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PRINCIPLES OF ENGINEERING

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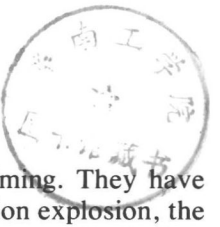
Principles of ENGINEERING

To Anne, Gladys, and Susan

PREFACE



The challenges faced by modern society are almost overwhelming. They have become a familiar part of our everyday vocabulary: the population explosion, the energy crisis, pollution, the arms race, the loss of identity and human dignity in a world increasingly dominated by automation, and the cultural shock caused by technological change. These are serious problems that threaten to disrupt civilization as we know it.

But these are also the challenges for the profession of engineering. The role of engineers is to apply their knowledge of science and technology to meet the needs of society, to solve its problems, and to pave the way for its future progress. As our society has become increasingly dependent upon science and technology, it has also become more dependent on engineers, not only for its prosperity but for its very survival. Many of the major problems faced by the world today cannot be solved by social or political actions alone; they require the knowledge, skills, and discipline of engineers.

Engineering students must prepare for this world and these challenges. In a world of change and diverse opportunity, the key to success in engineering is a broad education based on fundamental scientific concepts, coupled with the development of a disciplined approach to problem solving that is characteristic of engineering. But this is not enough. The technological and social aspects of the challenges faced by modern society have become closely intertwined. It is essential that an engineer's education also include studies in the arts, humanities, and social sciences.

Herein lies a dilemma. A broad-based education tends to concentrate technical subjects in engineering into the final two years of the undergraduate program. The first two years are given over almost entirely to basic courses in mathematics, physics, chemistry, the humanities, and social sciences. Many students find this program quite frustrating since they seek exposure to engineering and engineering faculty at the earliest possible moment. They wish to learn what engineering is all about, what its opportunities and challenges are, and how one prepares to become an engineer.

For this reason many engineering programs have introduced engineering courses in the freshman year. Varied approaches have been taken, including survey courses sampling various engineering fields, motivational courses designed to stimulate interest in the engineering profession, and even courses on modern computer methods (primarily programming) taught by engineering faculty. Of most interest have been those more ambitious attempts to introduce material on engineering problem solving in the freshman year, to begin development of the intellect and discipline required by the engineering profession.

This text is directed toward this latter type of course. Our particular goals are both diverse and ambitious:

1. To expose first-year students to engineering methods, to motivate them and provide orientation for further course work.
2. To demonstrate the engineering approach to problem solving using concepts from conventional science courses, but applying them to the complex, open-ended, and ill-defined problems so characteristic of the engineering profession.
3. To provide a satisfying experience in actually solving relevant problems at an early stage, thereby building confidence in one's ability.
4. To introduce the principal tools of engineering, including a survey of fundamental scientific concepts, mathematics, computing, and statistical and testing methods.

This text is intended to help students develop their own skills in self-teaching, engineering synthesis, the solution of open-ended problems, and other intellectual activities of engineering. The difference between problem solving in formal courses and in engineering practice is illustrated by applying concepts from basic science courses to a variety of relevant and practical problems taken from real-life situations. Of particular concern are an introduction to the art of problem definition, problem solving under constraints, the development of solution algorithms, solution verification and evaluation, modeling, simulation, and optimization.

The text has been organized into four major parts: the engineering *profession*, the *approach* to engineering problem solving, the *tools* of engineering, and *constraints* on engineering practice. In Part I we introduce the student to the excitement of engineering, the variety of roles and activities of the engineer, and the profession of engineering. In Part II we examine the principal intellectual activity of the engineer, problem solving, and develop a general procedure for attacking the array of complex engineering problems that arise in practice. This approach is illustrated by considering in detail the most important application of engineering problem solving: engineering design.

With this background, we proceed to Part III where we examine the tools of modern engineering. First, the essential tools of mathematical analysis and scientific principles are outlined. These chapters provide a foundation for further

studies of the engineering student. They are also intended to provide the student with sufficient knowledge to confront many challenging engineering problems and to sample the satisfaction (or frustration) that accompanies attempts to solve such problems. Students are introduced to the modern tools of engineering such as digital methods and computing, computer-aided design (CAD/CAM), and experimental and testing methods. We have also included a chapter on a most essential skill of engineering, communication through written, oral, and graphical means.

Part IV of the text is concerned with the constraints that complicate and restrict engineering practice. We introduce students to the important subject of engineering economics. We then discuss relations with people, with particular attention directed to the subjects of management activities and the legal aspects of engineering. Finally we examine interactions with the institutions of society such as government and the new constraints these interactions impose through regulation and technology assessment.

The text is organized into compact, self-contained units. Each subsection ends with a short summary that is followed by an example illustrating the material and a number of exercises to allow the student to master the material by actual practice.

The exercises vary greatly in both purpose and degree of difficulty. Most sets of exercises begin with straightforward problems designed to stress text material and develop student confidence. But we have also included several more complex problems of an open-ended, ill-defined nature typical of engineering practice. This latter approach is particularly evident in Chapters 3 and 4 where we have provided the student with an opportunity to apply mathematical and scientific concepts to engineering problems. We have also included problems designed for solution by various types of calculators and computers.

We introduce the SI system of units at an early stage and use this system throughout the text. Although other unit systems are not treated in detail, discussion and practice in converting from one system to another are given.

Our survey of introductory engineering courses used in various programs has revealed more diversity than commonality. Different programs have chosen to emphasize different goals, approaches, and topics. We have addressed this diversity by presenting a wide range of material in as flexible and independent a fashion as possible. In a sense we have solved the problem of what to cover by attempting to cover everything. It is hoped that the text will be appropriate for most introductory engineering courses with a suitable selection and sequencing of topics. The instructor's manual accompanying the text suggests several possible approaches and provides more detailed lesson plans.

Our efforts in developing this textbook have benefited greatly from the advice, encouragement, and assistance of many faculty and students at the University of Michigan. In particular we acknowledge the technical assistance of Joe G. Eisley and Maurita Holland, the assistance in problem preparation and solution provided by Keith Hampton and Tom Sutton, and the artistic contributions of Mike Manley. We acknowledge the considerable efforts of the editorial and pro-

duction staff at Wiley, with a particular note of thanks to Carol Beasley and Irene Zucker. Of most importance are the contributions of the many students who have toiled through earlier versions of the text and provided us with valuable insight and assistance.

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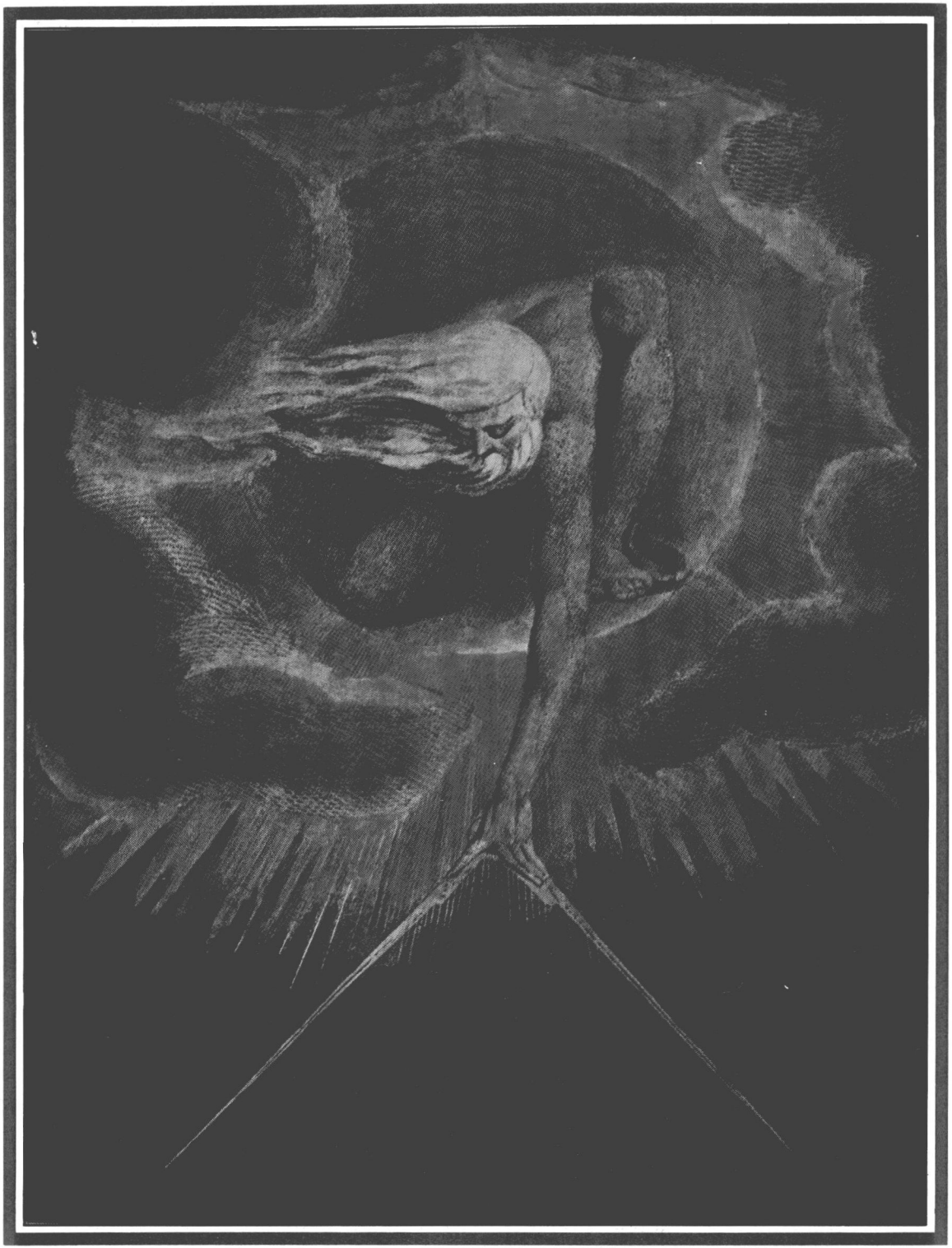

FIGURE I.1. The first engineer (William Blake's frontispiece for *Europe, A Prophecy*, 1794).

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PART I
The Profession

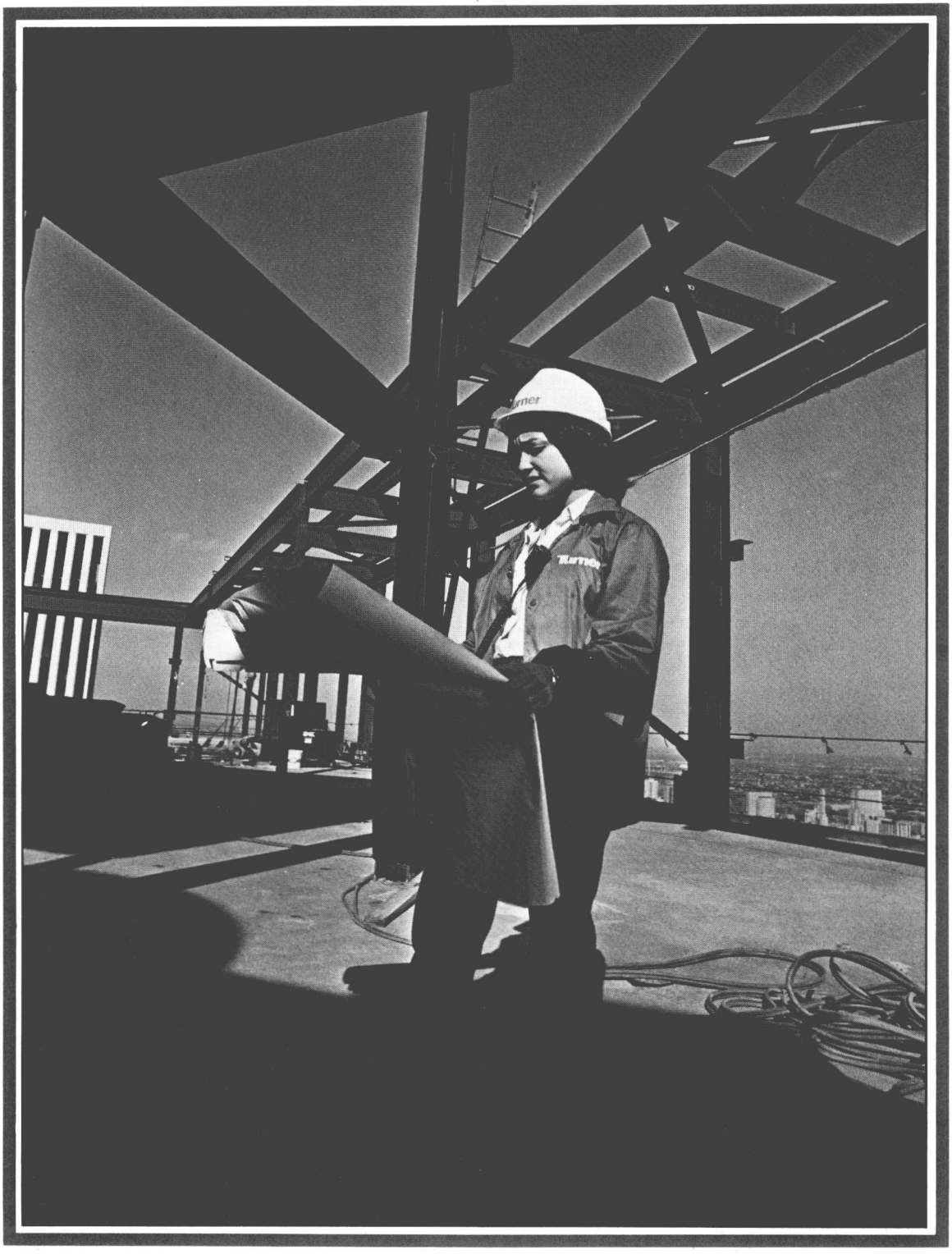
In his hand
He took the golden Compasses, prepar'd
In Gods Eternal store, to circumscribe
This Universe, and all created things:
One foot he center'd, and the other turn'd
Round through the vast profunditie obscure,
And said, thus farr extend, thus farr by bounds,
Thus be thy just Circumference, O World.

Milton, Paradise Lost, Book VII

What are engineers? What do they do? What does it take to become one? These are the first questions that usually occur to prospective engineering students, and these are also the first questions that should be addressed by any introductory text in engineering.

In a general sense engineers are *creators* of ideas and concepts, *builders* of devices and structures, and above all, *problem solvers*. They apply their knowledge of science and technology to meet the needs of society. These needs are often so complex and intertwined with social, economic, and political issues that engineers must be far more than problem solvers. They must also develop a broad perspective that will allow them to assess the impact of their activities on society and their natural environment. They must be prepared to face a world of change, of new and ever varying challenges.

In Chapter 1 we survey the various roles and activities of engineers and the role of the engineering profession in the modern world. We give the educational requirements for careers in engineering and engineering technology. In addition, we introduce the important concept of engineering as a learned profession, governed by laws of professional registration and guided by a code of ethics. Finally, we preview some of the challenges that will confront future engineers.



CHAPTER 1

The Profession of Engineering

Most living creatures are locked into a Darwinian pattern. They must either adapt to their changing environment for survival or perish. Only the human species is an exception. Only we possess the intellect to modify our environment, to adapt it to meet our needs. On the most primitive level, this role is most characteristic of the engineering profession. The roots of engineering lie with our ancestors' first use of tools in their struggle for survival. Throughout history engineers have sought to apply knowledge in the form of science and technology to meet the needs of society. Their accomplishments have had as much impact on history as any social, political, or artistic accomplishment. In a very real sense, the engineer has paved the way for the progress of civilization.

Today we are in a new era, as our population strains against the limits of its natural environment, threatening to disrupt nature, perhaps even to make this planet uninhabitable. Future historians may refer to the twentieth century as that moment in time when we first recognized the finite nature of the earth's resources, even as we rapidly approached their exhaustion. Today our expanding numbers and activities have the potential to destroy in an instant an environment produced after millions of years of evolution. It is against this ominous backdrop that we must examine the role of the modern engineer.

We are surrounded by and dependent on the work of engineers. Engineering supplies the food we eat and the clothing we wear; it provides us with shelter and energy, the means for transportation and communication. It has replaced human toil with machines, and today it is replacing tedious human mental tasks with computers, thereby providing us with the opportunity for other pursuits.

FIGURE 1.1 Engineers must face the challenges posed by an increasing population straining against the limits of its natural environment. (Courtesy National Aeronautics and Space Administration)

Our society has become increasingly dependent on science and technology, and therefore upon engineering, not only for its prosperity but, indeed, for its very survival. Problems of serious proportions loom before us today. How can we provide food and energy for an ever-growing population in the face of dwindling resources? How do we protect our natural environment from the impact of human activities? How do we preserve our dignity and freedom, even as new technologies such as genetic engineering and automatic data processing threaten our integrity and individualism, the very nature of our humanity? These problems cannot be solved by social or political actions alone. They will require the efforts and talents of engineers. Yet many social and technological problems have become so closely intertwined that modern engineers must be acutely sensitive to social and political factors. They must be concerned not only with the efficient use of our natural resources, the preservation of our natural environment, but also with the importance of human dignity in modern society.

The basic role of engineers has not really changed throughout history. Engineers continue to be innovators and problem solvers, applying science and technology for the benefit of society. However, as these needs have become more complex, they have required the development of more sophisticated and powerful scientific tools. The needs and problems of modern society also require an extraordinary combination of skill, experience, and knowledge, all of which must be acquired and applied by today's engineer.

Modern engineering remains both a science and an art. Before the basic principles of mathematics and science can be applied to engineering problems, engineers must identify, isolate, and analyze the essential features of these problems. They then must generate practical and acceptable solutions within the constraints posed by modern society. In this latter sense engineering problem solving