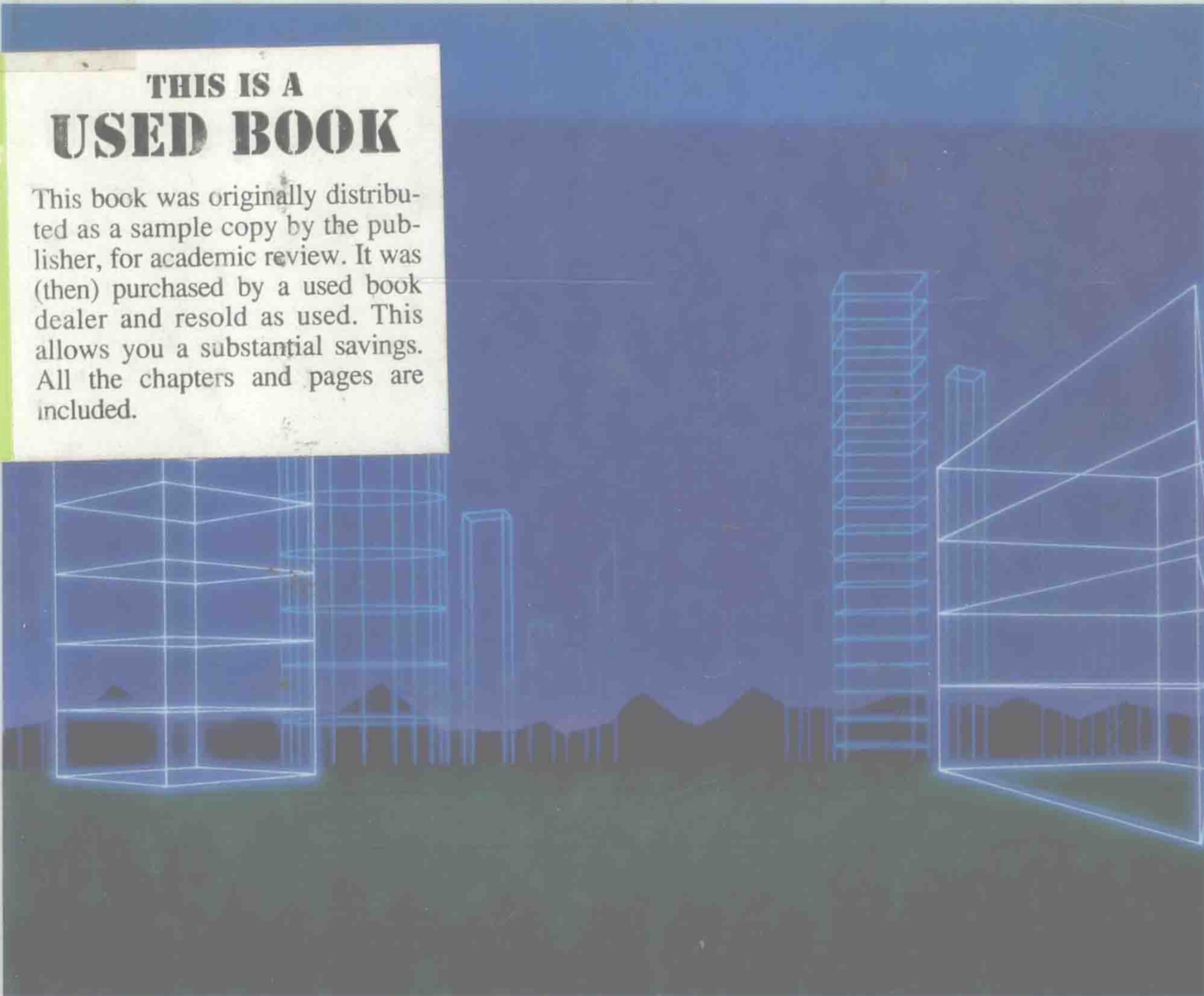

ENGINEERING DESIGN: FROM ART TO PRACTICE

JOSEPH WALTON

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From Art to Practice

Joseph W. Walton

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Preface

Engineering Design: From Art to Practice is an overview of fundamental methods and procedures for solving engineering design problems. It includes discussion of and emphasis on performing the essential, though sometimes routine, details of analyzing and implementing design solutions while stressing design flexibility and adaptability. It emphasizes analysis and synthesis techniques, for these allow an engineer to tackle new unsolved problems. Examples that illustrate various concepts are drawn primarily from my personal experiences in engineering. During the 13 years I was a manufacturing engineer in industry, I saw more problems caused by a low concern over how to manufacture a product than by poor product ideas. One of the reasons the United States is falling behind other industrial countries, Japan most notably, is not a lack of good ideas, but a lack of efficient manufacturing and financial implementation. Engineers don't spend most of their time solving earth-shaking revolutionary design problems; day-to-day mundane-seeming problems occupy most of their time. It is not usual for an engineer to solve calculus integrals after graduation, the more important problem being to determine how the best ideas can be manufactured economically into reliable products.

This book is my solution to a problem: to have a text for an engineering design course that contains a variety and quantity of problems without suggesting that there is a final word on any problem. This book has been used successfully in a two-semester, eight credit, senior-level engineering design course for Engineering Physics majors. The course is the last chance to put the pieces of many different courses together, many of which have been taught by professors who are experts in their own fields, but who do not combine the concepts into a coherent whole. Technology and state of the art changes require that engineers be prepared to keep up with the pace of change and be aware of the various interrelationships that exist in such areas as electronics, atomic physics, and material science.

During my 18 years of teaching, one of the most common student comments has been that textbooks are hard to read. I have tried to write in a style that reads easily and also keeps the reader aware of details. Many authors write for the experts, not for the students. The result is that students often do not read for learning or understanding. I also think that students learn as much from example as from theory, so I include examples where others would include theory.

This book has material for two, 15-week semesters meeting four hours a week. The amount of time spent on extended design problems, semester-long or year-long design projects, will influence how much time is spent on the exercises in each chapter.

Multiple, shorter projects can serve the same purpose as a semester long project, depending on personal objectives. Projects should be undertaken to broaden the experience of the student and the teacher, and to facilitate accurate and detailed analysis on the part of the student. Detailed formal reports, both written and oral, are part of the project work. Suggested technical prerequisite courses for this text are graphics, calculus, chemistry, physics, statics, strength of materials, material science, and computer programming.

The text is divided into two sections. Section I, Chapters 1-7, surveys the engineering problem solving procedure. Chapters 1 and 2 illustrate the range of problems and activities in which engineers are involved. Chapter 3 presents an overview of problem-solving procedures, and Chapters 4 through 7 present the details of the tasks engineers perform while solving design problems. It is assumed that student projects will be assigned and developed as the topics of the design procedure are studied. Some engineering students have never been exposed to the range of activities that complement the problem-solving task. Chapters 4 through 7 cover these activities and offer examples for illustration. Chapter 5 lists questions an engineer should ask to insure an optimum final design solution.

Section I contains over 200 exercises, ranging from those appropriate for group discussion, to those a student could spend a week or more investigating. The exercises stress the common, but essential, considerations necessary for good design. Many exercises have no single answer, which is a true engineering predicament. Answers the students provide will vary depending on their background, personal experience, and available references. Class discussion of the exercises is important so that ideas and experiences can be shared and the assumptions and compromises needed for solutions can be agreed on. Cooperation, understanding, and communication between specialty areas of engineering is a real engineering requirement.

A variety of design problems are proposed at the end of Chapter 7 for student work. The problems can be used for a month-long, semester-long, or year-long projects depending on the depth of analysis desired, how many students work together on a project, and whether working models are built. Students can start a design project from Chapter 7 at the beginning of the semester, and solutions can be developed as Chapters 4 through 7 are studied. To make the exercises on experimentation meaningful, solutions must be proposed, experiments run, and data collected and analyzed. Project analysis and refinement can be continued while students discuss the ideas and develop proficiency with the concepts discussed in the chapters in Section II.

Section II, Chapters 8-15, covers details necessary for thorough project analysis. Exercises in Section II are more apt to have one answer because they are intended for single concept discussion and practice. They are small details of the overall design process. Chapters 8 through 15 are mostly independent and can be studied as need and interest dictate. Some engineering students may have had separate courses on some of these topics, and if so, the chapters can be skipped over or used as a review. I have learned that students need review on a regular basis. There are a few exercises and case studies that are chapter-sequence dependent. The alignment of exercises with text material may at times appear random, and this is intentional. Real engineering problems do not come in chapter/topic order, they occur randomly and without hints. Over 450 exercises in Section II range from short answer to the nearly impossible. Time and talent will dictate which to use. Each chapter in Section II has additional study topics listed to encourage further study, provide topics for student research papers, and emphasize the seemingly inexhaustible nature of engineering concepts. The topics are purposely left unreferenced, and in the spirit of unstructured problems, the student must start from scratch. As a guide for the study topics, and as support for chapter discussions, references are listed at the end of each chapter and in Section 4.2, neither of which is meant to be exhaustive. Parenthetical notation, (2), used in the text refers to the numbered references at the end of the chapter. English to metric conversions were done using Theodore Wildi's *Units*, 2nd ed., published by Volta Inc., Canada, 1972.

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Introduction For Students

For students of engineering, or any discipline, understanding the levels of intellectual activity needed to enhance learning will assist with developing proficiency in using the problem solving procedures. A summary and brief discussion of these main intellectual activities will aid in your understanding of the role they play in your development as an engineer. The key words for the activities that affect the intellectual thought process are:

1. Know
2. Comprehend
3. Apply
4. Analyze
5. Organize
6. Synthesize
7. Evaluate
8. Create

Basic knowledge is important. Facts and figures must be *known*, but knowing is not enough. Knowing that the yield strength of a material is 30,000 psi is not of much value unless one *comprehends* what yield strength is. Once a concept is known and comprehended, it can be *applied* to a specific case. Example: A physical member made from a material with an allowable yield strength of 30,000 psi will withstand a load of 15,000 lbf before deforming permanently if it has a cross section of 0.50 in^2.

A problem can be *analyzed* by breaking it into component parts, each of which can be studied separately, as well as in the context of assembly. Fracture and other failure modes for each part are studied and the components designed accordingly. If the analysis results are *organized*, then the problem solver can *synthesize*. Synthesis includes the prediction of what will happen to the overall design solution when a change is made in a component. If the location of a component is changed, or its method of attachment to the next member is altered, or its material is changed, the size and shape of other components and the life of the product may also be affected. Synthesis is not complete until the prediction is *evaluated*, perhaps with a computer model, a scale model, or a full size model. If the evaluation results do not meet expectations, then alternative solutions must be *created* and the test process repeated. Iteration of ideas, analysis, and test is continued until the results satisfactorily solve the design problem.

The purpose of this book is to provide you with ideas, suggestions, and exercises to help develop your skills so you can perform design problem-solving activities in an efficient way. Reading about how to solve problems is only the beginning; practice is essential. Exercises are provided so you can practice the concepts and improve your problem-solving skills. Some of the exercises will be so easy you may wonder what the catch is. Others will be so complex you may wonder if a solution is possible. Open-ended design exercises at the end of Chapter 7 give you the opportunity to practice the steps required to solve a problem, including how to go about obtaining necessary support information. There is no single best answer to a design problem, only a compromise after you consider relevant and restricting factors. Discussion with your instructor and your fellow students is good learning; reading theory and examples is not enough. Example and practice are as valuable as theory.

Make good use of what you have learned in previous courses: calculus, differential equations, chemistry, material science, statics, dynamics, strength of materials, or computer science. Engineering problems don't appear with a footnote telling you what solution technique to use. Be creative and develop new solution techniques along the way.

The real problems of day-to-day engineering cannot be itemized in a checklist. Your ability to work and communicate with people, combined with your resourcefulness and creativity, will determine the success or failure of your projects. Do not be discouraged with failures. Learn from them and make the next solution better.

List of Symbols

A = Area, generally perpendicular to applied force; Annuity beginning amount.
α = Type I statistical error.
B = Light absorptivity; Intercept on semilog and log-log graph paper.
b = Intercept on linear coordinate graph paper.
β = Type II statistical error.
D = Ductility; Circle diameter.
δ = Beam deflection.
e = Column eccentricity.
ϵ = Normal strain.
E = Modulus of elasticity.
E_t = Tangent modulus of elasticity.
F_e = Static force equivalent to the effect of an impact load.
f_n = Natural frequency.
Φ = Shear strain.
γ = Thermal expansion coefficient.
G = Modulus of rigidity.
G_t = Tangent modulus of rigidity.
g = Gravitational constant, 32.17 ft/sec^2 (9.81 m/sec^2).
ν = Poisson's ratio.
I = Light intensity; Area moment of inertia.
I_r = Reflected light.
I_t = Transmitted light.
i = Period interest rate.
k = Electrical resistivity; Spring constant.
K_c = Fracture toughness.
K_t = Stress concentration factor.
LCL = Lower process control limit.
l_e = Column effective length.

Contents