

Exploring Engineering

An Introduction to Engineering and Design

Fourth Edition

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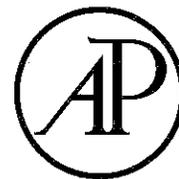
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What Engineers Do

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1.1 INTRODUCTION

What is an engineer, and what does he or she do? You can get a good answer to this question by just looking at the word itself. The word *engine* comes from the Latin *ingenere*, meaning “to create.” About 2000 years ago, the Latin word *ingenium* (the product of genius) was used to describe the design of a new machine. Soon after, the word *ingen* was used to describe all machines. In English, *ingen* was spelled “engine,” and people who designed creative things were known as “engine-ers.” In French, German, and Spanish today, the word for *engineer* is *ingenieur*, and in Italian, it is *ingegnere*.

What does the word engineer mean?

Answer: *The word engineer refers to someone who is a creative, ingenious person who finds solutions practical problems.*

Today the word *engineer* refers to people who use creative design and analysis processes that incorporate energy, materials, motion, and information to serve human needs in innovative ways. Engineers express knowledge in the form of variables, numbers, and units. There are many kinds of engineers, but all share the ideas and methods introduced in this book.

1.2 WHAT IS ENGINEERING?

The late scientist and science fiction writer Isaac Asimov once said that “Science can amuse and fascinate us all but it is engineering that changes the world.”¹ Almost everything you see around you has been touched by an engineer. Engineers are creative people who use mathematics, scientific principles, material properties, and computer methods to design new products and to solve human problems. Engineers can and do just about anything, designing and building roads, bridges, cars, planes, space stations, cell phones, computers, medical equipment, and so forth.

Engineers can be classified according to the kind of work they do—administration, construction, consulting, design, development, teaching, planning (also called *applications engineers*), production, research, sales, service, and test engineers. Because engineering deals with the world around us, the number of engineering disciplines is very large. Table 1.1 lists some of the many engineering fields.

Table 1.1 A Few of the Many Engineering Fields Available Today

Aerospace/aeronautical	Ceramic	Electrical	Mechanical	Petroleum
Agricultural	Chemical	Environmental	Metallurgical	Sanitary
Architectural	Civil	Geological	Mining	Systems
Automotive	Computer	Manufacturing	Nuclear	Textile
Biomedical	Ecological	Marine	Ocean	Transportation

1.3 WHAT DO ENGINEERS DO?

Most engineers specialize in a specific field of engineering. The following list contains information on a few of the engineering fields in the Federal Government’s Standard Occupational Classification (SOC) system.² Note that some of the engineering fields may have several subdivisions. For example, civil engineering includes structural and transportation engineering, and materials engineering includes ceramic, metallurgical, and polymer engineering.

- An **aeronautical, or aerospace, engineer**³ applies scientific and technological principles to research, design, develop, maintain, and test the performance of civil and military aircraft, missiles, weapons systems, satellites, and space vehicles. They also work on the different components that make up these aircraft and systems.
- **Biomedical engineers** develop devices and procedures that solve medical and health-related problems by combining biology and medicine with engineering principles. Many biomedical engineers develop and evaluate systems and products such as artificial organs, instrumentation, and health management and care delivery systems.
- **Chemical engineers** apply the principles of chemistry to solve problems involving the production or use of chemicals and other products. They design equipment and processes for biotechnical use, chemical

¹Isaac Asimov’s *Book of Science and Nature Quotations*, (New York: Simon & Schuster, 1970).

²Abstracted from the Bureau of Labor Statistics (<http://www.bls.gov/oco/ocos027.htm>).

³www.prospects.ac.uk

manufacturing, plan, and test methods of manufacturing products and treating byproducts, and supervise production.

- **Civil engineers** design and supervise the construction of roads, buildings, airports, tunnels, dams, bridges, and water supply and sewage systems. Civil engineering is one of the oldest engineering disciplines⁴ and encompasses many specialties. The major ones are structural, water resources, construction, transportation, and geotechnical engineering.
- **Computer engineers** research, design, develop, test, and oversee the manufacture and installation of computer hardware, including computer chips, circuit boards, computer systems, and related equipment, such as keyboards, routers, and printers. Computer engineers may also design and develop the software systems that control computers.
- **Electrical engineers** design, develop, test, and supervise the manufacture of electrical equipment. Some of this equipment includes electric motors; machinery controls, lighting, and wiring in buildings; radar and navigation systems; communications systems; and power generation, control, and transmission devices used by electric utilities.
- **Environmental engineers** use the principles of biology and chemistry to develop solutions to environmental problems. They are involved in water and air pollution control, recycling, waste disposal, and public health issues. Environmental engineers conduct hazardous-waste management studies in which they evaluate the significance of the hazard, and develop regulations to prevent mishaps.
- **Industrial and manufacturing engineers** determine the most effective ways to use the basic items of production—people, machines, materials, information, and energy—to make a product or provide a service. They are concerned with increasing productivity through the management of people, methods of business organization, and technology. These engineers study product requirements and then design manufacturing systems to meet those requirements.
- **Materials engineers** are involved in the development, processing, and testing of the materials used to create a range of products, from computer chips and aircraft wings to golf clubs and snow skis. They work with metals, ceramics, plastics, semiconductors, and composites to create new materials that meet certain mechanical, electrical, and chemical requirements.
- **Mechanical engineers** research, design, develop, manufacture, and test all types of mechanical devices. Mechanical engineering is one of the broadest engineering disciplines. Mechanical engineers work on power-producing machines such as electric generators, internal combustion engines, and steam and gas turbines; they also work on power-using machines such as refrigeration and air-conditioning equipment, machine tools, material-handling systems, and robots.
- **Nuclear engineers** research and develop the processes, instruments, and systems used to derive benefits from nuclear energy and radiation. They design, develop, monitor, and operate nuclear plants to generate power. They may work on the nuclear fuel cycle—the production, handling, and use of nuclear fuel and the safe disposal of nuclear waste.

You can find more about what today's engineers do within their specialties by searching the Internet. Here are some of the engineering societies⁵ that represent different engineering fields: AIAA (aeronautical engineering),

⁴The oldest type of engineering is Military Engineering. Civil engineers are specifically called *civil engineers* to distinguish them from *military engineers*. The word *civil* is a contraction of the word *civilian*.

⁵A typical engineering society has several functions. They define the core disciplines needed for membership and advocate for them. They also define codes and standards for their discipline, provide further educational courses, and offer a code of engineering ethics customized for that particular profession. Canadian engineering societies basically follow a similar nomenclature as do others worldwide.

AICHE (chemical engineers), ANS (nuclear engineering), ASCE (civil engineers), ASME (mechanical engineers), ASTM (materials and testing engineers), BMES (biomedical engineering), IEEE (electrical engineers), and many others.

Unsurprisingly you will discover that the basic college engineering courses have much in common with all engineering disciplines. They cover scientific principles, application of logical problem solving processes, principles of design, value of teamwork, and engineering ethics. If you are considering an engineering career, we highly recommend you consult web resources to refine your understanding of the various fields of engineering.

1.4 WHERE DO ENGINEERS WORK?

Most engineers work in office buildings, laboratories, or industrial plants. Others may spend time outdoors at construction sites and oil and gas exploration and production sites where they monitor or direct operations or solve onsite problems. Some engineers travel extensively to plants or worksites here and abroad. Many engineers work a nominal 40 h week. At times, deadlines or design standards may bring extra pressure to a job, requiring engineers to work longer hours.

Engineers usually work in teams. Sometimes, the team has only two or three engineers, but in large companies, engineering teams can have hundreds of people working on a single project (the design and manufacture of a large aircraft, for example). Engineers are responsible for communicating, planning, designing, manufacturing, and testing among other duties.

Engineers are capable of designing the processes and equipment needed for a project, and sometimes, that involves inventing new technologies. Engineers must also test their work carefully before it is used by trying to anticipate all of the things that could go wrong and make sure that their products perform safely and effectively.

More than 1.2 million engineers work in the United States today, making engineering the nation's second-largest profession. According to the 2014 survey by the National Association of Colleges and Employers, engineering majors have 8 of the 10 the highest baccalaureate degree starting salaries averaging \$67,480 per year.

An engineering degree also opens doors to other careers. Engineering graduates can move into other professions, such as medicine, law, and business, where their engineering problem solving ability is a valuable asset. A list⁶ is available of famous engineers who became American Presidents, Nobel Prize winners, astronauts, corporate presidents, entertainers, inventors, and scientists.

In the United States, distinguished engineers may be elected to the National Academy of Engineering (NAE); it is the highest national honor for engineers. In many countries, there are parallel organizations (e.g., The Royal Academy of Engineering in the United Kingdom).

1.5 WHAT IS ENGINEERING TECHNOLOGY?

The following definition of engineering technology was established by the Technology Accreditation Commission of ABET, Inc. (Accreditation Board for Engineering and Technology) and was approved by the Engineering Technology Council of the American Society for Engineering Education.

Engineering technology is the profession in which a knowledge of mathematics and natural sciences gained by higher education, experience, and practice is devoted primarily to the implementation and extension of existing technology for the benefit of humanity.

Engineering technologists work closely with engineers in coordinating people, material, and machinery to achieve the specific goals of a particular project. The engineering technologist is often responsible for design and development.

⁶See <http://www.sinc.sunysb.edu/Stu/hnaseer/interest.htm>.

Many engineering technicians work in quality control, inspecting products and processes, conducting tests, or collecting data. In manufacturing, they may assist in product design, development, or production.

There is a wide range of options when it comes to educational preparation in engineering technology. Most employers prefer to hire engineering technologists with at least a 2 year associate degree in engineering technology. Some universities offer 2 year associate degrees, others offer 3 or 4 year BS degree programs, and some offer both types of degrees.

1.6 WHAT MAKES A “GOOD” ENGINEER?

This is actually a difficult question to answer because the knowledge and skills required to be an engineer (i.e., to create ingenious solutions) is a moving target. The factors that will lead to your career success are not the same as they were 20 years ago (and never will be). In this book, we illustrate the key characteristics of a successful twenty-first century engineer by exploring the multidisciplinary creative engineering process required to produce “good” competitive products for the twenty-first century.

So just what *does* the twenty-first century hold for the young engineer? It will be characterized by the *convergence* of many technologies and engineering systems. The products of today and tomorrow will be “smarter.” The incorporation of computers, sensors, controls, modern alloys, and plastics are as important as continuing expertise in the traditional engineering disciplines. This book is also intended to appeal to a number of aspects of modern engineering subdisciplines.

1.7 WHAT THIS BOOK COVERS

In your mind what makes a “good” consumer product, say, an automobile? If you were in the market to purchase one, you might want one that has high performance and good gas mileage and is roomy, safe, and stylish. Or you might describe it in categories like new or used; sedan, sports car, or SUV; two doors or four doors. Or, maybe, you would be interested in only the price tag.

As a consumer making a decision about purchasing a car, it is enough to use the preceding words, categories, and questions to reach a decision. But engineers think differently. They design and analyze, and consequently, they must have a different set of words, categories, and questions. To design and analyze, engineers ask precise questions that can be answered with **variables**, **numbers**, and **units**. They do it to produce a safe and reliable product. From this point of view, an automobile is an engineer’s answer to the question “What is a good way to move people safely and reliably?”

The purpose of this book is to introduce you to the engineering profession. It does so by introducing you to the way engineers think, ask, and answer questions like these: What makes an automobile—or a computer, or an airplane, or a washing machine, or a bridge, or a prosthetic limb, or an oil refinery, or a space satellite—*good*?

We use the automobile as an example at this point strictly for convenience. Presumably, you have, or at least think you have, some idea of what constitutes an automobile. But, it no more or no less expresses the essence of engineering than would an example based on a computer, an airplane, a washing machine, a bridge, a prosthetic limb, an oil refinery, or a space satellite. In each case, the essence of the example would focus on the creative use of energy, materials, motion, and information to serve human needs, so a more detail-oriented engineer might answer our original question like this:

A good 21st-century automobile employs stored energy (on the order of 100 million joules), complex materials (on the order of 1000 kilograms [about one ton] of steel, aluminum, glass, and plastics), and information (on the order of millions of bits processed every second) so that it is capable of high speed (on the order of 40 meters/second \approx 90 mph), low cost (a few tens of a cent per mile), low pollution (a few grams of pollutants per mile), and high safety.

That is a long and multidimensional answer, but an engineer would be unapologetic. Engineering is *inherently* multidimensional and multidisciplinary. It needs to be multidimensional to create compromises among conflicting criteria, and it needs to be multidisciplinary to understand the technical impact of the compromises. Making a car heavier, for example, might make it safer, but it would also be less fuel efficient. Engineers often deal with such competing factors. They break down general issues into concrete questions. They then answer those questions with design variables, units, and numbers.

Engineering is not a spectator sport! It is a *hands-on* and *minds-on* activity. In this book, you will be asked to participate in a “Design Studio.” This is the part of the course that is “hands on”—and, it is *fun!* But, you will still learn the principles of good design practice (irrespective of your intended engineering major), and you will have to integrate skills learned in construction, electrical circuits, logic, and computers in building a device (the “device” could be a car, robot, boat, bridge, or anything else appropriate to your course). It will have to compete against similar devices built by other young engineers also in your class and whose motivation may be to stop your device from succeeding in achieving the same goals! You will learn how to organize data and the vital importance of good communication skills. You will present your ideas and your designs orally and in written format. In the Design Studio, you will design and build increasingly complex engineering systems, starting with the tallest tower made from a single sheet of paper and ending with a controlled device combining many parts into a system aimed at achieving complex goals.

As a start to the “minds-on” portion of the book, can you mentally take apart and put back together an imaginary automobile or toaster, or computer or bicycle? Instead of using wrenches and screwdrivers, your tools are mental and computerized tools for engineering thought.

Example 1.1

Figure 1.1 shows a generic car with numbered parts. Without cheating from the footnote, can you fill in the correct number corresponding to the parts in each of the blanks.⁷

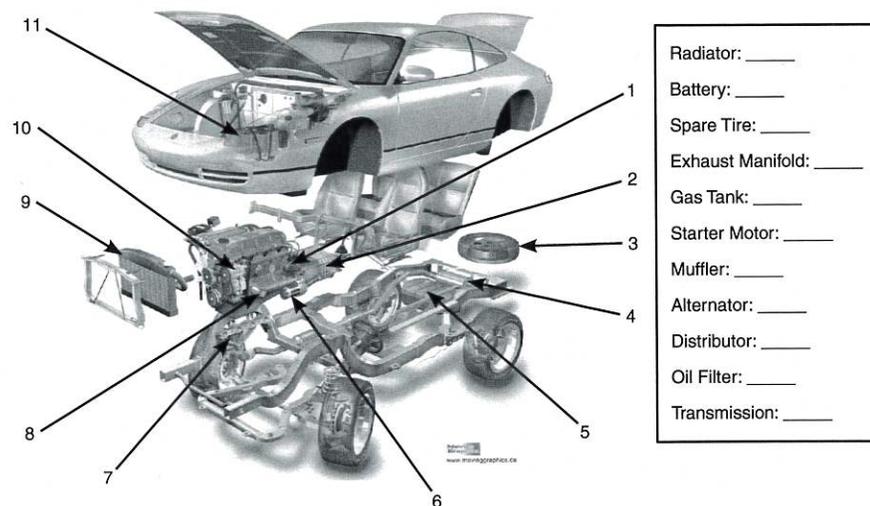


FIGURE 1.1 An exploded view of a modern automobile. Source: © Moving Graphics.

⁷Answer: 1—distributor, 2—transmission, 3—spare tire, 4—muffler, 5—gas tank, 6—starter motor, 7—exhaust manifold, 8—oil filter, 9—radiator, 10—alternator, 11—battery.

As visually appealing as Figure 1.1 is, an engineer would consider it inadequate because it fails to express the functional connections among the various parts. Expressing in visual form, the elements and relationships involved in a problem is a crucial tool of engineering, called a **conceptual sketch**. A first step in an engineer's approach to a problem is to draw a conceptual sketch of the problem. Artistic talent is not an issue nor is graphic accuracy. The engineer's conceptual sketch may not look at all like the thing it portrays. Rather, it is intended to (1) help the engineer identify the elements in a problem, (2) see how groups of elements are connected together to form subsystems, and (3) understand how all those subsystems work together to create a working system.

Example 1.2

On a piece of paper, draw a conceptual sketch of what happens when you push on the pedal of a bicycle. Before you begin here are some questions you should think about:

- What are the key components that connect the pedal to the wheel?
- Which ones are connected to each other?
- How does doing something to one of the components affect the others?
- What do those connections and changes have to do with accomplishing the task of accelerating the bicycle?

Solution

Figure 1.2a shows what your sketch probably looks like. But this is just the final form of the bicycle; it does not give much insight into what was needed to design and to build it. It's the utterly unphysical representation in Figure 1.2b that will clarify the functions needed to design it, "Form follows function" means first it has to work.

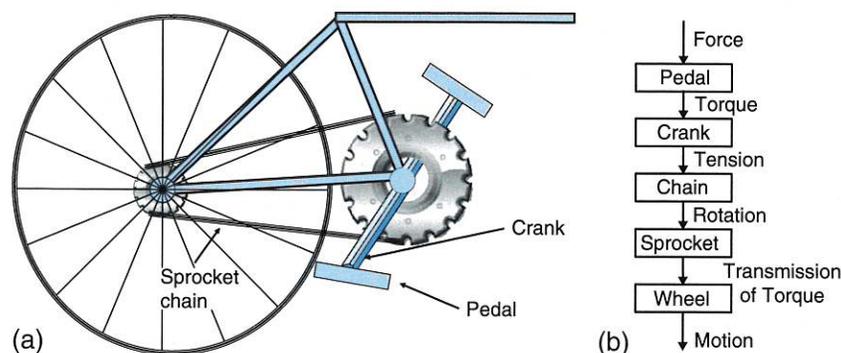


FIGURE 1.2 Bicycle transmission.

For any engineering concept, many different conceptual sketches are possible. You are encouraged to draw conceptual sketches of each of the key points in the learning sections in this book.

1.8 PERSONAL AND PROFESSIONAL ETHICS

The word "ethics" can have several meanings. It can mean philosophical ethics where reason is used to define the limits of right and wrong behavior in society or a profession. It can also mean a person's own ethical behavior relative to others. What are *personal* ethics and what do they have to do with engineering?