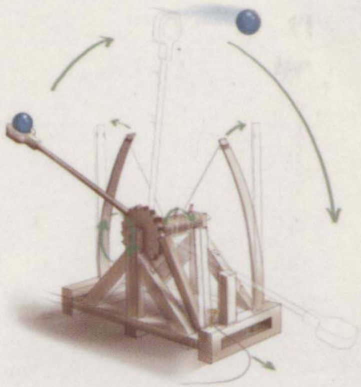
Engineering Design Graphics



sketching, modeling, and visualization

2nd edition

JAMES M. LEAKE | JACOB L. BORGERSON

ENGINEERING DESIGN GRAPHICS

SKETCHING, MODELING, AND VISUALIZATION

Second Edition

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James M. Leake
dedicates this work to
Stephanie, and to the
relationship that we share

Jacob L. Borgerson
dedicates this work to
Erin

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PREFACE

The traditional first-year engineering graphics course has undergone significant change in the past quarter century. Although the emergence of computer-aided design (CAD) and the expansion of the graphics curriculum to include design are perhaps the most significant developments, more recent trends include a movement away from 2D CAD and toward 3D parametric solid modeling, an increased emphasis on freehand sketching at the expense of instrument drawing, a greater focus on the development of spatial visualization skills, and an expansion of the curriculum to include the latest developments in design technology. All of this has occurred despite a strong countervailing trend to deemphasize graphics in order to accommodate other material in the four-year undergraduate engineering curriculum.

The aim of this book, then, is to provide a clear, concise treatment of the essential topics included in a modern engineering design graphics course. Projection theory provides the instructional framework, and freehand sketching the means for learning the important graphical concepts at the core of this work. The book includes several hundred sketching problems, all serving to develop the student's ability to use sketching for ideation and communication, as well as a means to develop critical visualization skills. New to this second edition are the additions of 38 worksheets containing more than 80 sketching problems. By encouraging students to work directly within the book, these worksheets make it easier to gain additional sketching experience. Also new to this second edition are two detailed example problems in Chapter 5 that focus on the development of visualization skills.

Engineering design serves to bracket the graphical content of the book with an introductory chapter on the engineering design process and a later chapter on product dissection. Material contained in the first chapter is based on introductory material found in leading engineering design textbooks. The chapter on product dissection concludes with thumbnail images of student projects. An extensive list of the products and devices that have been successfully reverse engineered is also included. Typically, the team obtains a commercial product, which is then dissected and reverse engineered. In other appropriate technology and history of technology projects where the product is unavailable, the student teams work from drawings, photographs, written descriptions, and so on.

A chapter on computer-aided product design software, with an emphasis on parametric solid modeling, is also included. The chapter is designed to complement, rather than replace, instructional materials for a specific CAD package. The chapter provides an overview of different kinds of CAD software, as well as general modeling concepts shared by all parametric modelers. Also in this chapter and new to the second edition is a discussion of nonuniform rational B-spline (NURBS) modeling. Parametric modeling is limited in its ability to create the freeform, sculpted geometry so popular in modern product design. In order to create these organic shapes, NURBS modeling is required. The development of NURBS is discussed, starting with physical splines. The important relationship between Bézier curves and B-splines is described. The chapter concludes with a discussion of NURBS surfaces, continuity, and curvature.

A chapter on perspective projections and sketching has been included because it reflects the way that engineering graphics has traditionally been taught at the University of Illinois at Urbana-Champaign (UIUC), starting from the general (e.g., perspective projection) and moving to the specific (e.g., multiview orthographic projection).

This second edition includes three new chapters: Reverse Engineering Tools, Digital

Simulation Tools, and Concept Design Tools. These chapters address some of the latest developments in design technology. The chapter on reverse engineering tools includes sections on 3D scanning and rapid prototyping. Both scanner hardware and reverse engineering software tools are discussed. While the scanner hardware is used to digitize a physical object, reverse engineering software is used to convert the scanner output (a point cloud) into either a polygon mesh or a CAD file. Rapid prototyping completes this cycle, converting a digital file into a physical prototype.

After an initial discussion of the benefits of conducting analysis early in the design process, both finite element stress analysis and kinematic analysis are discussed in the chapter on digital simulation tools. The chapter on concept design tools begins with sections on innovation, industrial design, and concept design. Concept design tools are then discussed, including digital sketching, direct modeling, and freeform modeling.

Key features of the book include the following:

- A succinct, scaled-down approach, with important concepts distilled to their essence
- Hundreds of sketching problems, including dozens of worksheet problems, to help students learn the language of technical graphics and develop their sketching, visualization, and modeling skills
- Assembly problems requiring a wide range of modeling tools, not just extrusions and revolutions
- Lots of visualization materials: sections on multiview visualization and the section view construction process are included, as are missing view problems, problems that require students to mentally rotate and then sketch a different pictorial view of the object, problems that require students to find a partial auxiliary, missing, and pictorial view when two views are given, as well as section view problems
- A strong student focus, with many examples showing what students can produce in an engineering design graphics course
- A chapter on engineering design that reflects the thinking of leading engineering design educators
- A chapter on product dissection, something unique to engineering design graphics textbooks
- A unified planar projection theory framework that provides a common basis for understanding the relationships between different kinds of sketches (e.g., perspective, oblique, isometric, multiview) and also serves as an introduction to the study of computer graphics
- Several detailed multistep example sketching problems that provide students with problem-solving procedural templates
- Significant coverage of such important trends and technologies as 3D scanning, rapid prototyping, digital sketching, direct modeling, FEA, kinematic analysis, and NURBS modeling

Much of the book's content, in particular, chapters 2 through 6, 8, and 13, is strongly influenced by a system of teaching engineering graphics that has developed over the years in the Department of General Engineering at UIUC. In particular, I would like to acknowledge the work of my immediate predecessor, Michael H. Pleck. Hallmarks of this approach include a focus on planar projection theory, starting from general case perspective projections and advancing to more specific projection types, as well as an emphasis on spatial visualization problems. A special thanks goes out to the many UIUC students who have made significant contributions to the content of this work. The book's co-author, Jacob Borgerson, is responsible for the many fine problems and worksheets that are included in the book's end-of-chapter exercises, as well as for his careful reading of and thoughtful comments on the text.

Our thanks go out to the book's many reviewers, including: Brian Brady, Ferris State University; Randy Emert, Clemson University; Andrea Giorgioni, New Jersey Institute of Technology; Davyda Hammond, Germanna Community College; Ghodrat Karami, North Dakota State University; Michael Keefe,

University of Delaware; Robert D. Knecht, Colorado School of Mines; Soo-Yen Lee, Central Michigan University; Anthony Maxwell, Buck's County Community College; Patrick McCuistion, Ohio University; Ramarathnam Narasimhan, University of Miami, College of Engineering; Jeff Raquet, University of North Carolina—Charlotte; and Ken Youssefi, University of California, Berkeley/San Jose State University.

The inspiration for certain chapters deserves special mention. Chapter 1 on Engineering Design is based on the introductory chapters from some of the best books on engineering design, including those of G. Pahl and W. Beitz, George Dieter, Rudolph Eggert, and Clive Dym. Chapter 9, Reverse Engineering Tools, owes much to the collection of essays, *Reverse Engineering: An Industrial Perspective*, edited by Vinesh Raja and Kiran J. Fernandes. Chapter 12 on Product Dissection is largely based on the work of Sheri Sheppard, Kevin Otto and Kristin Wood, and Ronald Barr.

James M. Leake
Urbana, Illinois
March 2012

CONTENTS

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CHAPTER 1
ENGINEERING DESIGN

INTRODUCTION

Design is the central activity of the engineering profession. ***Engineering design*** can be defined as a set of decision-making processes and activities that are used to determine the form of a product, component, system, or process, given the functions desired by the customer.[1] The term ***function*** refers to the behavior of the design, that is, what does the design need to do? ***Form***, on the other hand, has to do with the appearance of the design. A product's form refers to its size, shape, and configuration, as well as the materials and manufacturing processes used to produce it.

Engineering design is a part of the larger ***product realization process***. As we see in Figure 1-1, product realization starts with a customer need and ends with a finished product that satisfies this need. The product realization process consists of design and manufacturing processes that are used to convert information, materials, and energy into a completed product. The stages of the product realization process include sales and marketing, industrial design, engineering design, production design, manufacturing, distribution, service, and disposal. ***Product development*** refers to the first stages of the product realization process up to manufacturing. Product development includes engineering design, as well as sales/marketing, industrial design, and production design.

[1] Rudolph J. Eggert, *Engineering Design*, Pearson Prentice Hall, 2005.

ASPECTS OF ENGINEERING DESIGN

Our notion of engineering design encompasses many different aspects. For instance, it is a ***process***, one that prominently involves both ***problem-solving*** and ***decision-making*** activities.

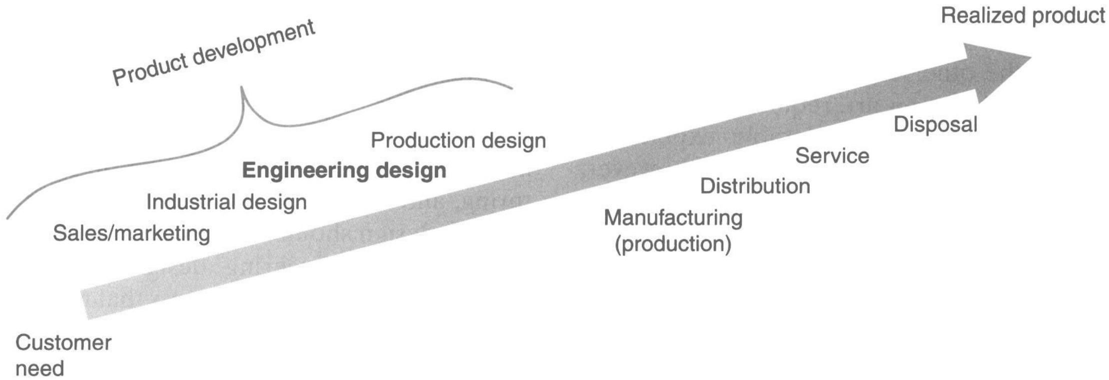

Figure 1-1 Product realization process (Eggert, Rudolph, J., *Engineering Design, 2nd Edition,* © 2010, Page 12. Reprinted by permission of High Peak Press, Meridian, ID.)

Engineering design also employs both ***analysis*** and ***synthesis***. By nature it is ***interdisciplinary*** and ***iterative***. Even prior to the emergence of such modern concepts as ***concurrent engineering*** and the design team, there has always been a strong ***social*** aspect to engineering design. Finally, in keeping with the main topic of this book, engineering design is characterized by strong ***graphical*** elements.

Engineering design is really about solving problems. In fact, a simple definition of engineering design is "a structured problem-solving approach."[2] Concisely described, the design process is no more than identifying a problem, carefully researching and defining the problem in order to better understand it, creatively generating possible alternative solutions to address the problem, evaluating these candidate solutions to ensure their feasibility, making a rational decision, and then implementing it. One of the hidden merits of an engineering education is that this problem-solving framework becomes so ingrained that it can easily be adapted to deal with life's many problems, technical or otherwise.

Although the need to make decisions is apparent throughout the course of a design's evolution, decision making in conjunction with engineering design typically refers to that part of the design process where competing feasible solutions are evaluated and an optimal solution is decided upon. Because of the numerous ***tradeoffs*** involved, these types of decisions are often difficult to make. Examples of such tradeoffs include strength versus weight, cost versus performance, and towing power versus free-running speed. Optimizing one criterion often means sacrificing the optimum position of the other criterion. Decision making is still something of an art, requiring solid information, good advice, considerable experience, and sound judgment. In recent decades, however, a mathematically based ***decision theory*** has been developed, and it is commonly used in the development of commercial products.

Synthesis is the process of combining different ideas, influences, or objects into a new unified whole. From this perspective, engineering design can be viewed as a synthesis technique, one used for creating new products based on customer needs. More specifically, synthesis refers to creative approaches used to generate potential solutions to a design problem.

Analysis, on the other hand, is the process of breaking a problem down into distinct components in order to better understand it. From the perspective of engineering design, analysis often refers to the tools used to predict the behavior and performance of potential solutions to a design problem.

Good design requires both divergent thinking (i.e., synthesis), which is used to expand the design space, and convergent thinking (i.e., analysis), which is used to narrow the design space by focusing on finding the best alternatives in order to converge to an optimal solution.

As a synthetic process, engineering design is interdisciplinary in nature. Although it relies heavily on basic science, mathematics, and the engineering sciences, engineering design still retains its artistic roots. Eugene Ferguson, in his book *Engineering and the Mind's Eye*, notes that "many of the cumulative decisions that establish a product's design are not based in science." He points out that even though design engineers certainly make decisions based on analytical calculations, many important design decisions are based on engineering intuition, a sense of fitness, and personal preference.[3]

An important element of engineering design is communication. It is often noted that a significant portion of an engineer's time is spent in communication (oral, written, listening) with others. Add to this the fact that modern engineering design draws on decision making, optimization, engineering economy, planning, applied statistics, materials selection and processing, and manufacturing, and the interdisciplinary nature of engineering design should be clear.

Although engineering design is frequently described as a sequential process that moves from one stage to the next, it can also be portrayed as

[2] Arvid Eide et al., *Engineering Fundamentals and Problem Solving*, McGraw-Hill, 1997.

[3] Eugene Ferguson, *Engineering and the Mind's Eye*, MIT Press, 1997.

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