**Engineering**

**Engineering**, term applied to the profession in which a knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied to the efficient use of the materials and forces of nature. The term *engineer* properly denotes a person who has received professional training in pure and applied science, but is often loosely used to describe the operator of an engine, as in the terms *locomotive engineer, marine engineer,* or *stationary engineer.* In modern terminology these latter occupations are known as crafts or trades. Between the professional engineer and the craftsperson or tradesperson, however, are those individuals known as subprofessionals or paraprofessionals, who apply scientific and engineering skills to technical problems; typical of these are engineering aides, technicians, inspectors, draftsmen, and the like.

Before the middle of the 18th century, large-scale construction work was usually placed in the hands of military engineers. Military engineering involved such work as the preparation of topographical maps, the location, design, and construction of roads and bridges; and the building of forts and docks; see Military Engineering below. In the 18th century, however, the term *civil engineering* came into use to describe engineering work that was performed by civilians for nonmilitary purposes. With the increasing use of machinery in the 19th century, mechanical engineering was recognized as a separate branch of engineering, and later mining engineering was similarly recognized.

The technical advances of the 19th century greatly broadened the field of engineering and introduced a large number of engineering specialties, and the rapidly changing demands of the socioeconomic environment in the 20th century have widened the scope even further.

***Fields of Engineering***

The main branches of engineering are discussed below in alphabetical order. The engineer who works in any of these fields usually requires a basic knowledge of the other engineering fields, because most engineering problems are complex and interrelated. Thus a chemical engineer designing a plant for the electrolytic refining of metal ores must deal with the design of structures, machinery, and electrical devices, as well as with purely chemical problems.

Besides the principal branches discussed below, engineering includes many more specialties than can be described here, such as acoustical engineering , architectural engineering automotive engineering, ceramic engineering, transportation engineering, and textile engineering.

**Aeronautical and Aerospace Engineering**

Aeronautics deals with the whole field of design, manufacture, maintenance, testing, and use of aircraft for both civilian and military purposes. It involves the knowledge of , structural design, propulsion engines, navigation, communication, and other related areas.

Aerospace engineering is closely allied to aeronautics, but is concerned with the flight of vehicles in space, beyond the earth's atmosphere, and includes the study and development of rocket engines, artificial satellites, and spacecraft for the exploration of outer space.

**Chemical Engineering**

This branch of engineering is concerned with the design, construction, and management of factories in which the essential processes consist of chemical reactions. Because of the diversity of the materials dealt with, the practice, for more than 50 years, has been to analyze chemical engineering problems in terms of fundamental unit operations or unit processes such as the grinding or pulverizing of solids. It is the task of the chemical engineer to select and specify the design that will best meet the particular requirements of production and the most appropriate equipment for the new applications.

With the advance of technology, the number of unit operations increases, but of continuing importance are distillation, crystallization, dissolution, filtration, and extraction. In each unit operation, engineers are concerned with four fundamentals: the conservation of matter; the conservation of energy; the principles of chemical equilibrium; the principles of chemical reactivity. In addition, chemical engineers must organize the unit operations in their correct sequence, and they must consider the economic cost of the overall process. Because a continuous, or assembly-line, operation is more economical than a batch process, and is frequently amenable to automatic control, chemical engineers were among the first to incorporate automatic controls into their designs.

**Civil Engineering**

Civil engineering is perhaps the broadest of the engineering fields, for it deals with the creation, improvement, and protection of the communal environment, providing facilities for living, industry and transportation, including large buildings, roads, bridges, canals, railroad lines, airports, water-supply systems, dams, irrigation, harbors, docks, aqueducts, tunnels, and other engineered constructions. The civil engineer must have a thorough knowledge of all types of surveying, of the properties and mechanics of construction materials, the mechanics of structures and soils, and of hydraulics and fluid mechanics. Among the important subdivisions of the field are construction engineering, irrigation engineering, transportation engineering, soils and foundation engineering, geodetic engineering, hydraulic engineering, and coastal and ocean engineering.

**Electrical and Electronics Engineering**

The largest and most diverse field of engineering, it is concerned with the development and design, application, and manufacture of systems and devices that use electric power and signals. Among the most important subjects in the field in the late 1980s are electric power and machinery, electronic circuits, control systems, computer design, superconductors, solid-state electronics, medical imaging systems, robotics, lasers, radar, consumer electronics, and fiber optics.

Despite its diversity, electrical engineering can be divided into four main branches: electric power and machinery, electronics, communications and control, and computers.

*Electric Power and Machinery*

The field of electric power is concerned with the design and operation of systems for generating, transmitting, and distributing electric power. Engineers in this field have brought about several important developments since the late 1970s. One of these is the ability to transmit power at extremely high voltages in both the direct current (DC) and alternating current (AC) modes, reducing power losses proportionately. Another is the real-time control of power generation, transmission, and distribution, using computers to analyze the data fed back from the power system to a central station and thereby optimizing the efficiency of the system while it is in operation.

A significant advance in the engineering of electric machinery has been the introduction of electronic controls that enable AC motors to run at variable speeds by adjusting the frequency of the current fed into them. DC motors have also been made to run more efficiently this way.

*Electronics*

Electronic engineering deals with the research, design, integration, and application of circuits and devices used in the transmission and processing of information. Information is now generated, transmitted, received, and stored electronically on a scale unprecedented in history, and there is every indication that the explosive rate of growth in this field will continue unabated.

Electronic engineers design circuits to perform specific tasks, such as amplifying electronic signals, adding binary numbers, and demodulating radio signals to recover the information they carry. Circuits are also used to generate waveforms useful for synchronization and timing, as in television, and for correcting errors in digital information, as in telecommunications.

Prior to the 1960s, circuits consisted of separate electronic devices—resistors, capacitors, inductors, and vacuum tubes—assembled on a chassis and connected by wires to form a bulky package. Since then, there has been a revolutionary trend toward integrating electronic devices on a single tiny chip of silicon or some other semiconductive material. The complex task of manufacturing these chips uses the most advanced technology, including computers, electron-beam lithography, micro-manipulators, ion-beam implantation, and ultraclean environments. Much of the research in electronics is directed toward creating even smaller chips, faster switching of components, and three-dimensional integrated circuits.

*Communications and Control*

Engineers in this field are concerned with all aspects of electrical communications, from fundamental questions such as “What is information?” to the highly practical, such as design of telephone systems. In designing communication systems, engineers rely heavily on various branches of advanced mathematics, such as Fourier analysis, linear systems theory, linear algebra, complex variables, differential equations, and probability theoryEngineers work on control systems ranging from the everyday, passenger-actuated, as those that run an elevator, to the exotic, as systems for keeping spacecraft on course. Control systems are used extensively in aircraft and ships, in military fire-control systems, in power transmission and distribution, in automated manufacturing, and in robotics.

Engineers have been working to bring about two revolutionary changes in the field of communications and control: Digital systems are replacing analog ones at the same time that fiber optics are superseding copper cables. Digital systems offer far greater immunity to electrical noise. Fiber optics are likewise immune to interference; they also have tremendous carrying capacity, and are extremely light and inexpensive to manufacture.

*Computers*

Virtually unknown just a few decades ago, computer engineering is now among the most rapidly growing fields. The electronics of computers involve engineers in design and manufacture of memory systems, of central processing units, and of peripheral devices . Foremost among the avenues now being pursued are the design of Very Large Scale Integration (VLSI) and new computer architectures. The field of computer science is closely related to computer engineering; however, the task of making computers more “intelligent” , through creation of sophisticated programs or development of higher level machine languages or other means, is generally regarded as being in the realm of computer science.

One current trend in computer engineering is microminiaturization. Using VLSI, engineers continue to work to squeeze greater and greater numbers of circuit elements onto smaller and smaller chips. Another trend is toward increasing the speed of computer operations through use of parallel processors, superconducting materials, and the like.

**Geological and Mining Engineering**

This branch of engineering includes activities related to the discovery and exploration of mineral deposits and the financing, construction, development, operation, recovery, processing, purification, and marketing of crude minerals and mineral products. The mining engineer is trained in historical geology, mineralogy, paleontology, and geophysics, and employs such tools as the seismograph and the magnetometer for the location of ore or petroleum deposits beneath the surface of the earth. The surveying and drawing of geological maps and sections is an important part of the work of the engineering geologist, who is also responsible for determining whether the geological structure of a given location is suitable for the building of such large structures as dams.

**Industrial or Management Engineering**

This field pertains to the efficient use of machinery, labor, and raw materials in industrial production. It is particularly important from the viewpoint of costs and economics of production, safety of human operators, and the most advantageous deployment of automatic machinery.

**Mechanical Engineering**

Engineers in this field design, test, build, and operate machinery of all types; they also work on a variety of manufactured goods and certain kinds of structures. The field is divided into machinery, mechanisms, materials, hydraulics, and pneumatics; and heat as applied to engines, work and energy, heating, ventilating, and air conditioning. The mechanical engineer, therefore, must be trained in mechanics, hydraulics, and thermodynamics and must be fully grounded in such subjects as metallurgy and machine design. Some mechanical engineers specialize in particular types of machines such as pumps or steam turbines. A mechanical engineer designs not only the machines that make products but the products themselves, and must design for both economy and efficiency. A typical example of the complexity of modern mechanical engineering is the design of an automobile, which entails not only the design of the engine that drives the car but also all its attendant accessories such as the steering and braking systems, the lighting system, the gearing by which the engine's power is delivered to the wheels, the controls, and the body, including such details as the door latches and the type of seat upholstery.

**Military Engineering**

This branch is concerned with the application of the engineering sciences to military purposes. It is generally divided into permanent land defense and field engineering. In war, army engineer battalions have been used to construct ports, harbors, depots, and airfields. In the U.S., military engineers also construct some public works, national monuments, and dams.

Military engineering has become an increasingly specialized science, resulting in separate engineering subdisciplines such as ordnance, which applies mechanical engineering to the development of guns and chemical engineering to the development of propellants, and the Signal Corps, which applies electrical engineering to all problems of telegraph, telephone, radio, and other communication.

**Naval or Marine Engineering**

Engineers who have the overall responsibility for designing and supervising construction of ships are called naval architects. The ships they design range in size from ocean-going supertankers as much as 1300 feet long to small tugboats that operate in rivers and bays. Regardless of size, ships must be designed and built so that they are safe, stable, strong, and fast enough to perform the type of work intended for them. To accomplish this, a naval architect must be familiar with the variety of techniques of modern shipbuilding, and must have a thorough grounding in applied sciences, such as fluid mechanics, that bear directly on how ships move through water.

Marine engineering is a specialized branch of mechanical engineering devoted to the design and operation of systems, both mechanical and electrical, needed to propel a ship. In helping the naval architect design ships, the marine engineer must choose a propulsion unit, such as a diesel engine or geared steam turbine, that provides enough power to move the ship at the speed required. In doing so, the engineer must take into consideration how much the engine and fuel bunkers will weigh and how much space they will occupy, as well as the projected costs of fuel and maintenance.

**Nuclear Engineering**

This branch of engineering is concerned with the design and construction of nuclear reactors and devices, and the manner in which nuclear fission may find practical applications, such as the production of commercial power from the energy generated by nuclear reactions and the use of nuclear reactors for propulsion and of nuclear radiation to induce chemical and biological changes. In addition to designing nuclear reactors to yield specified amounts of power, nuclear engineers develop the special materials necessary to withstand the high temperatures and concentrated bombardment of nuclear particles that accompany nuclear fission and fusion. Nuclear engineers also develop methods to shield people from the harmful radiation produced by nuclear reactions and to ensure safe storage and disposal of fissionable materials.

**Safety Engineering**

This field of engineering has as its object the prevention of accidents. In recent years safety engineering has become a specialty adopted by individuals trained in other branches of engineering. Safety engineers develop methods and procedures to safeguard workers in hazardous occupations. They also assist in designing machinery, factories, ships, and roads, suggesting alterations and improvements to reduce the likelihood of accident. In the design of machinery, for example, the safety engineer seeks to cover all moving parts or keep them from accidental contact with the operator, to put cutoff switches within reach of the operator, and to eliminate dangerous projecting parts. In designing roads the safety engineer seeks to avoid such hazards as sharp turns and blind intersections, known to result in traffic accidents. Many large industrial and construction firms, and insurance companies engaged in the field of workers compensation, today maintain safety engineering departments.

**Sanitary Engineering**

This is a branch of civil engineering, but because of its great importance for a healthy environment, especially in dense urban-population areas, it has acquired the importance of a specialized field. It chiefly deals with problems involving water supply, treatment, and distribution; disposal of community wastes and reclamation of useful components of such wastes; control of pollution of surface waterways, groundwaters, and soils; milk and food sanitation; housing and institutional sanitation; rural and recreational-site sanitation; insect and vermin control; control of atmospheric pollution; industrial hygiene, including control of light, noise, vibration, and toxic materials in work areas; and other fields concerned with the control of environmental factors affecting health. The methods used for supplying communities with pure water and for the disposal of sewage and other wastes are described separately.

***Modern Engineering Trends***

Scientific methods of engineering are applied in several fields not connected directly to manufacture and construction. Modern engineering is characterized by the broad application of what is known as systems engineering principles. The systems approach is a methodology of decision-making in design, operation, or construction that adopts (1) the formal process included in what is known as the scientific method; (2) an interdisciplinary, or team, approach, using specialists from not only the various engineering disciplines, but from legal, social, aesthetic, and behavioral fields as well; (3) a formal sequence of procedure employing the principles of operations research.

In effect, therefore, transportation engineering in its broadest sense includes not only design of the transportation system and building of its lines and rolling stock, but also determination of the traffic requirements of the route followed. It is also concerned with setting up efficient and safe schedules, and the interaction of the system with the community and the environment. Engineers in industry work not only with machines but also with people, to determine, for example, how machines can be operated most efficiently by the workers. A small change in the location of the controls of a machine or of its position with relation to other machines or equipment, or a change in the muscular movements of the operator, often results in greatly increased production. This type of engineering work is called time-study engineering.

A related field of engineering, human-factors engineering, also known as ergonomics, received wide attention in the late 1970s and the '80s when the safety of nuclear reactors was questioned following serious accidents that were caused by operator errors, design failures, and malfunctioning equipment. Human-factors engineering seeks to establish criteria for the efficient, human-centered design of, among other things, the large, complicated control panels that monitor and govern nuclear reactor operations.

Among various recent trends in the engineering profession, licensing and computerization are the most widespread. Today, many engineers, like doctors and lawyers, are licensed by the state. Approvals by professionally licensed engineers are required for construction of public and commercial structures, especially installations where public and worker safety is a consideration. The trend in modern engineering offices is overwhelmingly toward computerization. Computers are increasingly used for solving complex problems as well as for handling, storing, and generating the enormous volume of data modern engineers must work with.

The National Academy of Engineering, founded in 1964 as a private organization, sponsors engineering programs aimed at meeting national needs, encourages new research, and is concerned with the relationship of engineering to society.

For articles on professional engineering societies, see separate articles under individual names.