ENGINEERING GRAPHICS

DESIGN • ANALYSIS • COMMUNICATION

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Preface

The study of engineering graphics is continually subject to critical scrutiny and re-evaluation by engineering educators associated with the teaching of fundamental concepts, by administrators responsible for curriculum planning, and by professional engineers concerned with practical applications of engineering graphics. The result of this appraisal is a fresh look at traditional procedures and a new approach to subject matter presentation. Two major developments currently exerting a strong influence on engineering graphics course content are: (1) the emphasis on design as the primary function of the engineer and the need for introducing the concepts of design beginning with the freshman year of undergraduate study, and (2) the advent of computer graphics as a practical reality.

This Second Edition of *Engineering Graphics* reflects the changes in emphasis that have occurred since the publication of the First Edition. The theme of the text is established in a new introductory section which discusses the interdisciplinary role of design in engineering practice and the logical steps in the design process.

A new section discusses the nature of engineering materials, the manufacturing processes that form raw materials into functional elements, and the appearance, purpose, and method of representing and specifying the basic mechanical elements of an engineering design. Also new is the introduction of a real space coordinate system, similar to that used in analytical geometry, which demonstrates clearly that the descriptive geometry solution of a problem is a graphic representation of the analytical geometry solution, thus tying together two important tools of engineering analysis. Moreover, the coordinate system is compatible with the forms used by computers in the graphical solution of problems. Hence, the student is provided with an important foundation for further study of computer graphics.

The aim of *Engineering Graphics* is to provide the student with a precise language for the expression and communication of design concepts and their specifications for manufacture. The skills—sketching, instrument drawing, lettering, and the techniques of size and shape description—are presented in sufficient detail so that the student upon completion of his course should be able to read and write the language successfully.

The authors wish to thank their many colleagues from both education and industry for their valuable suggestions for improvement. They are particularly grateful for the helpful comments and suggestions proffered by the teachers who have used the First Edition in their classrooms. The authors also wish to acknowledge and thank the several companies who supplied photographic illustrations. Special acknowledgment is made to the American National Standards Institute for the illustrations and tables extracted, with permission, from their publications and included herein.

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Contents

IV SPATIAL ANALYSIS

V NUMERICAL RELATIONSHIPS

APPENDIX

PART I

DESIGN IN ENGINEERING

1

GRAPHICS, DESIGN, AND THE ENGINEER

1–1 INTRODUCTION

Before a student can fully appreciate the importance of the subject matter of any single course in a professional curriculum, he first needs to establish the relevance of that course to his total career commitment. The primary purpose of this chapter is to relate engineering graphics to the career of a practicing engineer.

The discussion begins with a brief historical narrative outlining the evolution of engineering from its origin into the profession as defined in Art. 1–3. Short descriptions of the general fields and functions of engineering point out the importance of design in all areas of engineering practice. The discussion concludes with the vital role of engineering graphics in design communication and analysis.

1–2 A SHORT HISTORY OF ENGINEERING

Engineering began some eight thousand years ago while man was making the transition from a nomadic tribal existence, continually on the move from one hunting ground to another, to communal group living in permanent abodes with cultivated fields nearby providing a source of food. This permanent attachment to fixed land areas made it necessary to establish boundaries to separate the fields of one man from those of another, and a system of measurement was devised. The requirement for water, both for man himself and for his crops, led to the development of irrigation systems to bring water from distant streams or wells to the fields.

With a bountiful food supply assured, early man had more time to think of other ways of improving his situation and making the struggle for life less arduous. Copper, in its native state, was used for the construction of utensils, tools, and weapons. Bronze, the first metal alloy (copper and tin), probably occurred by accident, and was an improvement over the base metal, copper. A means was discovered for separating metals from their ores, and a completely new family of materials became available. Simple machines, such as the wheel and axle, and the pulley, facilitated the transportation of goods and made it possible for man to amplify the power of his muscles and produce more useful work from his domestic animals. Thus were the origins of civil, metallurgical, and mechanical engineering.

Evolving concurrently with the delineation of boundaries, construction of earthworks, discovery of metals, and invention of simple machines, were the beginnings of a system for counting and manipulating numbers and the development of a means of written communication. The use of written communication and mathematical calculations created a need for recording and preserving writings, drawings, and calculations. Much of what was written or drawn was undoubtedly scratched in the sand or hard earth, and was soon obliterated. Markings on the walls of caves, clay tiles, and animal skins provided a longer lasting record. The earliest known records with an engineering significance that have been translated and understood date from the time of the construction of the Pyramids of Egypt around 3000 B.C. The skill of the early Egyptian engineers was considerable. Modern measurements of the Great Pyramid show an error of only half an inch along a 755-foot side. The Egyptians were able to restore boundary markers washed away by the annual flooding of the Nile River, establish dykes for flood control, and irrigate large desert areas for farm use.

The Greeks, borrowing from the Egyptians, built improved irrigation systems and developed the corbeled arch, an important feature in building construction. Their scorn for manual labor as fit only for slaves restricted the use of experimentation as a means of verification. Nevertheless, the early Greeks hypothesized that the physical world around them obeyed certain general laws.

Following the decline of the Egyptian and Greek civilizations, the Roman Empire grew and flourished. The Roman engineers, though doing little original work, quickly adopted ideas that were found in conquered areas and became superior in their application of those concepts to their own needs. Roman engineers constructed almost 200,000 miles of roads required for communications within the Roman Empire. They built aqueducts for water supply, stone bridges for their roads, and developed the Roman arch widely used in bridges and buildings. It is a mark of their excellence that some of these roads and aqueducts are still usable today. It has been said that growth of the Roman Empire was due largely to the abilities of its engineers.

After the fall of the Roman Empire, engineering knowledge found little application, surviving only as hidden volumes in the libraries of religious orders. Little new scientific thought or interest was evident during the years prior to the seventeenth century except among a few isolated individuals such as Leonardo da Vinci (1452–1519) who conceived feasible designs for a steam engine, camera, submarine, and a flying machine, and Galileo Galilei (1564–1642) who formalized the "scientific method" and is known for the telescope which bears his name.

With the seventeenth century came a rebirth of interest in engineering and scientific investigation. The hostility of the previous years towards the exploration of the laws of nature slowly relaxed, and freedom of thought again became permissible. Well-designed canals and locks were constructed for inland water communication. Ship design and the ports to handle the ships and their cargos were improved. Probably the most important innovation was the beginning of practical design for steam engines to power machinery.

With the development of an efficient steam engine and methods for refining iron in the nineteenth century, the pace of engineering development accelerated rapidly. Knowledge of engineering principles became so extensive and so detailed that engineers began to concentrate more deeply in narrow fields of study. Today, engineers have applied scientific discoveries in achieving the wonders of television, electronic computers, supersonic aircraft, space flight, and atomic power, plus the innumerable consumer products accepted without question as a part of everyday life: the automobile, telephone, electric light, etc. This list could go on and on. The discoveries and developments of the future depend only on the willingness of ingenious man to apply his imagination, and the public to accept the results.

1–3 DEFINITION OF ENGINEERING

The words *engineer* and *engineering* have been repeatedly used in the previous article. But what is an engineer? Historically, the term originated almost 800 years ago when the name *ingeniator* was applied to a man who operated an invention that was actually a machine for battering down the walls of defensive fortifications. From this limited origin grew the word "engineer," meaning one who works in engineering. Hence, to completely define an engineer, engineering must first be defined.

So varied are the activities of engineers today that it is difficult to arrive at a definition of engineering that encompasses all of the activities included in it. The most generally accepted definition is one adopted by the Engineers Council for Professional Development: "Engineering is the profession in which a knowledge of the mathematical and natural sciences gained through study, experience, and practice is applied with judgment to develop ways to utilize economically the materials and forces of nature for the benefit of mankind." To say this another way: engineering involves application of science in utilizing nature's materials and forces in the design, construction, operation, and production of products and facilities for human welfare.

It is important to recognize the difference in the missions and attitudes of the scientist and those of the engineer. It is the mission of the scientist to discover new knowledge; the mission of the engineer is to apply known knowledge. Or as others have stated: "Science makes it known, engineering makes it, and makes it work." The late Dr. Theodore von Karman (1881–1963), a leading authority of his time on aerodynamics, stated the difference another way: "The scientist explores what is . . . the engineer creates what has not been."

1–4 FIELDS OF ENGINEERING

To better understand engineering today, one must consider the various fields of engineering, over fifty of which are designated by name. Some of these fields vary only slightly; however, most of the special fields fall within the scope of one of the following general distinctly unique fields recognized in the engineering profession.

Aerospace Engineering. When man orbited the earth, great interest was stimulated in space efforts, and many schools broadened their aeronautical engineering coverage, which was theretofore concerned primarily with flight in the relatively dense air near the earth, to include courses dealing with aerospace engineering. Aerospace engineers apply the combined knowledge of many fields of engineering to all types of flight vehicles from aircraft to missiles. Their work ranges from the design of spacecraft and airplanes to aerodynamic analyses of the performance, control, and stability of aircraft and guided missiles. The aerospace engineer is also concerned with the design of the associated propulsion and fuel systems. Air traffic control is becoming increasingly complex, and the aerospace engineer is interested in the design and operational control of systems which will permit the safe operation of aircraft in all weather and traffic conditions.

Agricultural Engineering. To cope with the problem of feeding the rapidly expanding world population, the need for agricultural engineers is expanding. These engineers design equipment and develop methods required to improve the efficiency and economy in the growing, processing, and distribution of agricultural products. The agricultural engineer is also interested in soil and water conservation and management, and is active in the work of developing new food uses of plants through innovative processing methods.

Ceramic Engineering. The ceramic engineer, one of the more recent engineering specialists, works with non-metallic materials and develops methods for processing them into useful products, such as glassware, insulators, cements, protective and refractory coats for metals, and other materials that are resistant to high temperatures or corrosion (see Fig. 1–1). A practical solution to the problem of insulating space vehicles from the extreme heat generated during reentry into the earth's atmosphere was solved by the development of a workable refractory coat for the nose cone (see also Fig. 1–4). The

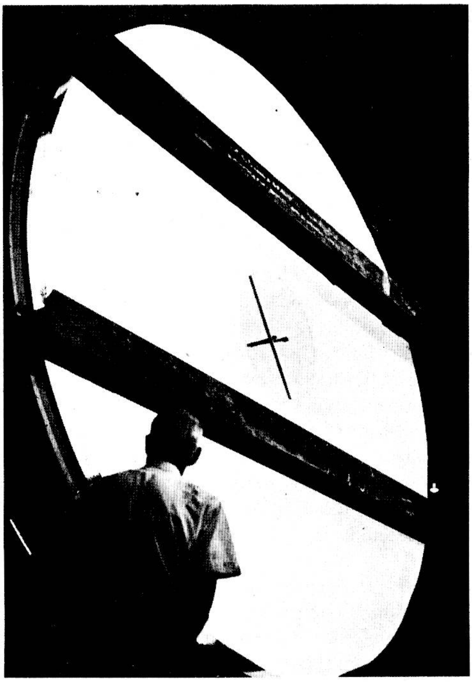

Fig. 1–1. Engineers watch the final turning of a fused silica mirror blank made for Canada's Mount Kobau National Observatory. The mirror is 157 inches in diameter and 25 inches thick. (Photograph courtesy of the Corning Glass Works.)

ceramic engineer often designs the equipment necessary to process ceramic products. He frequently works with the chemical and the nuclear engineer in developing new processing methods.

Chemical Engineering. The chemical engineer designs and operates plants for the production of materials that undergo chemical change during their processing. He also designs the equipment used in the process of changing raw materials into useful products. Synthetic fibers, drugs and medicines, petrochemicals, and plastics are a few of the products of the chemical engineer; and he is involved in the development, testing, and evaluation of new fuels for turbine and rocket propulsion systems.

Civil Engineering. Civil engineering, the oldest engineering field, evolved from the work of the early military engineers, and was so called to distinguish the engineer engaged in civil works from his military counterpart. The civil engineer may be involved in transportation where he plans, designs, and builds highways, railroads, airports, pipelines, and harbors (see Fig. 1–2). Or he may work primarily in the construction area where he designs and constructs buildings, tunnels, dams, and bridges. Other areas in which the civil engineer applies his knowledge include soil mechanics and foundation investigations, the design and construction of water supply and waste disposal systems, and mapping.

Electrical Engineering. The electrical engineer may design systems for the generation, transmission, and utilization of electrical energy in many forms as well as the elements of the electrical systems, such as generators and electric motors; or he may work in electronics, where he designs and operates radio and television transmitters and receivers, telemetering systems, and computers. The automatic control of machine tools is an increasingly important phase of modern production methods and the electrical engineer works with the mechanical engineer in the design of these systems.

Industrial Engineering. Most fields of engineering specialty tend to impose natural disciplinary restrictions. However, the industrial engineer must be interdisciplinary in his attitude since he works with and coordinates many parts of all engineering fields. The industrial engineer traditionally designs, operates, and manages industrial systems. His work includes plant design and layout, methods planning, quality and production control, and cost analysis. Not only must the industrial engineer have a sound knowledge of the principles of engineering, but he must possess an understanding of the human factor. Recently the work of the industrial en-

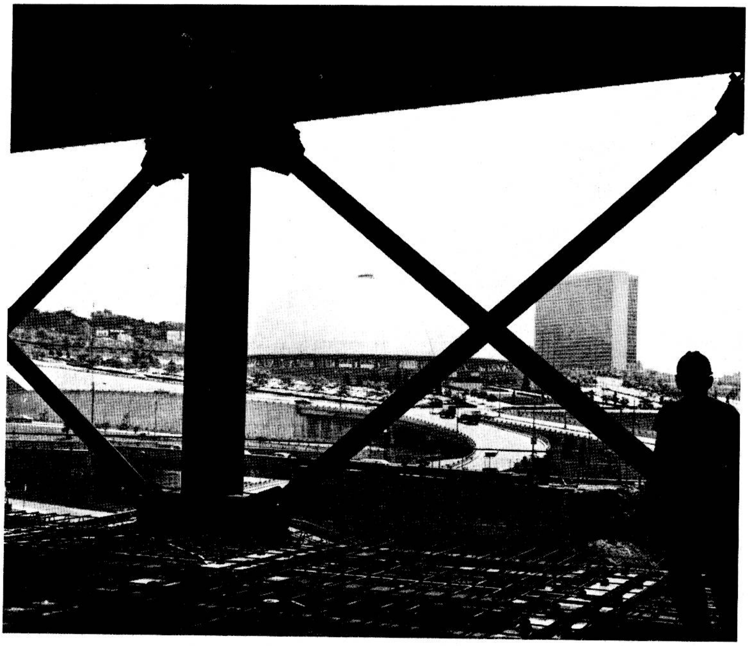

Fig. 1–2. Some areas of involvement for the civil engineer. (Photograph courtesy of the Bethlehem Steel Corporation.)

gineer has broadened to include the efficient operation of all service systems. An example is the employment of industrial engineers to manage the efficient, economic operation of hospitals.

Mechanical Engineering. Mechanical engineers, the first departure from the early civil engineers, specialize in the design of machinery and the associated power generating systems. Mechanical engineers design and build automobiles, trains, ships, machine tools, gas and steam engines, jet and rocket motors, and turbines. The mechanical engineer's design work may vary from almost microscopic parts to gigantic pieces of heavy machinery. A major specialty area in the mechanical engineering field is the design and operation of heating and air conditioning systems.

Metallurgical Engineering. The work of the metallurgical engineer is similar to that of the ceramic engineer, except that the metallurgical engineer is concerned only with metals. He deals in the location, extraction, and refining of metals. He also experiments with the alteration of the molecular structure of metals, through alloying and other processes, in order to produce a metal with the characteristics required by other engineers for specific applications. The metallurgical engineer frequently must design special equipment necessary for his work.

Nuclear Engineering. Another of the newer specialists, the nuclear engineer, is involved in the design and operation of nuclear-power systems for generating electrical power and for operating surface ships, submarines, and railways. The possibility of applying nuclear power systems in airplanes and automobiles presents an exciting challenge. Other major areas of work for the nuclear engineer are in the use of isotopes in chemical, biological, and medical applications, and in the changing of the physical and chemical properties of materials through radiation.

1–5 FUNCTIONS OF THE ENGINEER

The happiness and the satisfaction that an engineer receives from his work depends more on what he does than where he does it. "What he does" could be called the function, and "where he does it" could be the field of engineering. The function is selected because of the individual's psychological characteristics and his motivations, while the field can be, and often is, selected because it "sounds good," because of a boyhood ambition, or because some friend or relative is in the same field. The field is usually chosen while one is a student; the function is commonly determined after one begins practice.

There are many specialized functions in engineering; several of the more clearly defined functions are here discussed. The important point to realize is that an engineering function applies to all engineering fields. Research, design, and production, for example, are functions that apply in any engineering field.

Research. Research is one of the more glamorous-sounding functions of engineering; it is also one of the most demanding. The research engineer investigates the composition and behavior of matter and searches for new processes to utilize engineering materials. The work of the research scientist and the engineer often appear to overlap. However, the intent of the research is different. The research scientist is working to discover basic truths, while the research engineer is not only working to discover but also to find a practical use for his discovery. He makes critical studies of all engineering materials and activities for the purpose of opening up new ways of applying science for the betterment of mankind.

Development. After the initial breakthrough by the research scientist or engineer, the processes or equipment must be developed for utilizing the discovery. Development engineers attempt to create new systems and equipment that will do a job better, faster, and more economically than was previously possible. The development engineer frequently works with an experimental or pilot model. The development engineer works with the design engineer and may perform the design function himself. Development and design are overlapping functions.

Design. Our modern way of life is possible because mass production methods have made more and cheaper products available to more people. After the development engineer has developed and tested a pilot process or product, the design engineer must design means to adapt the product for manufacture and production. The design engineer combines his knowledge of engineering principles, machine tools and production methods, and manufacturing economy to design a product that can sell in the open market against competitive products. The design engineer consults with the development and the production engineers to resolve the many questions that arise during the design process. The output of the design engineer is in the detailed engineering drawings that tell how the product is to be manufactured.

Production. The production engineer is more closely associated with the men in the shop than engineers in other functional areas. Working with the engineering drawings made under the supervision of the design engineer, he plans and supervises the efficient and economic production of the item (see Fig. 1–3). In addition to the production engineer's knowledge of engineering, production machinery and methods, and labor relations, he must have a familiarity with the technical details of his industry. The production engineer is not only responsible for the planning of the production of a single item, he is also responsible for the operation of the plant as a whole. Due to production problems, the production engineer may be involved in the

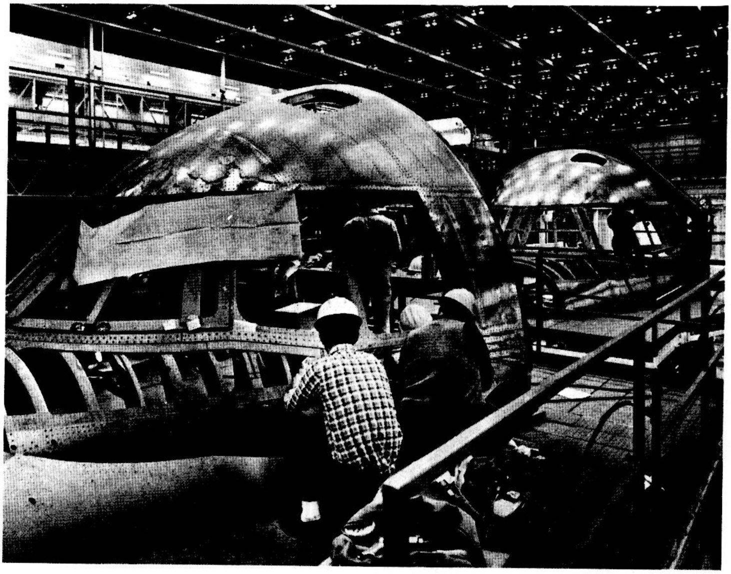

Fig. 1–3. Workers under the production engineer install final skin panels and other components in the TriStar nose. Notice the large drawing taped to the assembly. (Photograph courtesy of the Lockheed-California Company.)

design function, changing design specifications so that the part can be made by an alternate method. In the case where the product is a building, highway, dam, etc., the production engineer is known instead as a construction engineer. However, his basic responsibility, timely delivery of the finished product, is the same.

Operations. The operations engineer, or, as he is often called, the plant engineer, is responsible for the maintenance of the buildings, machinery, and utilities. The efficient and safe operation of boilers, generators, and their auxiliary equipment is also the task of the operations engineer. If a new facility is to be constructed, the operations engineer may design and specify equipment and supervise the construction of the building and the installation of equipment. Since an operations engineer's responsibilities include the efficient use of machinery within the plant, he works closely with the production engineer (see Fig. 1–4).

Sales and Service. The phenomenal growth in size and complexity of industrial technology has created the need for engineers specializing in sales and services. New applications are being developed so rapidly that other engineers must be made aware of and persuaded to try new processes and materials as they become available. It is the work of the sales engineer to recognize possible users and then to educate these potential customers in the new products and their applications. The sales engineer must be knowledgeable about his customers' needs. He must be able to show how his process or product will apply to his customer's operations and perform the required job economically. Once the customer has purchased the product, the sales engineer is responsible for proper

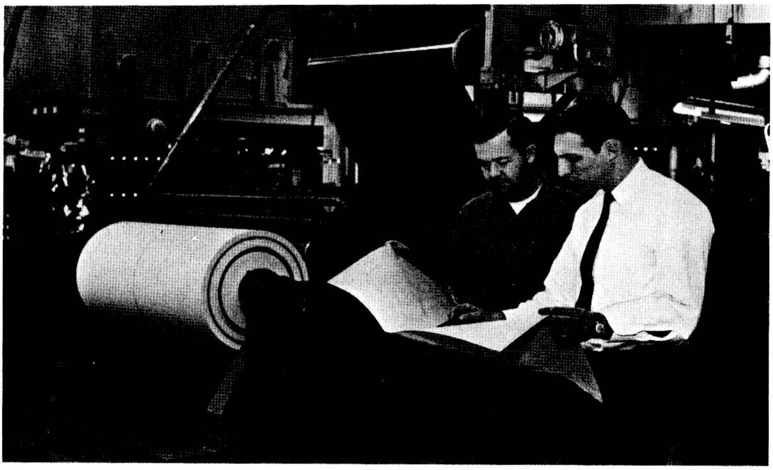

Fig. 1–4. The plant engineer checks the drawing of a new installation. (Photograph courtesy of North Carolina State University.)

operation and servicing. This sometimes leads to ideas for the improvement of the product, and the sales engineer may either submit a design change or communicate the idea or complaint to the design engineer.

Management. Recent surveys have revealed that an increasing number of corporate board chairmen, presidents, and senior vice-presidents have an engineering or science background. This is probably the result of increasing technological involvement on the part of all corporations. This function normally comes to an engineer after a successful practice in some other capacity, and the young engineering graduate should not expect to assume a high-level corporate management function at the start of his career.

Consulting. An engineer who has become proficient in a particular field of engineering may function as a professional consultant, providing engineering services for a fee. Several engineers from different fields may combine their knowledge to offer a more comprehensive consulting service. More and more consulting companies are being formed every year. A desirable feature of consulting work is the variety and challenge of the assignments and the independence of action. A successful consulting practice must be preceded by considerable experience, and while he may be employed by a consulting company, the beginning engineer rarely works as an independent practitioner.

Teaching. The number of universities, colleges, technical institutes, and junior colleges that train engineers and technicians is on the increase. Along with this growth is the need for engineers as teachers. Engineering faculty members often spend part of their time in research and consulting activities. The student should discuss the advantages of a teaching career with his instructor.

1–6 IMPORTANCE OF DESIGN

A career in engineering offers more variety of interests and applications than almost any other profession. Yet, in discussing the work of the