1 Introduction

1.1 The Making of This Book

Computing is essentially important in both engineering education and engineering practice. The use of mathematical software packages can greatly enhance the learning of various topics in science and technology, and surely help increase the efficiency and accuracy of engineering designs. The recent technological advancements in computers, software, and telecommunications make it possible for individuals to enjoy an interactive and mobile computing environment in their study and work.

Taking advantage of such a fast-changing environment, this book is intended to provide a new type of reference to statics and dynamics of solids and structures, with unique interactive computing capabilities. The purpose, approach, scope, and features of this writing are described under the following headlines.

Who Will Find the Book Useful
This book is ideal for both professionals and students dealing with aerospace, mechanical, and civil engineering, as well as naval architecture, biomechanics, robotics, and mechatronics. For engineers and specialists, the book is a valuable resource and handy design tool in research and development. For engineering students at both undergraduate and graduate levels, the book serves as a useful study guide and powerful learning aid in many courses. And for instructors, the book offers an easy and efficient approach to curriculum development and teaching innovation.

Uniqueness
This book differs from standard handbooks in that it integrates the development of formulas, fundamental theories, mathematical models, and solution methods with user-friendly interactive computer programs. Unlike the commonly adopted approach of “finish-the-book-first-and-add-software-later,” the text-software integration is harmonically fabricated in the
book writing from scratch. This unique merger of technical referencing and interactive computing allows instant solution of a variety of engineering problems and in-depth exploration of the physics of deformation, stress, and motion by analysis, simulation, graphics, and animation.

**Interactive Computing with MATLAB**
The computer programs for the book are written in the powerful and popular MATLAB, which is a premier software package that provides an interactive environment for technical computation. Different from many books that teach people how to use MATLAB in engineering analysis, this book shows how to obtain instant engineering solutions by hundreds of preprogrammed MATLAB functions from a CD-ROM that is attached to the book. These functions permit easy generation of data, figures, animation, and even analytical expressions, and produce results that are equivalent to the contents covered in pages of a conventional handbook and beyond.

**Motive for Writing**
This writing is motivated by the following two needs in engineering education and technical referencing.

*Need for Interactive Computing Capabilities in Engineering Education*  The solution of a problem in an undergraduate engineering course usually requires knowledge in the following four areas:

- The background material of the problem in consideration, such as strength of materials, vibrations, and structural dynamics;
- Mathematical physics, including differential equations, linear algebra, and matrix theory;
- Solution algorithms, which can be either analytical or numerical; and
- Computer coding in programming languages like C, Fortran, and MATLAB.

While computer coding is normally introduced in the freshman year, adequate knowledge in mathematical physics and solution algorithms is not available until the senior year or later. This lack of mathematical skills often limits undergraduate teaching to a few “classroom problems.” Of course, commercial computer programs may be used for solution of complicated problems. The usage of those codes, however, still requires a background in mathematical physics and numerical algorithms.

The current book fills this gap by providing adequate computing capabilities to many engineering courses. With this book, an undergraduate student in earlier years can solve various engineering problems without worrying about numerical algorithms. This allows the student to focus on important aspects of fundamental principles in engineering science and to explore the physical insight of practical problems. Moreover, with the computing capabilities provided by this book, more advanced topics can be introduced to adopt an undergraduate or graduate curriculum in response to today’s environment of emerging technologies.

*Need for Interactive Computing Capabilities in Technical Referencing*  A standard reference collects formulas and tables that normally cover a number of simple cases. Although general-purpose computer codes are available, they usually only deliver numerical results and are not integrated with many analytical formulas given in a standard reference. Quite often, an engineer or specialist would like to get a quick solution for verifying a design concept or a research idea. In this case, a reference with attached computer programs, which yield numerical or analytical solutions according to user-selected parameters, boundary conditions, and loads, would definitely be desirable.

---

**2 STRESS, STRAIN, AND STRUCTURAL DYNAMICS**
This book provides such needed interactive computing capabilities to technical referencing. With hundreds of preprogrammed MATLAB functions, numerical and analytical solutions of various engineering problems can be easily obtained. Besides facilitating quick concept proof in design and research, these solutions can serve as a benchmark for verification of numerical algorithms and computer codes developed by the user.

Scope
This book covers basic topics regarding solids and structures, including strength of materials, structural mechanics, elasticity, particle and rigid-body dynamics, vibrations, structural dynamics, and structural controls. As indicated by the table of contents, these topics are presented in five parts with a total of 15 chapters. Each chapter deals with a type of problem or a class of systems encountered in engineering. Each chapter is a self-contained package of subject review, fundamental theories, formulas, and a set (toolbox) of MATLAB functions for numerical and analytical solutions.

For efficient utility of this book, no attempt has been made to include every topic in such a wide range of subjects. Instead, the following three criteria have been applied in selecting the book materials:

(a) The problem in consideration is fundamentally important to engineering education and engineering practice. Examples include static analysis of Euler-Bernoulli beams (Chapter 2), stress and deformation of elastic bodies (Chapters 5 and 15), and rigid-body dynamics (Chapter 9).
(b) The problem in consideration is representative of a wide class of engineering applications. Examples include columns (chapter 4), trusses (Chapter 7), frames (Chapter 8), and multispan beam structures (Chapters 6 and 14).
(c) The problem in consideration requires substantial analytical and numerical efforts for better understanding of its physics. Examples include vibration of multiple-degree-of-freedom systems (Chapter 11), dynamics and control of Euler-Bernoulli beams (Chapter 12), and vibration of plates (Chapter 16).

Special Features
Besides its unique interactive computing capabilities, this book has several special features, some of which are not available in the existing references.

New Formulas and Solutions
This book contains many new formulas and analytical solutions. Examples include

- Analytical expressions of static response of beams subject to general external loads and arbitrary boundary disturbances;
- Exact static deflections and stresses of flexible frames under arbitrary external loads and support settlement;
- Influence lines of statically indeterminate multispan beam structures;
- Exact vibration solutions of one-degree-of-freedom systems subject to general forcing functions;
- Exact expressions of normalized mode shapes (eigenfunctions) of beams, bars, shafts, and strings, under arbitrary boundary conditions;
- Eigenfrequency loci of constrained beam structures;
- Control system formulation for beams with feedback controllers; and
- Exact free vibration solutions of plates with various boundary conditions.

What makes these new results more useful is that they can be obtained easily through use of the attached MATLAB toolboxes.
Exact Solution via the Distributed Transfer Function Method  This book presents exact static and dynamic responses of beams, bars, shafts, columns, and frames, which are determined by the Distributed Transfer Function Method (DTFM). The DTFM is a closed-form analytical solution technique for modeling, analysis, and control of flexible structures. The DTFM is flexible in dealing with different geometric configurations and boundary conditions, and convenient in computer coding. The DTFM is introduced in Appendix C and its application to specific problems is given in related chapters.

Instant Animation of Motion and Vibration  The MATLAB toolboxes of the book have functions for animating the modes of vibration and transient response of beams, bars, shafts, constrained and combined beam structures, and plates, the motion of rigid bodies in two and three dimensions, and the response of lumped parameter systems and flexible beams under feedback control. This animation functionality, which takes advantage of the rich resources of MATLAB, helps better understand the physics of motion and vibration and makes learning of difficult subjects a fun experience.

Integrated System Modeling and Controller Design  Feedback control has wide applications in machines and structures. This important topic is addressed in this book, for lumped dynamic systems (Chapter 11) and flexible beams (Chapter 12). For these systems, the book presents major steps in control system design, including system modeling, dynamic analysis, control system formulation, controller design and numerical simulation, and provides MATLAB functions for each of the steps. This integration of modeling, analysis, design, and simulation for feedback control of machines and structures is not available in any other reference on structural dynamics.

1.2 How to Use This Book

Chapters 2 to 16 cover topics in strength of materials, structural mechanics, elasticity, particle and rigid-body dynamics, vibrations, structural dynamics, and structural controls. Each of the chapters has the following parts:

- Getting started
- Fundamental principles, formulas, and solutions
- MATLAB functions
- Examples
- Quick Solution Guide
- References

Each chapter has a toolbox of MATLAB functions contained in the attached CD-ROM. In addition, Appendices A to E will be useful for engineering design and analyses.

Some key points in using this book are given below.

Getting Started
To start, find the right chapter from the Contents for the problem or system in consideration, then go to the first section of the chapter, titled Getting Started. This section tells what the chapter is about, how to install the MATLAB Toolbox, how to use the Toolbox through a tutorial example (in most chapters), and what to do next.

Fundamental Principles
The fundamental principles of each subject covered are briefly reviewed. Some derivations of theories and mathematical models are provided. For detailed information on these basic issues, a list of references is given at the end of each chapter.

4 STRESS, STRAIN, AND STRUCTURAL DYNAMICS
Formulas and Solutions
Formulas and solutions in a few special cases can be directly found from the text of a chapter. Formulas and solutions in general cases of geometric configurations, boundary conditions, and loadings can be obtained through use of the MATLAB toolbox for the chapter. This requires computing and programming with MATLAB.

MATLAB
MATLAB is a software product of The MathWorks, Inc., headquartered in Natick, Massachusetts. MATLAB is a registered trademark of The MathWorks, Inc. To obtain MATLAB, visit the company’s Web site http://www.mathworks.com/. A quick tutorial and brief summary of computing and programming with MATLAB is given in Appendix B of this book, which is useful for both beginners and advanced users.

MATLAB Functions in CD-ROM
Attached to this book is a CD-ROM with hundreds of preprogrammed MATLAB functions. These functions form 15 toolboxes, one for each of Chapters 2 to 16. The license agreement and limited warranty about the software package is given at the end of the book. For possible updated revisions of the MATLAB toolboxes contained in the CD-ROM, check the publisher’s Web site.

Windows
“Windows” are used to summarize the purpose and utility of the MATLAB functions from the attached CD-ROM. The windows are distributed in the text flow so that they are naturally related to the formulas and solutions presented.

Examples
The windows are normally followed by step-by-step examples demonstrating how the MATLAB functions can be used in analysis, simulation, graphics, and animation. Furthermore, each toolbox has a function RunEx, which, when launched, displays all the numerical examples contained in the chapter.

Quick Solution Guide
Each chapter has a section titled Quick Solution Guide. This section briefly describes the problem or system in consideration, lists the MATLAB functions from the toolbox with window or section numbers for easy reference, and outlines the solution procedure in the MATLAB-based computation. This section is especially convenient to those who are familiar with the material covered in the chapter and would like to engage in technical computation directly.

References
At the end of each chapter is a list of references for further reading. These references are mostly textbooks and monographs.

Unit Conversion
In all the examples, quantities are given in either the standard international system (SI) of units or nondimensional units. For conversion between SI system and the U.S. customary system, refer to Appendix D.
Mathematical Formulas
For convenience in engineering analyses, this book collects commonly used mathematical formulas in algebra, trigonometry, analytical geometry, calculus, vector analysis, matrix theory, complex analysis, differential equations, and Laplace transforms; see Appendix A.

Mechanical Properties of Engineering Materials
For convenience in engineering designs, the mechanical properties of selected engineering materials are given in Appendix E.

Comments and Technical Questions
For comments on this book and technical questions about the attached MATLAB toolboxes, please contact the author by the following mail and e-mail address:

Professor Bingen Yang  
Department of Aerospace and Mechanical Engineering  
University of Southern California  
3650 McClintock Avenue, Room 430  
Los Angeles, CA 90089-1453  
E-mail: gingen@usc.edu

6 STRESS, STRAIN, AND STRUCTURAL DYNAMICS