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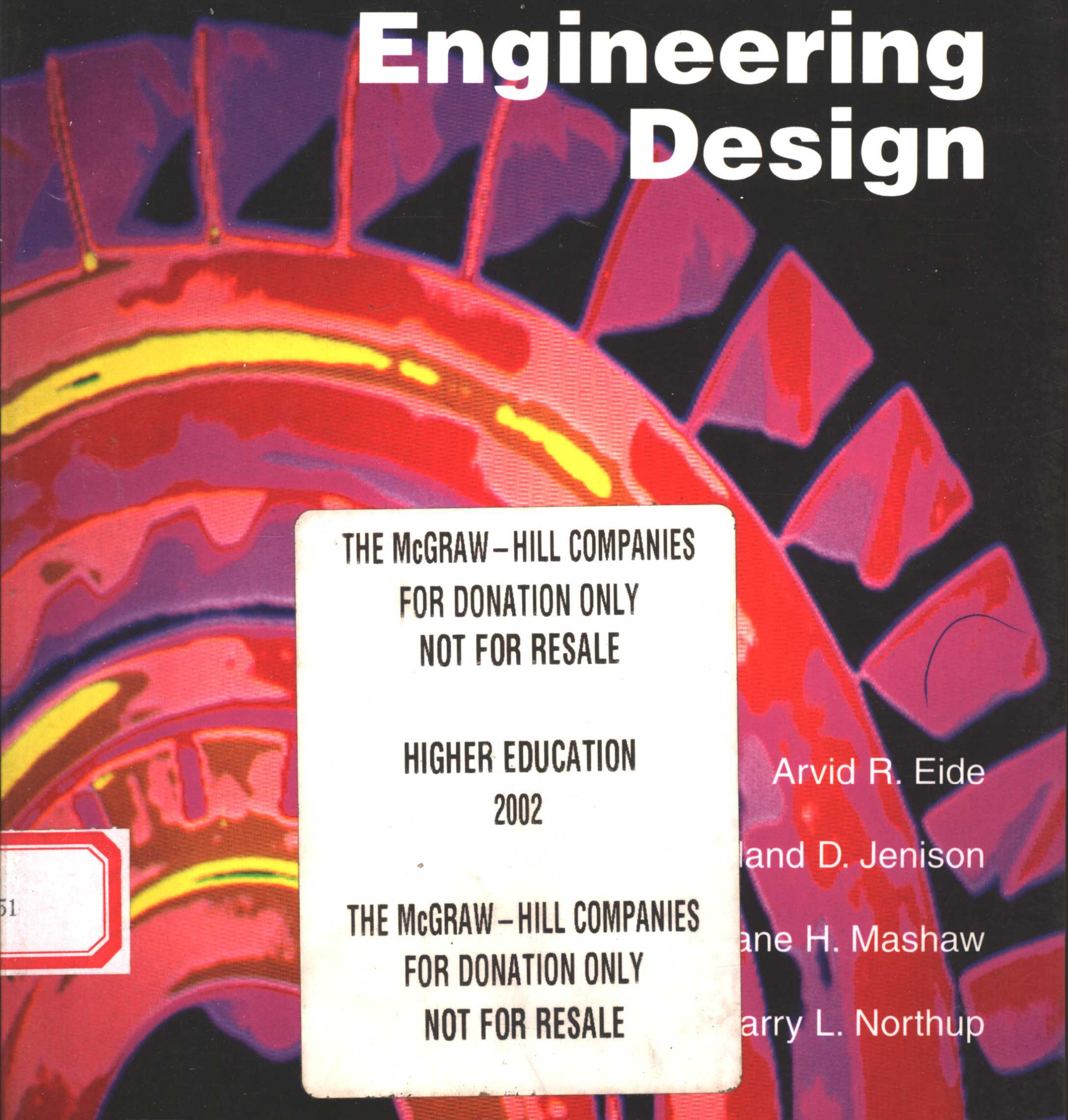

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INTRODUCTION TO ENGINEERING DESIGN

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INTRODUCTION TO ENGINEERING DESIGN

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Arvid R. Eide is a native Iowan. He received his baccalaureate degree in mechanical engineering from Iowa State University in 1962. Upon graduation he spent two years in the U.S. Army as a commissioned officer and then returned to Iowa State as a full-time instructor while completing a master's degree in mechanical engineering. Professor Eide has worked for Western Electric, John Deere, and the Trane Company. He received his Ph.D. in 1974 and was appointed professor and chair of Freshman Engineering at Iowa State from 1974 to 1989. Dr. Eide was selected Associate Dean of Academic Affairs from 1989 to 1995 and currently serves as professor of Mechanical Engineering.

Roland D. Jenison is a professor of aerospace engineering and engineering mechanics at Iowa State University. He has 30 years of teaching experience in lower division engineering and engineering technology. He has taught courses in engineering design graphics and engineering problem solving and has published numerous papers in these areas. His scholarly activities include learning-based instruction in design graphics, design education, and design-build projects for lower division engineering students. He is a long-time member of ASEE and served as chair of the Engineering Design Graphics Division in 1986–1987.

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Larry L. Northup is a professor of civil and construction engineering at Iowa State University. He has more than 30 years of teaching experience, with the past 20 years devoted to lower division engineering courses in problem solving, graphics, and design. He has 2 years of industrial experience and is a registered engineer in Iowa. He has been active in ASEE (Engineering Design Graphics Division), having served as chair of the Freshman Year Committee and Director of Technical and Professional Committees (1981–1984). He also served as chair of the Freshman Programs Constituent Committee (now Division) of ASEE in 1983–1984.

Foreword

Engineering educators have had long-standing debates over the content of introductory freshman engineering courses. Some schools emphasize computer-based instruction, some focus on engineering analysis, some concentrate on graphics and visualization, while others emphasize hands-on design. Two things, however, appear certain: no two schools do exactly the same thing, and at most schools, the introductory engineering courses frequently change from one year to the next. In fact, the introductory engineering courses at many schools have become a smorgasbord of different topics, some classical and others closely tied to computer software applications. Given this diversity in content and purpose, the task of providing appropriate text material becomes problematic, since every instructor requires something different.

McGraw-Hill has responded to this challenge by creating a series of modularized textbooks for the topics covered in most first-year introductory engineering courses. Written by authors who are acknowledged authorities in their respective fields, the individual modules vary in length, in accordance with the time typically devoted to each subject. For example, modules on programming languages are written as introductory-level textbooks, providing material for an entire semester of study, whereas modules that cover shorter topics such as ethics and technical writing provide less material, as appropriate for a few weeks of instruction. Individual instructors can easily combine these modules to conform to their particular courses. Most modules include numerous problems and/or projects, and are suitable for use within an active-learning environment.

The goal of this series is to provide the educational community with text material that is timely, affordable, of high quality, and flexible in how it is used. We ask that you assist us in fulfilling this goal by letting us know how well we are serving your needs. We are particularly interested in knowing what, in your opinion, we have done well, and where we can make improvements or offer new modules.

Byron S. Gottfried
Consulting Editor
University of Pittsburgh

Preface

TO THE STUDENT

As you begin the study of engineering you are no doubt filled with enthusiasm, curiosity, and a desire to succeed. Your first year will be spent primarily establishing a solid foundation in mathematics, basic sciences, and communications. You may at times question what the benefits of this background material are and when actual engineering experiences will begin. We believe that they begin now. Additionally, we believe that the material presented in this module will provide you a fundamental understanding of how engineers approach design in today's technological world.

TO THE INSTRUCTOR

Engineering courses for first-year students continue to be in a state of transition. A diverse set of goals such as providing motivation to study engineering, introducing cooperative learning, and encouraging work in a team environment have each provided reasons to study engineering design during the first year. The traditional engineering drawing and descriptive geometry courses have been largely replaced with computer graphics and CAD-based courses. Courses in introductory engineering and problem solving are now utilizing spreadsheets and mathematical solvers in addition to teaching the rudiments of a computer language. The World Wide Web (WWW) is rapidly becoming a major instructional tool, providing a wealth of data to supplement class notes and textbooks.

Since 1974, students at Iowa State University have taken a course that has a major objective of introducing engineering design. This module has thus evolved from more than 20 years of experience with teaching engineering design to thousands of first-year students.

A 10-step design process is explained and supplemented with an actual preliminary design performed by a first-year student team. The process as described allows you to supplement the text material with personal examples to bring your own design experience into the classroom. Mathematical expertise beyond algebra, trigonometry and analytical geometry is not required for any material in the module.

ACKNOWLEDGMENTS

The authors are indebted to many persons who assisted in the development of this module. First we would like to thank the faculty of the former Division of Engineering Fundamentals and Multidisciplinary Design at Iowa State University who taught engineering design to freshman students over the past 20 years. They, with support of engineering faculty from other departments, have made the courses a success by their efforts. Several thousands of students have taken the courses, and we want to thank them for their comments and ideas that have influenced this module. The many suggestions of faculty and students alike have provided us with much information necessary to prepare this material. A special thanks to the reviewers whose suggestions were extremely valuable and greatly shaped the manuscript. We also express grateful appreciation to Jane Stowe who worked many hours to type the manuscript. Finally we thank our families for their constant support of our efforts.

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Larry L. Northup

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The Engineering Profession

1.1 Introduction

The rapidly expanding sphere of science and technology may seem overwhelming to the individual seeking a career in a technological field. A technical specialist today may be called either engineer, scientist, technologist, or technician, depending upon education, industrial affiliation, or specific work. For example, nearly 350 colleges and universities offer engineering programs accredited by the Accreditation Board for Engineering and Technology (ABET) or the Canadian Engineering Accreditation Board (CEAB). Included are such traditional specialties as aerospace, agricultural, chemical, civil, electrical, industrial, and mechanical engineering—as well as the expanding areas of computer, energy, environmental, and materials engineering. Programs in construction engineering, engineering science, mining engineering, and petroleum engineering add to a lengthy list of career options in engineering alone. Coupled with thousands of programs in science and technical training offered at hundreds of other schools, the task of choosing the right field no doubt seems formidable.

Since you are reading this book, we assume that you are interested in studying engineering or at least are trying to decide whether or not to do so. Up to this point in your academic life, you have probably had little experience with engineering and have gathered your impressions of engineering from advertising materials, counselors, educators, and perhaps a practicing engineer or two. Now you must investigate as many careers as you can as soon as possible to be sure of making the right choice.

The study of engineering requires a strong background in mathematics and the physical sciences. Section 1.5 discusses typical areas of study within an engineering program that lead to the bachelor's degree. You should also consult with your counselor about specific course requirements. If you are enrolled in an engineering college but have not chosen a specific discipline, consult with an adviser or someone on the engineering faculty about particular course requirements in your areas of interest.

When considering a career in engineering or any closely related fields, you should explore the answers to several questions. What is engineering? What is an engineer? What are the func-

Figure 1.1
An engineering student observes stress formation in an automobile frame with the aid of a virtual reality device. *(Iowa State University.)*

tions of engineering? What are the engineering disciplines? Where does the engineer fit into the technical spectrum? How are engineers educated? What is meant by professionalism and engineering ethics? What have engineers done in the past? What are engineers doing now? What will engineers do in the future? Finding answers to such questions will assist you in assessing your educational goals and obtaining a clearer picture of the technological sphere.

Brief answers to some of these questions are given in this chapter. By no means are they intended to be a complete discussion of engineering and related fields. You can find additional and more detailed technical career information in the reference materials listed in the bibliography at the end of the book and by searching the World Wide Web.

1.2 The Technology Team

In 1876, 15 men led by Thomas Alva Edison gathered in Menlo Park, New Jersey, to work on "inventions." By 1887, the group had secured over 400 patents, including ones for the electric light bulb and the phonograph. Edison's approach typified that used for early engineering developments. Usually one person possessed nearly all the knowledge in one field and directed the research, development, design, and manufacture of new products in this field.

Today, however, technology has become so advanced and sophisticated that one person cannot possibly be aware of all the intricacies of a single device or process. The concept of systems engineering has thus evolved—that is, technological problems are studied and solved by a technology team.

Scientists, engineers, technologists, technicians, and craftspersons form the *technology team.* The functions of the team range across what is often called the *technical spectrum*. At one end of the spectrum are functions which involve work with scientific and engineering principles. At the other end of this technical spectrum are functions which bring designs into reality. Successful technology teams use the unique abilities of all team members to bring about a successful solution to a human need.

Each of the technology team members has a specific function in the technical spectrum, and it is of utmost importance that each specialist understand the role of all team members. It is not difficult to find instances where the education and tasks of team members overlap. For any engineering accomplishment, successful team performance requires cooperation that can be realized only through an understanding of the functions of the technology team. We will now investigate each of the team specialists in more detail. The technology team is one part of a larger team which has the overall responsibility for bringing a device, process, or system into reality. This team, frequently called a project or design team, may include, in addition to the technology team members, managers, sales representatives, field service persons, financial representatives, and purchasing personnel. These project teams meet frequently from the beginning of the project to insure that schedules and design specifications are met, and that potential problems are diagnosed early. This approach, intended to meet or exceed the customer's expectations, is referred to as total quality management (TQM) or continuous improvement (CI).

1.2.1 Scientist

Scientists have as their prime objective increased knowledge of nature (see Fig. 1.2). In the quest for new knowledge, the scientist conducts research in a systematic manner. The research steps referred to as the *scientific method* are often summarized as follows:

1. Formulate a hypothesis to explain a natural phenomenon.
2. Conceive and execute experiments to test the hypothesis.
3. Analyze test results and state conclusions.
4. Generalize the hypothesis into the form of a law or theory if experimental results are in harmony with the hypothesis.
5. Publish the new knowledge.

An open and inquisitive mind is an obvious characteristic of a scientist. Although the scientist's primary objective is that of obtaining an increased knowledge of nature, many scientists are also engaged in the development of their ideas into new and use-

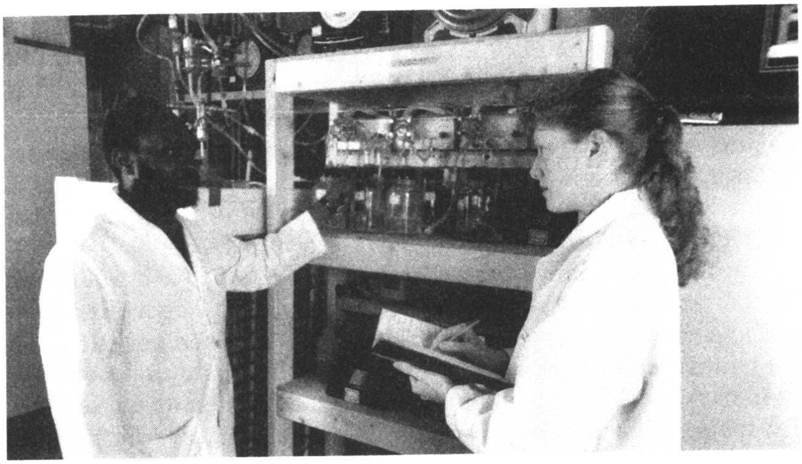


Figure 1.2
Scientific research conducted in an environmental laboratory. *(Iowa State University.)*

ful creations. But to differentiate quite simply between the scientist and engineer, we might say that the true scientist seeks to understand more about natural phenomena, whereas the engineer primarily engages in applying new knowledge.

1.2.2 Engineer

The profession of engineering takes the knowledge of mathematics and natural sciences gained through study, experience, and practice and applies this knowledge with judgment to develop ways to utilize the materials and forces of nature for the benefit of all humans.

An engineer is a person who possesses this knowledge of mathematics and natural sciences, and through the principles of analysis and design, applies this knowledge to the solution of problems and the development of devices, processes, structures, and systems for the benefit of all humans.

Both the engineer and scientist are thoroughly educated in the mathematical and physical sciences, but the scientist primarily uses this knowledge to acquire new knowledge, whereas the engineer applies the knowledge to design and develop usable devices, structures, and processes. In other words, the scientist seeks to know, the engineer aims to do.

You might conclude that the engineer is totally dependent on the scientist for the knowledge to develop ideas for human benefit. Such is not always the case. Scientists learn a great deal from the work of engineers. For example, the science of thermodynamics was developed by a physicist from studies of practical steam engines built by engineers who had no science to guide them. On the other hand, engineers have applied the principles of nuclear fission discovered by scientists to develop nuclear power plants and numerous other devices and systems requiring nuclear reactions for their operation. The scientist's and engineer's functions frequently overlap, leading at times to a somewhat blurred image of the engineer. What distinguishes the engineer from the scientist in broad terms, however, is that the engineer often conducts research, but does so for the purpose of solving a problem.

The end result of an engineering effort—generally referred to as *design*—is a device, structure, system, or process which satisfies a need. A successful design is achieved when a logical procedure is followed to meet a specific need. The procedure, called the *design process,* is similar to the scientific method with respect to a step-by-step routine, but it differs in objectives and end results. The design process encompasses the following activities, all of which must be completed.

1. Identification of a need
2. Problem definition
3. Search
4. Constraints
5. Criteria
6. Alternative solutions
7. Analysis
8. Decision
9. Specification
10. Communication

In the majority of cases, designs are not accomplished by an engineer simply completing the 10 steps shown in the order given. As the designer proceeds through each step, new information may be discovered and new objectives may be specified for the design. If so, the designer must backtrack and repeat steps. For example, if none of the alternatives appear to be economically feasible when the final solution is to be selected, the designer must redefine the problem or possibly relax some of the criteria to admit less expensive alternatives. Thus, because decisions must frequently be made at each step as a result of new developments or unexpected outcomes, the design process becomes iterative.

It is very important that you begin your engineering studies with an appreciation of the thinking process used to arrive at a solution to a problem and ultimately to produce a successful result.

As you progress through your engineering education you will solve problems and learn the design process using the techniques of analysis and synthesis. Analysis is the act of separating a system into its constituent parts, whereas synthesis is the act of combining parts into a useful system. In the design process (Chapter 3), you will observe how analysis and synthesis are utilized to generate a solution to a human need.

Consider the cruise control in an automobile as a system. You can analyze the performance of this system by setting up a test under carefully controlled conditions—that is, you will define and control the operating environment for the system and note the performance of the system. For example, you may determine acceleration or deceleration when a speed change is requested by the driver. You may check to see if the speed returns to the desired level after braking to reduce the speed and using the resume control. During the design of a cruise control system, the system would be modeled on a computer, and performance would be predicted by adjusting the variables and observing the results through various graphical formats on the monitor. You can analyze the physical makeup of the cruise control by actually taking apart the control, identifying the parts according to form and function, and reassembling the control. In general, analysis is the taking of a system, establishing the operating environment, and determining the response (performance) of the system.

If you were attempting to design a new cruise control system, you would consider many methods for sensing speed, ways to adjust engine speed for acceleration and deceleration, ideas for driver interface with the control, and so forth. Many possible solutions will be generated, mostly in the form of conceptual solutions without the details. During the design phase, the computer model may be continually improved by "repeated analysis," that is, finding the best or optimum design by observing the effect of changes in the system variables. This is synthesis and is the inverse of analysis. Synthesis may be said to be the process of defining the desired response (performance) of a system, establishing the operating environment, and, from this, developing the system.

An example will illustrate.

Example problem 1.1 A protective liner exactly 12 m wide is available to line a channel for conveying water from a reservoir to downstream areas. If a trapezoidal-shaped channel (see Fig. 1.3) is constructed so that the liner will cover the surface completely, what is the flow area for $x = 2$ m and $\theta = 45°$? The geometry is defined such that $0 \leq x \leq 6$ and $0 \leq \theta \leq 90°$. Flow area multiplied by average flow velocity will yield volume rate of flow, an important parameter in the study of open-channel flows.

Solution The geometry is defined in Fig. 1.3. The flow area is given by the expression for the area of a trapezoid:

$$A = \tfrac{1}{2}(b_1 + b_2)h$$

where $b_1 = 12 - 2x$

$$b_2 = 12 - 2x + 2x\cos\theta$$

$$h = x\sin\theta$$

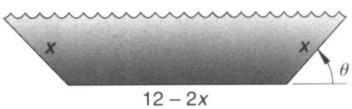


Figure 1.3

Therefore,

$$A = 12x \sin \theta - 2x^2 \sin \theta + x^2 \sin \theta \cos \theta$$

For the situation where $x = 2$ and $\theta = 45°$, the flow area is

$$A = (12)(2)(\sin 45°) - 2(2)^2(\sin 45°) + (2)^2(\sin 45°)(\cos 45°)$$
$$= 13.3 \text{ m}^2$$

Values of A can be quickly found for any combination of x and θ with a spreadsheet. Fig. 1.4a shows areas for $x = 2$ and a series of θ values. You have solved many problems of this nature by analysis; that is, a system is given (the channel as shown in Fig. 1.3), the operating environment is specified (the channel is flowing full), and you must find the system performance (determine the flow area). Analysis usually yields a unique solution.

Example problem 1.2 A protective liner exactly 12 m wide is available to line a channel conveying water from a reservoir to downstream areas. For the trapezoidal cross section shown in Fig. 1.3, what are the values of x and θ for a flow area of 16 m^2?

Solution Based on our work in Example prob. 1.1, we would have

$$16 = 12x \sin \theta - 2x^2 \sin \theta + x^2 \sin \theta \cos \theta$$

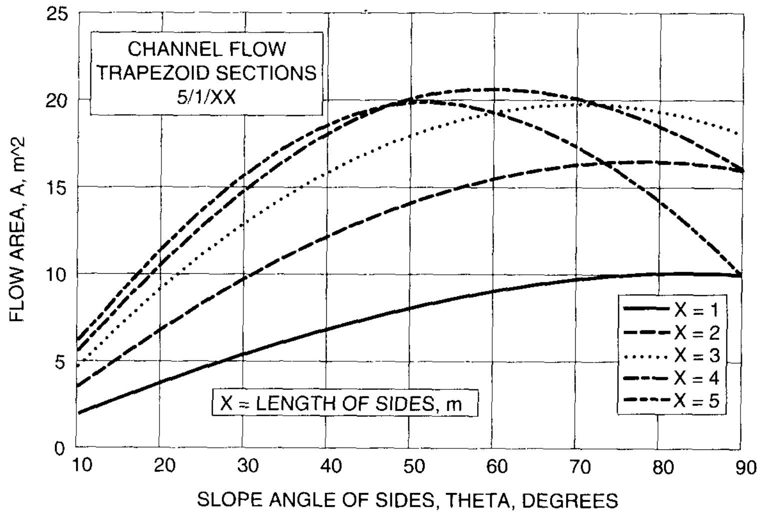
The solution procedure is not direct, and the solution is not unique, as it was in Example prob. 1.2. We begin our solution procedure by using a spreadsheet to generate a family of curves that illustrate the behavior of the implicit function of x and θ. Figure 1.4b shows the flow area as a function of θ for five values of x. We quickly observe that for $x = 1$ we cannot generate a flow area of 16 m^2. Also for $x = 4$ and 5, we definitely have two values of θ where a flow of 16 m^2 is possible. The spreadsheet will perform a search for the correct values. Figure 1.4c shows the result of a search between 0 and 90 at $x = 3$ m. In this situation a flow area of 16 m^2 occurs at a θ of 0.698014 radians or 40.0°. Other results are quickly obtainable by simply changing the value of x in the spreadsheet program in Fig. 1.4c.

You probably have not solved many problems of this nature. Example prob. 1.2 is a synthesis problem; that is, the operating environment is specified (channel flowing full), the performance is known (flow area is 16 m^2), and you must determine the system (values for x and θ). Example prob. 1.2 is the inverse problem to Example prob. 1.1. In general, synthesis problems do not have a unique solution, as can be seen from Example prob. 1.2.

Most of us have difficulty synthesizing. We cannot "see" a direct method to find an x and θ that yield a flow area of 16 m^2. Our solution to Example prob. 1.2 involved repeated analysis to "synthesize" the solution. We studied a family of curves (x is constant) of A versus θ, which enabled us to verify the spreadsheet analysis for values of x and θ that yield a specified flow area.

	x		Theta, *D*		Theta, *R*		Area
	2		0		0		0
	2		15		0.261799		5.141105
	2		30		0.523599		9.732051
	2		45		0.785398		13.31371
	2		60		1.047198		15.58846
	2		75		1.308997		16.45481
	2		90		1.570796		16
Area = 12**x**sin(Theta)-2**x*^{2}*sin(Theta)+*x*^{2}*sin(Theta)*cos(Theta)							

(*a*)



(*b*)

	x		Theta,D		Theta, R		Area
	3		0		0		0
			90		1.570 796		18
		Area = 16 For Theta =			0.698014 Radians		

(*c*)

Theta, Degree		Theta, Radians		*x*, m			
0		0		1			
15		0.261799		2			
35		0.610865		3			
55		0.959931		4			
75		1.308997		5			
90		1.570796		6			
Max flow area		Theta		*x*			Area
		1.047198		4			20.78461
Area = 12**x**sin(Theta)-2**x*^{2}*sin(Theta)+*x*^{2}*sin(Theta)*cos(Theta)							

(*d*)

Figure 1.4