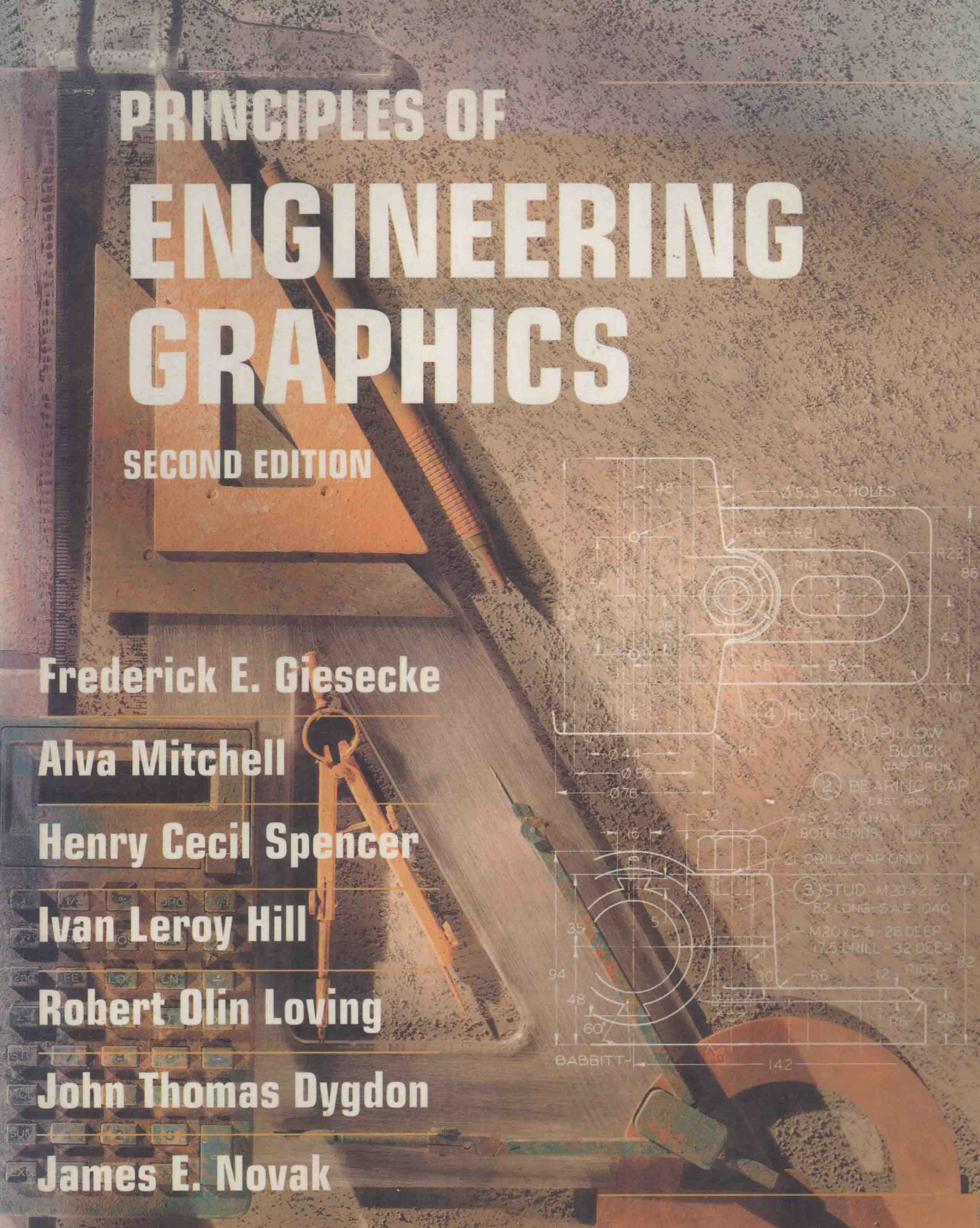

PRINCIPLES OF

ENGINEERING GRAPHICS

SECOND EDITION

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Preface

Principles of Engineering Graphics is our response to the latest developments in engineering and technical education. Our goals in writing this new text were to

1. Produce a concise and affordable textbook that can be used for either a one- or a two-semester course in technical drawing and design, descriptive geometry, graphs and diagrams, and computer graphics.
2. Include worksheets with the text rather than as a supplement.
3. Include a thorough introduction to computer graphics.
4. Retain the high standard of accuracy and excellence established in nine editions of *Technical Drawing* and five editions of *Engineering Graphics*.
5. Provide the student with a text that will cover the foundations of the subject and serve as a valuable reference book long after graduation.

For those instructors teaching an introductory course on the theory of engineering graphics including manual and computer graphics techniques, the contents of this text will be sufficient. For those wishing to spend additional time developing the manual or computer drafting skills of their students, the book has been priced so a supplemental manual workbook or computer software manual may be required without imposing too great a financial burden.

Principles of Engineering Graphics meets the needs of today's curriculum. Much of this text is adapted or condensed from *Engineering Graphics,* 5th Edition, by the same authors and published by Macmillan Publishing Company. The purpose of this book is *to teach the language of the engineer.* This goal has prompted the authors to illustrate and explain the basic principles from the standpoint of the student—that is, to present each principle so clearly that the student is certain to understand it, and to make the text interesting enough to encourage all students to read and study on their own initiative. By this means the authors hope to free the instructor from the repetitive labor of teaching each student individually the subject matter that the textbook can teach. Thus more class time can be given to the special requirements of individual programs—such as explaining the features of your school's brand of computer graphics software—or in giving more attention to those students having real difficulties.

Features of This Text/Workbook

A unique feature of this book is the combination of the textbook and workbook. By including worksheets in the same volume, we are able to provide a more convenient learning tool at an affordable paperback price.

A long-standing feature is the emphasis on technical sketching throughout the text as well as in an early chapter devoted specifically to sketching. This chapter is unique in integrating the basic concepts of views with freehand sketching so that the subject of multiview drawing can be introduced through the medium of sketches.

The increased use of computer technology for drafting, design work, and manufacturing processes is reflected in many chapters. Two chapters are specifically devoted to this new technology. Chapter 3 presents a generic introduction to computer-aided design and drafting and a survey of computer equipment, or hardware, of current CAD systems. Chapter 8 includes a general discussion of the use and operation of a CAD system focusing on computer graphics programs, or software. Rather than describing one particular software package, examples are given showing how several popular programs can be applied by the user. In addition, relevant material has been added to the other chapters with examples of how computer graphics may be used in particular applications. Many illustrations of computer-generated drawings and the equipment used to make them have been included. These discussions emphasize the relationship between traditional drafting techniques and computer graphics. A comprehensive glossary of CAD/CAM terms and concepts is given in the Appendix.

The growing importance of the engineer's design function is emphasized, especially in the chapter on design and working drawings. The chapter is designed to give the student an understanding of the fundamentals of the design process.

The book consistently reflects the latest trends and practices in education, industry, and especially the various current sections of the ANSI Y14 *American National Standard Drafting Manual* and other relevant ANSI standards.

The chapters on manufacturing processes, dimensioning, tolerancing, and threads and fasteners have been extensively reviewed to ensure their conformity with the latest ANSI standards. Every effort has been made to ensure that this book is completely abreast of the many technological developments of recent years.

The high quality of drafting in the illustrations and problems that appear in *Engineering Graphics*, 5th Edition, has been maintained in *Principles of Engineering Graphics*. A large number of drawings include the approved system of metric dimensions, now that the metric system is more widely used internationally. The current editions of ANSI standards also indicate a preference for the use of metric units. Many problems, especially in the chapter on design and working drawings, provide an opportunity for the student to convert dimensions to either the decimal-inch system or the metric system.

It is expected that the instructor who uses this text/workbook will supplement the worksheet problems with assignments from the text, to be drawn on blank paper. Many of the text problems are designed for Size A4 or Size A sheets, the same size as the easily filed worksheets. A supply of blank sheets and cross section sheets, both rectangular and isometric, is provided on the reverse sides of the worksheets.

Acknowledgments

The authors wish to express their thanks to the many individuals and companies who so generously contributed their services and materials to the production of this text. We are especially indebted to Mr. E. J. Mysiak, Engineering Product Manager, Pyle

National, Inc.; Mr. Stephen A. Smith, Manager, Product Design and Development, Packaging Corporation of America; the late Mr. Byron Urbanick, Vice President, Instructional Design Systems; and Mr. James W. Zagorski, Kelly High School, Chicago Public Schools. The authors also express their thanks to Mr. Gary W. Rybicki and Mr. William T. Briggs Jr., Department of Engineering Graphics, Illinois Institute of Technology, for their helpful suggestions and cooperation.

Special thanks are due to our editor John Griffin and to our production supervisor Elisabeth Belfer.

Students, teachers, engineers, designers, and drafters are invited to write concerning any questions that may arise. All comments and suggestions will be welcomed.

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Contents

CHAPTER

1

The Graphic Language and Design

The old saying "necessity is the mother of invention" continues to hold, and a new machine, structure, system, or device is the result of that need. If the new device, machine, system, or gadget is really needed or desired, people will buy it, providing it does not cost too much. Then, naturally, these questions may arise: Is there a wide potential market? Can this device or system be made available at a price that people are willing to pay? If these questions can be answered satisfactorily, then the inventor, designer, or officials of a company may elect to go ahead with the development of production and marketing plans for the new project or system.

A new machine, structure, or system, or an improvement thereof, must exist in the mind of the engineer or designer before it can become a reality. This original concept or idea is usually placed on paper, or as an image on a computer screen, and communicated to others by the way of the *graphic language* in the form of freehand *idea sketches,* Figs. 1.1 and 6.1. These idea or design sketches are then followed by other sketches, such as *computation sketches,* for developing the idea more fully.

1.1 The Young Engineer*

The engineer or designer must be able to create idea sketches, calculate stresses, analyze motions, size the parts, specify materials and production methods, make design layouts, and supervise the preparation of drawings and specifications that will control the numerous details of production, assembly, and maintenance of the product. In order to perform or supervise these many tasks, the engineer makes liberal use of freehand sketches. He or she must be able to record and communicate ideas quickly to associate and support personnel. Facility in freehand sketching (Chapter 6) or the ability to work with computer-controlled drawing techniques, §16.27, requires a thorough knowledge of the graphic language. The engineer or designer who

*Henceforth in this text, all conventional titles such as student, drafter, designer, engineer, engineering technician, engineering technologist, and so on are intended to refer to all persons, male and female.

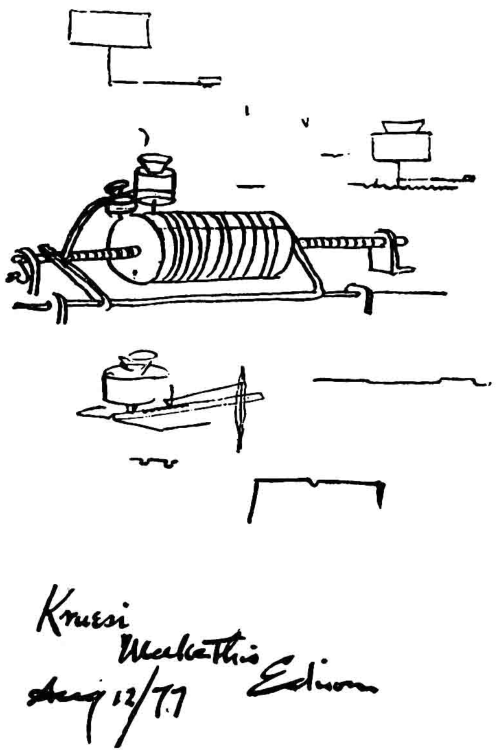

Fig. 1.1 Edison's Phonograph. *Original sketch of Thomas A. Edison's first conception of the phonograph; reproduced by special permission of Mrs. Edison.*

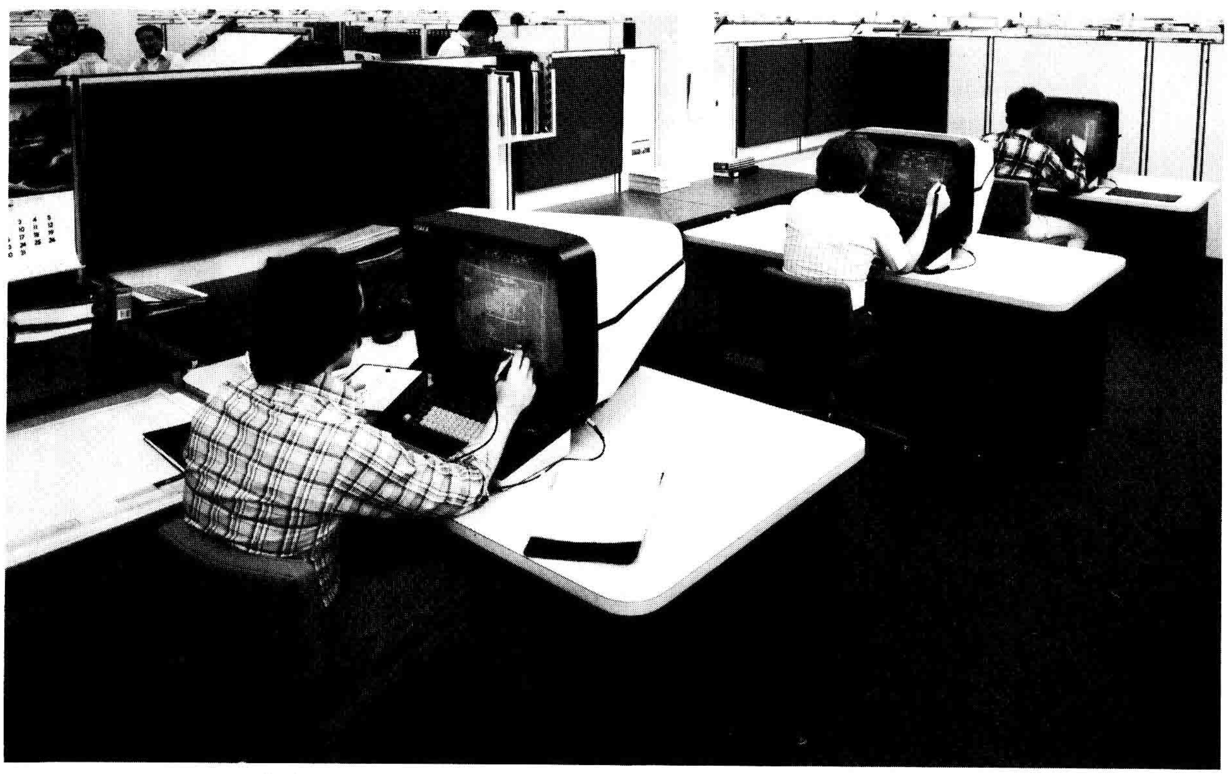

Fig. 1.2 Computer-Aided Design and Drafting Section of an Engineering Department. *Courtesy of Jervis B. Webb Co.*

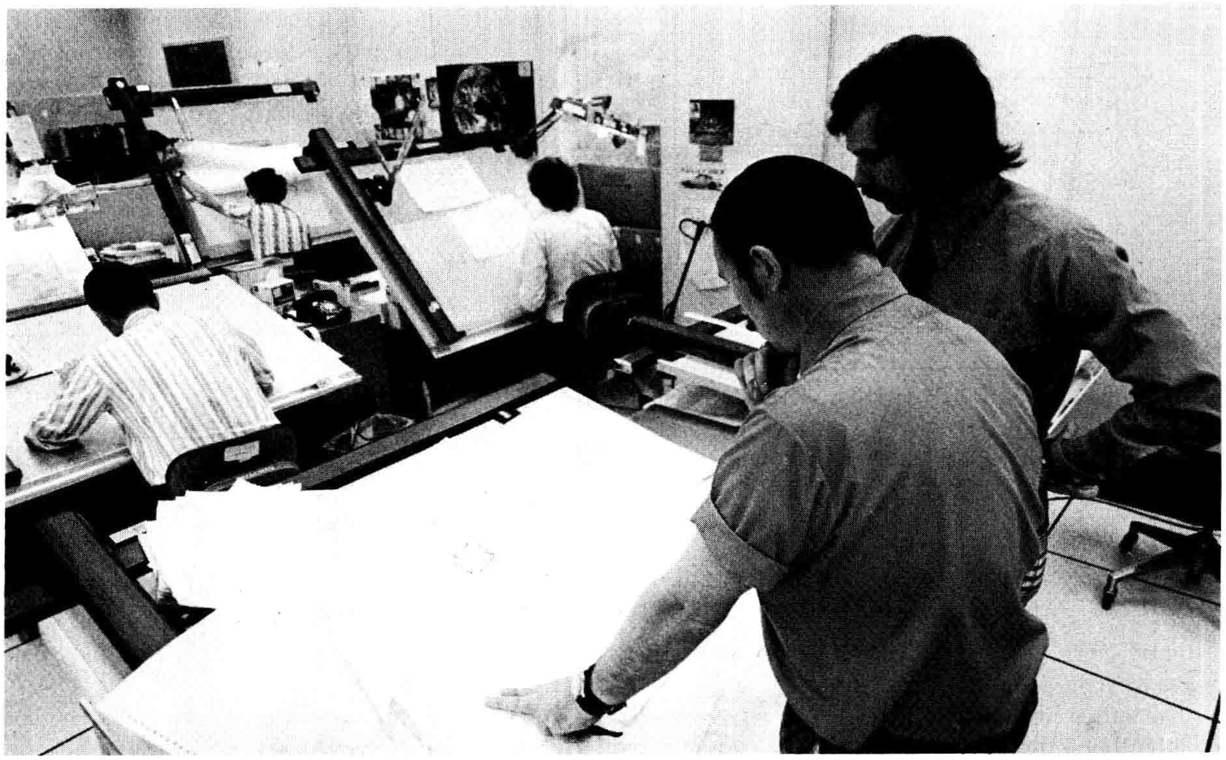

Fig. 1.3 Engineering Drafting Department. *Courtesy of AT&T Bell Laboratories.*

uses a computer for drawing and design work must be proficient in drafting, designing, and conceptualizing.

Typical engineering and design departments are shown in Figs. 1.2 and 1.3. Many of the staff have considerable training and experience; others are recent graduates who are gaining experience. There is much to be learned on the job, and it is necessary for the inexperienced person to start at a low level and advance to more responsibility as experience is gained.

1.2 The Graphic Language

Although people around the world speak different languages, a universal graphic language has existed since the earliest of times. The earliest forms of writing were through picture forms, such as the Egyptian hieroglyphics, Fig. 1.4. Later these forms were simplified and became the abstract symbols used in our writing today.

A drawing is a *graphic representation* of a real thing, an idea, or a proposed design for later manufacture or construction. Drawings may take many forms, but the graphic method of representation is a basic natural form of communication of ideas that is universal and timeless in character.

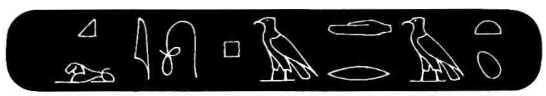

Fig. 1.4 Egyptian Hieroglyphics.

1.3 Two Types of Drawings

Graphic representation has been developed along two distinct lines, according to the purpose: (1) artistic and (2) technical.

From the beginning of time, artists have used drawings to express aesthetic, philosophic, or other abstract ideas. People learned by listening to their elders and by looking at sculptures, pictures, or drawings in public places. Everybody could understand pictures, and they were a principal source of information. The artist was not just an artist in the

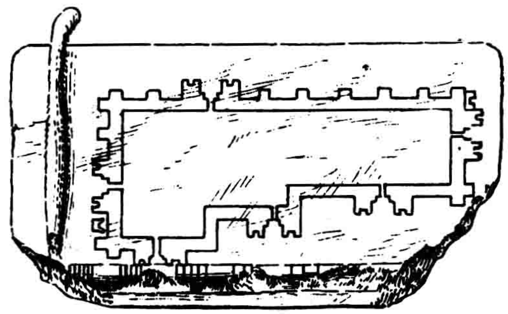

Fig. 1.5 Plan of a Fortress. This stone tablet is part of a statue now in the Louvre, in Paris, and is classified in the earliest period of Chaldean art, about 4000 B.C. *From Transactions ASCE, May 1891*

aesthetic sense, but also a teacher or philosopher, a means of expression and communication.

The other line along which drawing has developed has been the technical. From the beginning of recorded history, people have used drawings to represent the design of objects to be built or constructed. Of these earliest drawings no trace remains, but we definitely know that drawings were used, for people could not have designed and built as they did without using fairly accurate drawings.

1.4 Earliest Technical Drawings

Perhaps the earliest known technical drawing in existence is the plan view for a design of a fortress drawn by the Chaldean engineer Gudea and engraved upon a stone tablet, Fig. 1.5. It is remarkable how similar this plan is to those made by modern architects, although "drawn" thousands of years before paper was invented.

In museums we can see actual specimens of early drawing instruments. Compasses were made of bronze and were about the same size as those in current use. As shown in Fig. 1.6, the old compass resembled the dividers of today. Pens were cut from reeds.

The theory of projections of objects upon imaginary plans of projection (to obtain *views*, Chapter 7) apparently was not developed until the early part of the fifteenth century—by the Italian architects Alberti, Brunelleschi, and others. It is well known that Leonardo da Vinci used drawings to record and transmit to others his ideas and designs for mechanical constructions, and many of these drawings are still in existence, Fig. 1.7. It is not clear whether Leonardo ever made mechanical drawings showing orthographic views as we now know them, but it is probable that he did. Leonardo's treatise on painting, published in 1651, is regarded as the first book ever printed on the theory of projection drawing; however, its subject was perspective and not orthographic projection.

The scriber-type compass gave way to the compass with a graphite lead shortly after graphite pencils were developed. At Mount Vernon we can see the drawing instruments used by the great civil engineer George Washington, bearing the date 1749. This set, Fig. 1.8, is very similar to the conventional drawing instruments used today, consisting of a divider and a compass with pencil and pen attachments plus a ruling pen with parallel blades similar to the modern pens.

1.5 Early Descriptive Geometry

The beginnings of descriptive geometry are associated with the problems encountered in designs for building construction and military fortifications of France in the eighteenth century. Gaspard Monge (1746–1818) is considered the "inventor" of descrip-

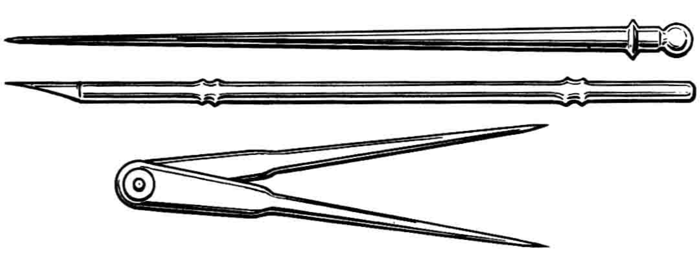

Fig. 1.6 Roman Stylus, Pen, and Compass. *From Historical Note on Drawing Instruments, published by V & E Manufacturing Co.*

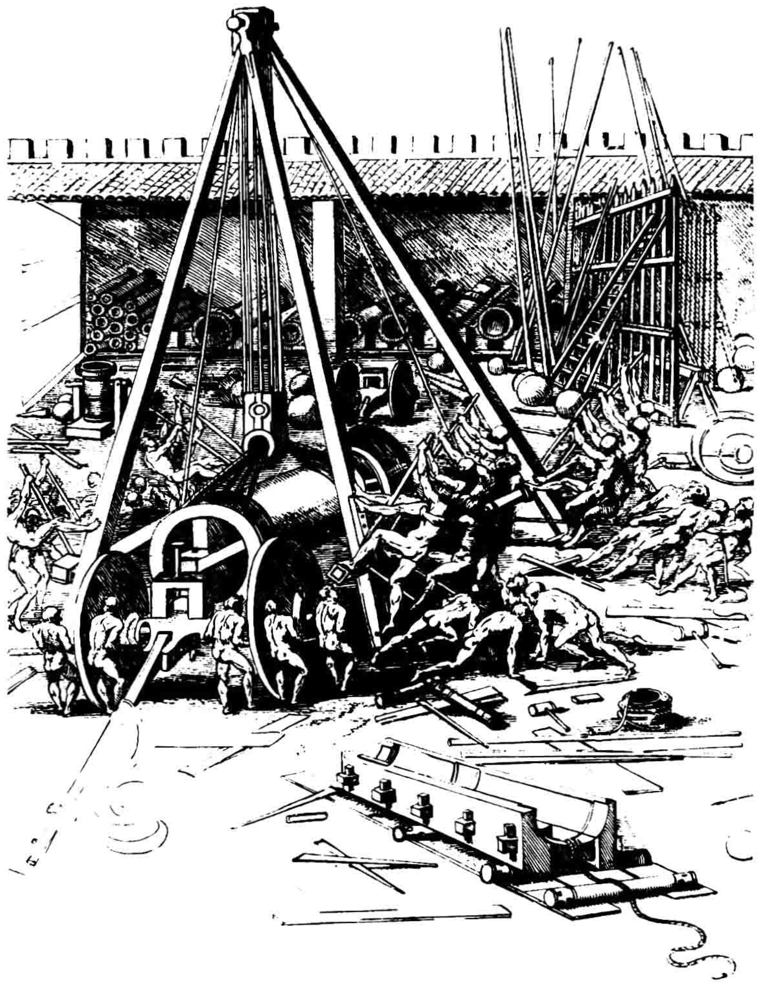

Fig. 1.7 An Arsenal, by Leonardo da Vinci. *The Bettmann Archive*

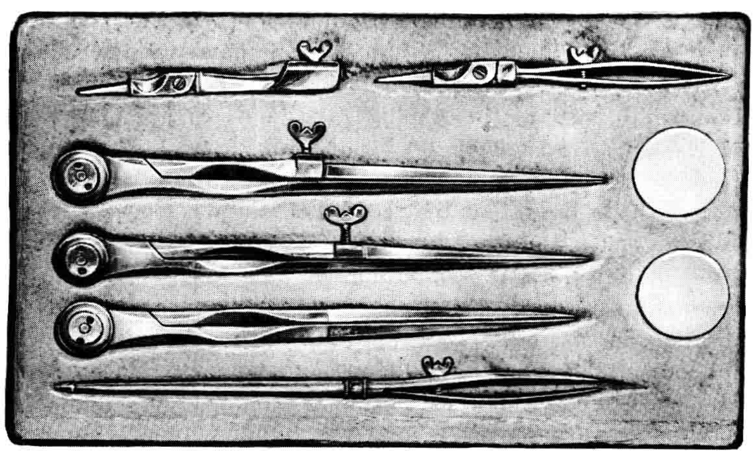

Fig. 1.8 George Washington's Drawing Instruments. *From Historical Note on Drawing Instruments, published by V & E Manufacturing Co.*

tive geometry, although his efforts were preceded by publications on stereotomy, architecture, and perspective in which many of the principles were used. It was while he was a professor at the Polytechnic School in France near the close of the eighteenth century that Monge developed the principles of projection that are now the basis of our technical drawing. These principles of descriptive geometry were soon recognized to be of such military importance that Monge was compelled to keep his principles secret until 1795, following which they became an important part of technical education in France and Germany and later in the United States. His book, *La Géométrie Descriptive*, is still regarded as the first text to expound the basic principles of projection drawing.

Monge's principles were brought to the United States from France in 1816 by Claude Crozet, an alumnus of the Polytechnic School and a professor at the United States Military Academy at West Point. He published the first text on the subject of descriptive geometry in the English language in 1821. In the years immediately following, these principles became a regular part of early engineering curricula at Rensselaer Polytechnic Institute, Harvard University, Yale University, and others. During the same period, the idea of manufacturing interchangeable parts in the early arms industries was being developed, and the principles of projection drawing were applied to these problems.

1.6 Modern Technical Drawing

Perhaps the first text on technical drawing in this country was *Geometrical Drawing*, published in 1849 by William Minifie, a high school teacher in Baltimore. In 1850 the Alteneder family organized the first drawing instrument manufacturing company in the United States (Theo. Alteneder & Sons, Philadelphia). In 1876 the blueprint process was introduced at the Philadelphia Centennial Exposition. Up to this time the graphic language was more or less an art, characterized by fine-line drawings made to resemble copper-plate engraving, by the use of shade lines, and by the use of water color "washes." These techniques became unnecessary after the introduction of blueprinting, and drawings gradually were made less ornate to obtain the best results from this method of reproduction. This was the beginning of modern technical drawing. The graphic language now became a relatively exact method of representation, and the building of a working model as a regular preliminary to construction became unnecessary.

Up to about 1900, drawings everywhere were generally made in what is called first-angle projection, §7.38, in which the top view was placed under the front view, the left-side view was placed at the right of the front view, and so on. At this time in the United States, after a considerable period of argument pro and con, practice gradually settled on the present *third-angle projection* in which the views are situated in what we regard as their more logical or natural positions. Today, third-angle projection is standard in the United States, but first-angle projection is still used throughout much of the world.

During the early part of the twentieth century, many books were published in which the graphic language was analyzed and explained in connection with its rapidly changing engineering design and industrial applications. Many of these writers were not satisfied with the term "mechanical drawing" because they recognized that technical drawing was really a graphic language. Anthony's *An Introduction to the Graphic Language*, French's *Engineering Drawing*, and Giesecke et al., *Technical Drawing* were all written with this point of view.

1.7 Drafting Standards

In all of the previously mentioned books there has been a definite tendency to standardize the characters of the graphic language, to eliminate its provincialisms and dialects, and to give industry, engineering, and science a uniform, effective graphic language. Of prime importance in this movement in the United States has been the work of the American National Standards Institute (ANSI) with the American Society for Engineering Education, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. As sponsors they have prepared the *American National Standard Drafting Manual—Y14*, which is comprised of several separate sections that were published as approved standards as they were completed over a period of years. See Appendix 1.

These sections outline the most important idioms and usages in a form that is acceptable to the majority and are considered the most authoritative guide to uniform drafting practices in this country today. The Y14 Standard gives the characters of the graphic language, and it remains for the textbooks to explain the grammar and the penmanship.

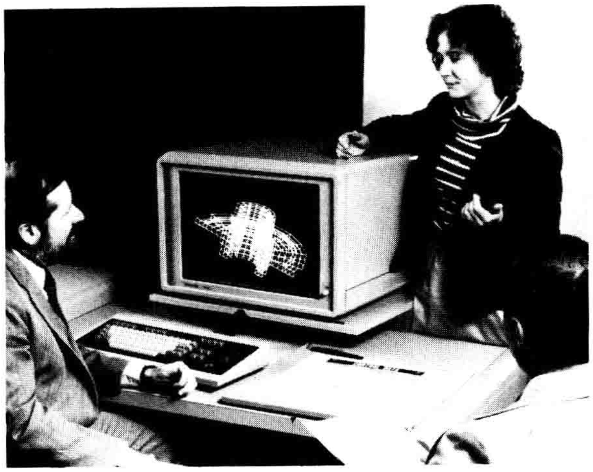

Fig. 1.9 CAD Workstation. *Courtesy of Control Data Corporation*

1.8 Definitions

After this brief survey of the historical development of the graphic language, and before we begin a serious study of theory and applications, a few terms need to be defined.

Descriptive geometry. The grammar of the graphic language; it is the three-dimensional geometry forming the background for the practical applications of the language and through which many of its problems may be solved graphically.

Instrumental or ***mechanical drawing.*** Properly applies only to a drawing made with drawing instruments. The use of "mechanical drawing" to denote all industrial drawings is unfortunate not only because such drawings are not always mechanically drawn but also because that usage tends to belittle the broad scope of the graphic language by naming it superficially for its principal mode of execution.

Computer graphics. The application of conventional computer techniques with the aid of one of many graphic data processing systems available to the analysis, modification, and the finalizing of a graphical solution. The use of computers to produce technical drawings is called computer-aided design or computer-aided drafting (CAD) and also computer-aided design and drafting (CADD). A typical CAD workstation is shown in Fig. 1.9.

Engineering drawing and ***engineering drafting.*** Broad terms widely used to denote the graphic language. However, since the language is used not only by engineers but also by a much larger group of people in diverse fields who are concerned with technical work or with industrial production, these terms are still not broad enough.

Technical drawing. A broad term that adequately suggests the scope of the graphic language. It is rightly applied to any drawing used to express technical ideas. This term has been used by various writers since Monge's time at least and is still widely used, mostly in Europe.

Engineering graphics or ***engineering design graphics.*** Generally applied to drawings for technical use and has come to mean that part of technical drawing that is concerned with the graphical representation of designs and specifications for physical objects and data relationships as used in engineering and science.

Technical sketching. The freehand expression of the graphic language, whereas ***mechanical drawing*** is the instrumental expression of it. Technical sketching is a most valuable tool for the engineer and others engaged in technical work because through it most technical ideas can be expressed quickly and effectively without the use of special equipment.

Blueprint reading. The term applied to the "reading" of the language from drawings made by others. Actually, the blueprint process is only one of many forms by which drawings are reproduced today, but the term "blueprint reading" has been accepted through usage to mean the interpretation of all ideas expressed on technical drawings, whether or not the drawings are blueprints.

1.9 What Engineering, Science, and Technology Students Should Know

From the dawn of history the development of technical knowledge has been accompanied, and to a large extent made possible, by a corresponding graphic language. Today the intimate connection between engineering and science and the universal graphic language is more vital than ever before, and the engineer, scientist, or technician who is ignorant of or deficient in the principal mode of expression in his or her technical field is professionally illiterate. Thus, training in the application of technical drawing is required in virtually every engineering school in the world.

The old days of fine-line drawings and of shading and "washes" are gone forever; artistic talent is no longer a prerequisite to learning the fundamentals of the graphic language. Instead, today's student of graphics needs precisely the aptitudes, abilities, and computer skills that will be needed in the science and engineering courses that are studied concurrently and later.

The well-trained engineer, scientist, or technician must be able to make and read correct graphical representations of engineering structures, designs, and data relationships. This means that the individual must understand the fundamental principles, or the *grammar*, of the language and be able to execute the work with reasonable skill, which is *penmanship*.

Graphics students often try to excuse themselves for inferior results (usually caused by lack of application) by arguing that after graduation they do not expect to do any drafting at all; they expect to have others make any needed drawings under their direction. Such a student presumptuously expects, immediately after graduation, to be the accomplished engineer concerned with bigger things and forgets that a first assignment may involve working with drawings and possibly revising drawings, either on the board or with computerized aids, under the direction of an experienced engineer. Entering the engineering profession via graphics provides an excellent opportunity to learn about the product, the company operations, and the supervision of others.

Even a young engineer who has not been successful in developing a skillful penmanship in the graphic language will have use for its grammar, since the ability to *read* a drawing will be of utmost importance. See Chapter 16.

Furthermore, the engineering student is apt to overlook the fact that, in practically all the subsequent courses taken in college, technical drawings will be encountered in most textbooks. The student is often called upon by instructors to supplement calculations with mechanical drawings or sketches. Thus, a mastery of a course in technical drawing utilizing both traditional methods and computer systems (CAD) will aid materially not only in professional practice after graduation but more immediately in other technical courses, and it will have a definite bearing on scholastic progress.

Besides the direct values to be obtained from a serious study of the graphic language, there are a number of very important training values that, though they may be considered by-products, are as essential as the language itself. Many students learn the meaning of neatness, speed, and accuracy for the first time in a drawing course. These are basic habits that every successful engineer, scientist, and technician must have or acquire.

All authorities agree that the ability to *think in three dimensions* is one of the most important requisites of the successful scientist and engineer. This training to visualize objects in space, to use the constructive imagination, is one of the principal values to be obtained from a study of the graphic language. The ability to *visualize* is possessed to an outstanding degree by persons of extraordinary creative ability. It is difficult to think of Edison, De Forest, or Einstein as being deficient in constructive imagination.

With the increase in technological development and the consequent crowding of drawing courses by the other engineering and science courses in our colleges, it is doubly necessary for students to make the most of the limited time devoted to the language of the profession, to the end that they will not be professionally illiterate, but will possess an ability to express ideas quickly and accurately through the correct use of the graphic language.

1.10 Projections

Behind every drawing of an object is a space relationship involving four imaginary things.

1. The *observer's eye*, or the *station point*.
2. The *object*.
3. The *plane* or *planes of projection*.

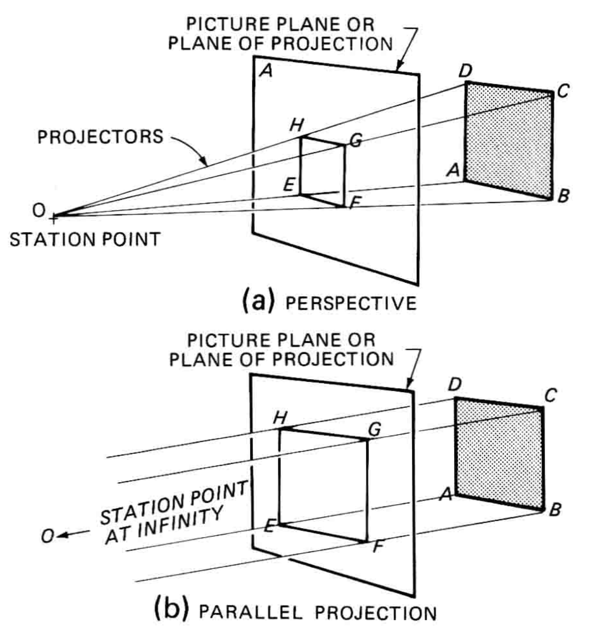

Fig. 1.10 Projections.

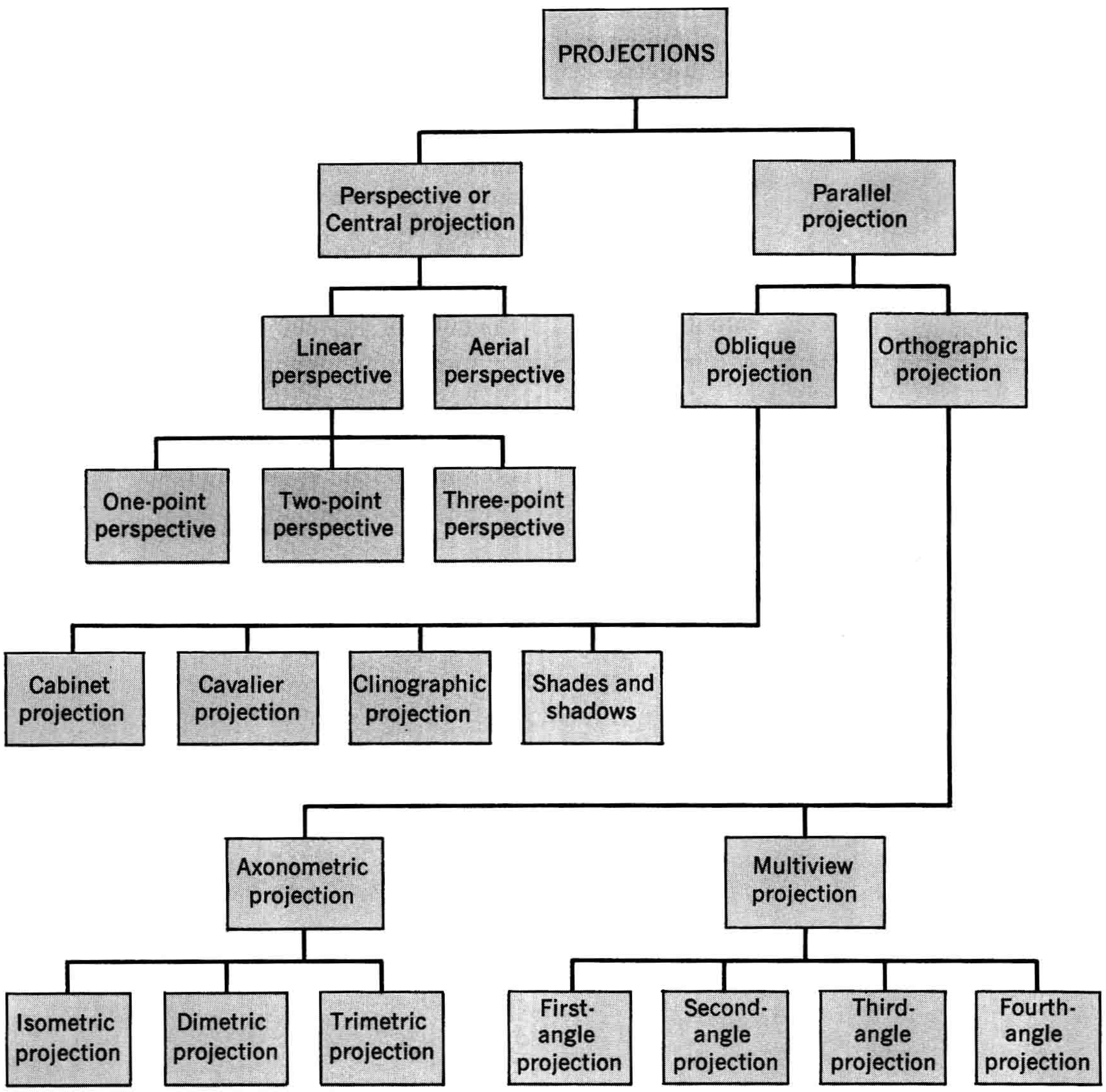

Fig. 1.11 Classification of Projections.

4. The *projectors*, also called visual rays and lines of sight.

For example, in Fig. 1.10 (a) the drawing EFGH is the projection, on the plane of projection A, of the square ABCD as viewed by an observer whose eye is at the point O. The projection or drawing upon the plane is produced by the points where the projectors pierce the plane of projection (piercing points). In this case, where the observer is relatively close to the object and the projectors form a "cone" of projectors, the resulting projection is known as a perspective.

If the observer's eye is imagined as infinitely distant from the object and the plane of projection, the projectors will be parallel, as shown in Fig. 1.10 (b); hence, this type of projection is known as a *parallel* projection. If the projectors, in addition to being parallel to each other, are perpendicular (normal) to the plane of projection, the result is an *orthographic*, or right-angle, projection. If they are parallel to each other but oblique to the plane of projection, the result is an *oblique* projection.

These two main types of projection—perspective and central or parallel projection—are further broken down into many subtypes, as shown in Fig. 1.11,

Table 1.1 *Classification by Projectors*

Classes of Projection	Distance from Observer to Plane of Projection	Direction of Projectors
Perspective	Finite	Radiating from station point
Parallel	Infinite	Parallel to each other
Oblique	Infinite	Parallel to each other and oblique to plane of projection
Orthographic	Infinite	Perpendicular to plane of projection
Axonometric	Infinite	Perpendicular to plane of projection
Multiview	Infinite	Perpendicular to planes of projection

and will be treated at length in the various chapters that follow.

A classification of the main types of projection according to their projectors is shown in Table 1.1.