways; that is, by displaying them using logarithmic compression, in polar coordinates, as contours, or as surfaces. The emphasis is on the ways that the basic figure can be modified, enhanced, and individualized to improve its visual impact by using color, inset figures and text, figure titles, axes labels, curve labels, legends, combining figures, filled plot regions, and tooltips.

In Chapter 7, the creation and implementation of interactive graphics and animations are introduced and discussed in detail and illustrated with many examples. The control devices that are considered are the slider/animator,

slider, 2D sliders, radio buttons, setter buttons, popup menus, locators, angular gauges, and horizontal gauges.

In Chapter 8, the response of single and two degree-of-freedom systems and thin elastic beams are determined when they are subject to various loadings, damping, initial conditions, boundary conditions, and nonlinearities.

In Chapter 9, the commands used to determine the mean, median, root mean square, variance, and quartile of discrete data are presented and the display of these data using histograms and whisker plots are illustrated. It is shown how to display the results from a regression analysis using a probability plot, a plot of the residuals, and confidence bands. The ways to perform an analysis of variance (ANOVA) and to setup and analyze factorial designs are introduced with examples.

In Chapter 10, the modeling and analysis of control systems using transfer function models and state-space models are presented. It is shown how to connect system components to form closed-loop systems and to determine their time-domain response. Examples are given to show how to optimize a system's response with a PID controller and any of its special cases using different criteria. The creation and use of different models of high-pass, low-pass, band-pass, and band-stop filters are presented and the effects of different types of windows on the short-time Fourier transform are illustrated. The spectral analyses of sinusoidal signals in the presence of noise are presented using root mean square averaging and using vector averaging.

In Chapter 11, several topics in heat transfer and fluid mechanics are examined numerically and interactive environments are developed to explore the characteristics of the different systems. The general topic areas include:

conduction, convection, and radiation heat transfer, and internal and external flows.

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