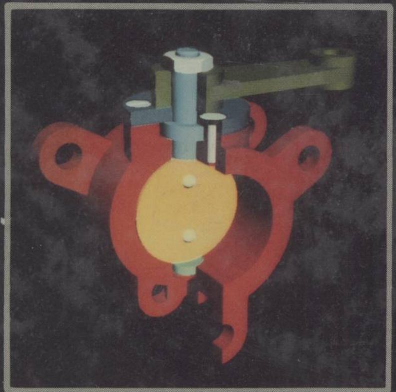
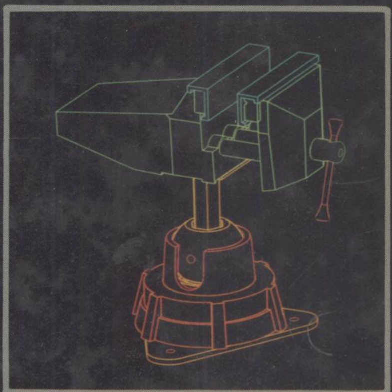
2nd EDITION

GRAPHICS FOR ENGINEERS

VISUALIZATION, COMMUNICATION, AND DESIGN





JERRY S. DOBROVOLNY

DAVID C. O'BRYANT

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GRAPHICS FOR ENGINEERS

VISUALIZATION, COMMUNICATION, AND DESIGN

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PREFACE

Engineers, designers, drafters, and technicians must work together to build the many products and projects, both large and small, that are necessary for our modern life. Teamwork and an intercommunication of ideas are essential in this task.

The language used in engineering drawing, together with supporting graphical systems for computation and representation, must be thoroughly understood by all who carry on the work of engineering. This book has been designed so as to enable the student who plans to enter the field of engineering or production can learn this language and use it proficiently. It contains the latest standards that have been nationally and internationally accepted by the various national standardization bodies. Therefore, it serves as an excellent reference book in engineering offices.

This is the latest of a series of books based on the successful organization and teaching methods of a department that has been in existence for over 80 years. During this time, it has had consecutive overlapping leadership of experienced individuals, all of them graduate engineers. It represents a philosophy of teaching in engineering drawing and graphic sciences that is in harmony with the current trend in engineering education practice. The same sound and valid objectives that guided the preparation of first edition of *Graphics for Engineers* by Hoelscher, Springer, and Dobrovolny have been followed in this edition.

The current edition has been somewhat shortened to bring it more into line with subject matter being taught in college engineering graphics courses. The material in the chapters on dimensioning has been revised to include the use of the metric system. Since almost all schools use some type of problem workbooks in teaching graphics, the problem sets after each chapter have been omitted. The major objectives of the book are as follows:

1. To provide a textbook so clear in its verbal discussion and pictorial illustration that it can be readily understood by the student. To accomplish this, more step-by-step illustrations and explanations have been given.
2. To make a textbook that presents the best in drafting practice but emphasizes the development of the reasoning process in its theoretical discussion rather than manual skill.
3. To stress the fundamentals of descriptive geometry in covering the work in a basic graphics course.
4. To present the material in such a way that it will stimulate creative imagination, develop visual perception in three dimensions, and promote original thinking, useful in engineering design.
5. To eliminate all material that is not essential for engineering students or useful in a reference work on drawing for practicing engineers. Thus, it serves as both a learning and reference material.
6. To adhere rigorously to third-quadrant projection, not only for the three principal views but also for auxiliary views, which is the basis for the unification of drawing practice among the United States, Great Britain, and Canada. Thus, the plane of projection is always between the object and the viewer. Consequently, the reference line, if used, is always between the adjacent views.

7. To facilitate understanding of the material by a strategic use of color. In some chapters color is used not only for distinguishing planes of projection but also for the more functional purpose of aiding the student in differentiating between auxiliary planes, cutting planes, and other surfaces. In the chapter "Auxiliary Views," reference lines between the various views and the projecting lines to them are also drawn in color. This makes the construction for each view stand out clearly.

The chapter "Auxiliary Views" has been expanded to include all of the basic topics in descriptive geometry. This enables a rigorous treatment of the theory of projection in solving spatial visualization problems.

The chapters "Sectional Views," "Fasteners," and "Shop Terms and Processes" have been placed ahead of "Basic Dimensioning," since the information in those chapters is necessary for the shape description on any engineering part before size dimensions can be applied. Although this order seems logical, each chapter is self-contained, and the instructor can change the assignment schedule to suit any objectives.

On the subject of dimensioning, two chapters have been presented. This is the area in which the greatest advancement has been made in recent years. The first chapter, "Basic Dimensioning," covers all of the material needed by students in such fields as civil engineering and architecture and in general engineering practice. The second chapter, "Production Dimensioning," is quite essential for students who will go into mass-production industries, such as the automotive industries, aeronautics, and space vehicles.

In the chapters on axonometric and oblique projections, conventional methods of construction have been placed first. The exact theory of projection has been presented at the end of each chapter for those who wish to give a more rigorous course. Considerable proficiency in making these two types of pictorial drawings can be attained by the conventional methods. Many schools will not have time for more thorough study.

To meet the problem situation we have provided 15 workbooks, with the aid of staff members at the University of Illinois, to cover a variety of courses. These are available from the Stipes Publishing Company, 10 Chester Street, Champaign, Illinois 61820. At present there are

1. Five workbooks for straight drawing courses, designated Series A, B, C, D, and E.
2. Two workbooks for straight descriptive geometry courses, designated Series 1 and 2.
3. Seven workbooks for combination courses, designated Series 12, 13, 15, 16, 31, 32, and 33 (Series 31, 32, and 33 are metric).
4. One workbook for advanced drawing and geometry courses with application to design, designated Series 22.

Full-scale solution files are available to instructors for workbooks, Series A, B, C, D, and E; Series 1 and 2; and Series 12, 13, 15, 16, 22, 31, 32, and 33. Workbooks save a great deal of the student's time since the layout for the solution is printed and the student can forego the labor of making it.

ACKNOWLEDGMENTS

We are indebted to several of our colleagues for valuable assistance in the development of this book. Chapter 20, "Computer Graphics and CAD/CAM," was prepared by Professor Michael H. Pleck. We wish to thank Tadeusz Kaczor for his assistance in preparing illustrations and Mrs. Marilyn Butler for typing the manuscript. We express our appreciation to each of these persons for their contribution to the usefulness of this book. Our thanks go also to Professors H. H. Jordan, R. P. Hoelscher, and C. H. Springer, the originators of a long series of books of which this one is the culmination. We also express our appreciation for the many valuable suggestions and criticisms received from members of the staff of the University of Illinois, both at Urbana and at the Chicago campus. We would also like to thank the following reviewers and questionnaire respondents: Professor David Carlson, Michigan Technological University; Professor Norman Powers, University of Wisconsin; Professor Lowell K. Dirksen, Washburn University; Professor Moustafa R. Mustafa, Old Dominion University; and Dr. Michael Wozny, Rensselaer Polytechnic University. To these individuals and many others at other schools we express our gratitude. Many industrial concerns have contributed drawings for illustration purposes, for which credit is given in the appropriate places.

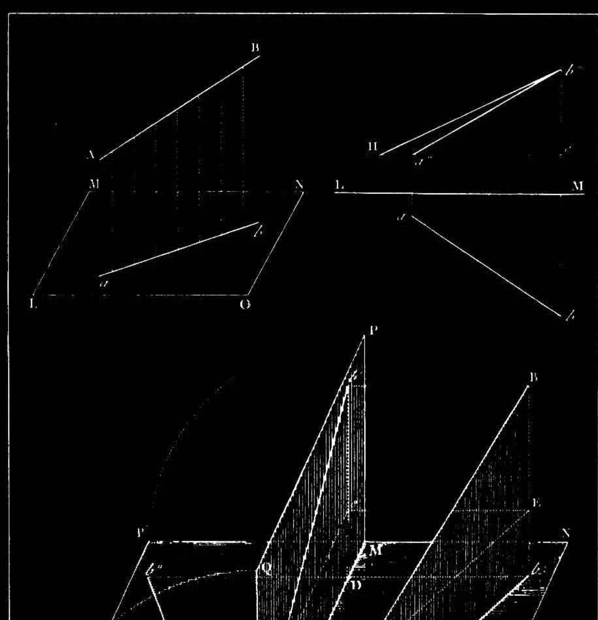
Urbana, Illinois
January 1984

Jerry S. Dobrovolny
David C. O'Bryant

CONTENTS

CHAPTER 1

AN INTRODUCTION TO ENGINEERING GRAPHICS



CHAPTER 1

1.1 ORIGIN OF PROJECTION DRAWING

The representation of three-dimensional objects on two-dimensional surfaces by means of geometric drawings, such as plans and elevations, has involved a gradual change. Through the centuries drawings developed from crude pictorial of prehistoric man, such as that in Fig. 1.1, through a period of highly artistic drawings to the present well-developed types of industrial drawing. In Mesopotamia, maps were made on clay tablets such as that shown in Fig. 1.2. In the early Middle Ages, most of the construction work was concerned with buildings. During the Roman period, drawings of building plans were made before construction was undertaken. Frequently construction problems were worked out by the mason or builder from general specifications as the work progressed. However, very few examples of these drawings have been preserved.

One early Egyptian drawing made on papyrus that shows two views of a shrine without dimensions has been found. Pictorial drawings seemed to have been quite common during the Middle Ages. See Fig. 1.3.

Two elevations are in existence of the west front of the Cathedral of Orvieto, supposed to have been made by Lorenzo del Maitano of Siena soon after 1310. These are not true front views, since each is in slight perspective. By the end of the fifteenth century, there were draftsmen who could make true elevations. One of the earliest examples of the use of plan and elevation is

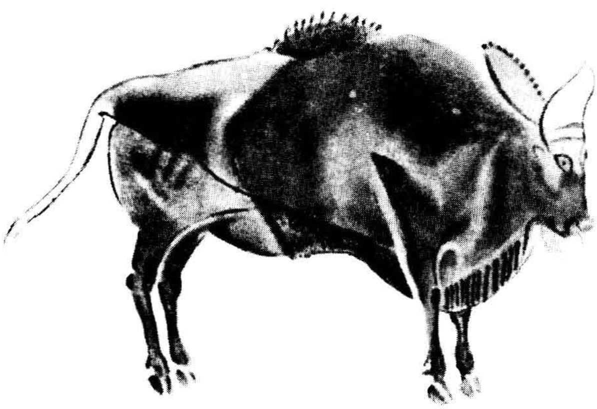


FIG. 1.1. Late Palaeolithic representation of a bison (from Singer, Holmyard, and Hall, *A History of Technology,* Vol. 1, Oxford University Press, London/New York, 1954).

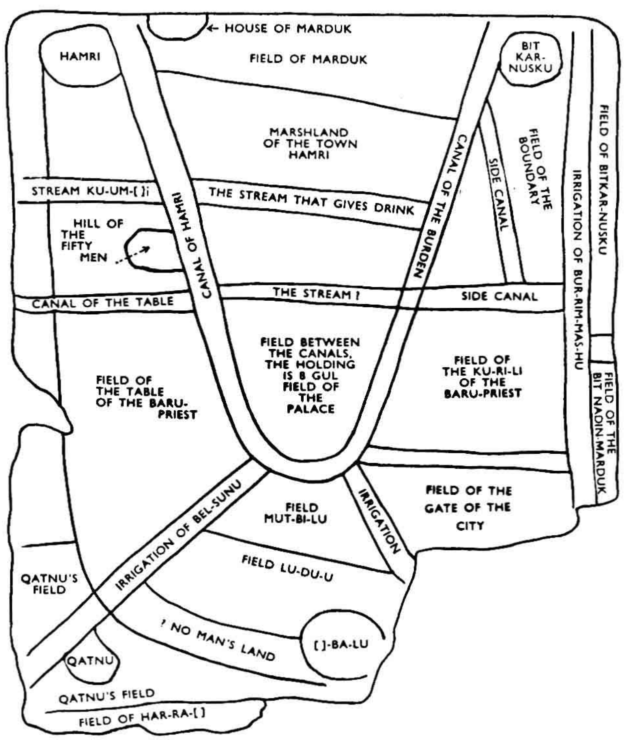


FIG. 1.2. Map of fields and canals near Nippur (from Singer, Holmyard, and Hall, *A History of Technology,* Vol. 1, Oxford University Press, London/New York, 1954).

included in an album of drawings in the Vatican Library, drawn by Giuliano da Sangallo. The date on the title page is 1465, but the book was not actually completed until 1490.

The drawings of early architects and engineers contained the basic idea of the theory that was to be developed into our modern forms of geometric projection. The system of right-angle projection on planes set up perpendicular to each other was first completely worked out by Gaspard Monge in the eighteenth century and was used to solve geometric problems. See Fig. 1.4. The work of Monge is the basis of descriptive geometry, which is the fundamental theory underlying all modern industrial drawing.

1.2 FUNCTION OR PURPOSE OF ENGINEERING DRAWING

In order that the student may understand the reason for studying engineering graphics, this chapter gives a brief overall view of the scope of the subject and its place in engineering practice.

The ideas for all the works of man are conceived in some person's mind. These ideas may require extensive computations. But they do not end there. Inevitably what is sometimes referred to as *hardware* must be produced. This hardware can rarely be produced without drawings. Even though computers are being designed to make drawings, some kind of preliminary drawing or layout is necessary to program the computer.

Some of the more common uses of drawings are stated in the following paragraphs.

1.2.1 Design of Machines. In designing machines and other structures, the engineer or technician must first form a clear mental picture of the thing to be made. He/she must then convey this idea to others. This cannot be done by the written word alone, but it can be done by drawings combined with verbal instructions or specifications.

1.2.2 Fabrication Details. Most machines require a number of separate parts. These parts

FIG. 1.3. First stages in the excavation of a mine (from Agricola, *De Re Metallica*, 1556).

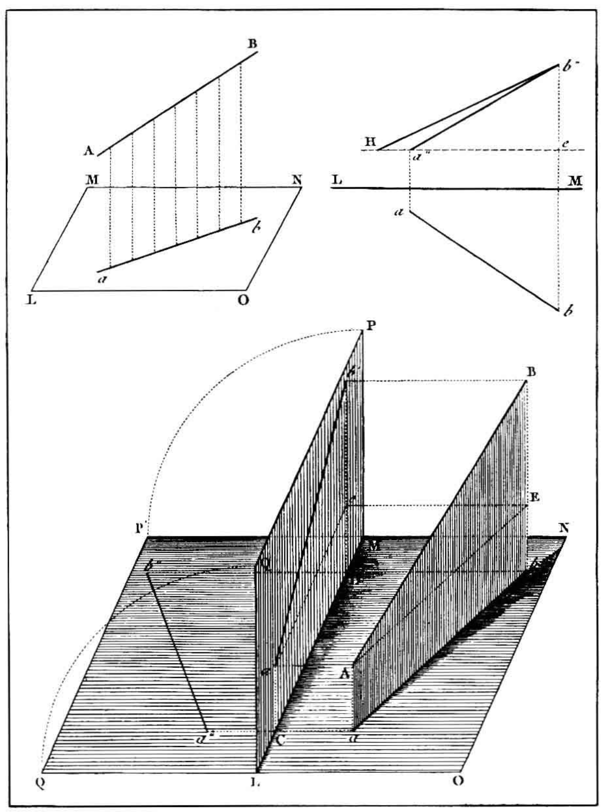


FIG. 1.4. Typical illustration from *Descriptive Geometrie* by Gaspard Monge.

are then assembled, either permanently or in a definite position, as moving parts. In either event, the parts must fit together exactly. This requires that the size and location of parts be held to very close tolerances. See Chapter 12.

1.2.3 Design of Buildings. The basic drawings for buildings consist of floor plans for each story, elevations for each side, and numerous sectional views and large-scale detail drawings of various parts. Even a relatively simple home will require a considerable amount of such drawings.

1.2.4 Detail Drawings. Larger structures will require separate sets of steel or reinforced concrete framing plans, plumbing plans, heating and ventilating plans, as well as drawings, for elevators, electrical wiring, and any special equipment that may be involved.

1.2.5 Cost Estimates. Before any contracts for construction or manufacturing can be made, cost estimates must be prepared. Such estimates are made from drawings and specifications. The drawing must delineate the exact size and shape of all parts. The kind and quality of materials to be used must be clearly stated.

1.2.6 Highway and Railroad Construction Plans. In order to construct highways or railroads, maps must be made showing the exact location of the center line of the road, the "right of way" lines, and the boundary lines of adjacent property.

In addition to the plan, a profile showing the elevation of the ground along the center line must be made. This drawing also shows the grade line for the finished road. At frequent intervals along the road, cross-sectional views must be made showing the "cut" or "fill" required. See Chapter 19.

Other details such as drainage, culverts, bridges, and viaducts must also be supplied before any contracts for construction can be entered into.

1.2.7 Department of Defense. Drawings for military equipment must be made to the specification and standards required by the Department of Defense. Thousands of such drawings are made annually. Thus, a battleship or submarine will require 40,000 to 50,000 drawings.

1.2.8 Aerospace Applications. A very large amount of complex mathematics is necessary to place a satellite in orbit. Many sciences are also involved, but nothing happens until "hardware" is designed and produced. Satellites, missiles, and space platforms require thousands of drawings. Some of these parts involve close and very accurate tolerances in order to function properly.

1.2.9 Sales Presentations. In many projects, companies will submit *proposals* as a part of the sales promotion. These are very frequently printed booklets describing in detail what the company proposes to furnish or supply. The proposals are illustrated with many kinds of drawings including those of a pictorial character such as isometric, oblique, or perspective.

1.3 MEANING OF TERMS

In the area of graphics, a number of terms have been used, such as *mechanical drawing, engineering drawing, technical drawing, engineering graphics,* and *graphic science.* Many of these terms are used loosely to mean the same thing. Some are misnomers. To clarify the meanings of terms as used in this book, the following paragraphs explain the terms and the contents of the field of drawing as used in industry and science.

1.3.1 Instrumental and Freehand Drawing. The older term *mechanical drawing* is really a misnomer since it seems to imply the drawing of mechanical things. It really means drawings made with instruments or instrumental drawings, as contrasted with freehand drawing, which is done without the aid of instruments. Hence, with the advent of computer graphics we have three comprehensive types of drawings: instrumental, freehand, and computer generated. Drawings of any kind may be made by either of the three methods, although it should be quite clear that where very accurate line work is required, instruments or a computer must be used.

1.3.2 Engineering Graphics. This is the most inclusive term now applied to drawings of all varieties made with pen or pencil, except those that may be classified as pure art. It ranges from the simple three-view drawing of a machine part to the most complex graphical layout of nomographs or graphical calculus computations.

This extensive group of drawings divides itself quite naturally into two major groups: *projection drawings,* or drawings based on a geometrical theory of projection, and *nonprojection drawings,* having a fundamental basis of algebraic mathematics. An outline of these two major categories is given in the paragraphs that follow.

1.4 PROJECTION DRAWING

This type includes drawings based on a fundamental geometric theory of projection. It includes the major portion of drawings made in industry. Some kinds of projection drawing, particularly in the pictorial area, may be made by "rule of thumb," but the underlying theoretical construction on which all rules are based is orthographic projection. *This term simply means that the projecting lines from the object to the plane of projection are at right angles to that plane.*

1.4.1 Orthographic Multiview Drawing. Drawings of this variety involve one, two, three, or more views based on right-angle projection. The planes on which the views are made are also at right angles to each other. This is the type most commonly used in industry. Fig. 1.5 shows such a three-view drawing. For a complete discussion see Chapter 6.

1.4.2 Pictorial Projections. These drawings show three faces of an object in one view. Since they look like photographs, they are called *pictorial drawings.* Many types of pictorial drawings can be made by rule-of-thumb methods. In all cases these methods are based on orthographic projection theory. The fact that the underlying basis for all forms of projection is orthographic projection should become clear to the student as he/she proceeds through the text.

1.4.2.1 Axonometric Projection. All axonometric projections are purely orthographic. Three types of axonometric drawings are possible, depending on the position of the object relative to the plane of projection.

a. ***Isometric projection*** results when the plane of projection makes equal angles with the three principal faces of the object or when the axes of the object make equal angles with the plane of projection. See Fig. 1.6*a*. For a complete discussion see Chapter 13.

b. ***Dimetric projection*** results when two axes of the object make equal angles with the plane of projection and the third axis has a different value. This type of drawing gives a more pleasing appearance, as shown in Fig. 1.6*b*. See also Chapter 13.

c. ***Trimetric projection*** is produced when the three axes of the object each make different angles with the plane of projection. These should always be made in true projection because rule-of-thumb methods are too slow. See Fig. 1.6*c* and Chapter 13.

1.4.2.2 Oblique Projection. An oblique projection results when parallel projecting lines make an angle other than 90° with the plane of projection. Obviously, many types of oblique projection can be made. A few of these have been given special names.

a. ***Cavalier Projection.*** When the projecting lines make an angle of 45° with the plane of projection, the drawing is called a *Cavalier projection* or drawing. An example is shown in Fig. 1.7*a*. For further details see Chapter 14.

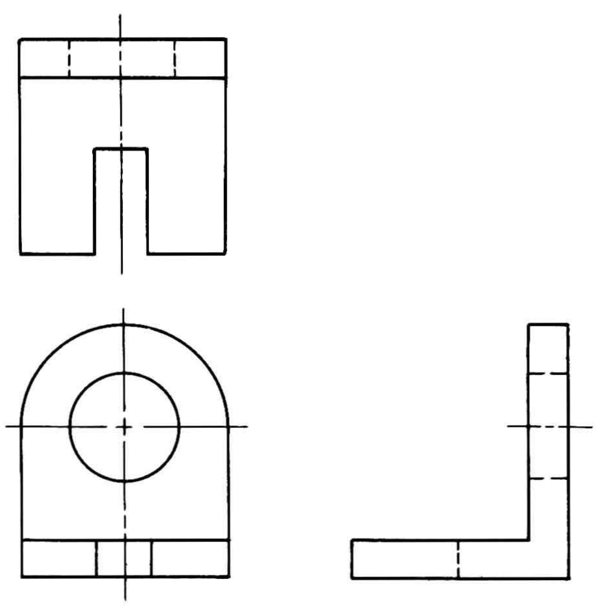


FIG. 1.5. Three-view orthographic projection.

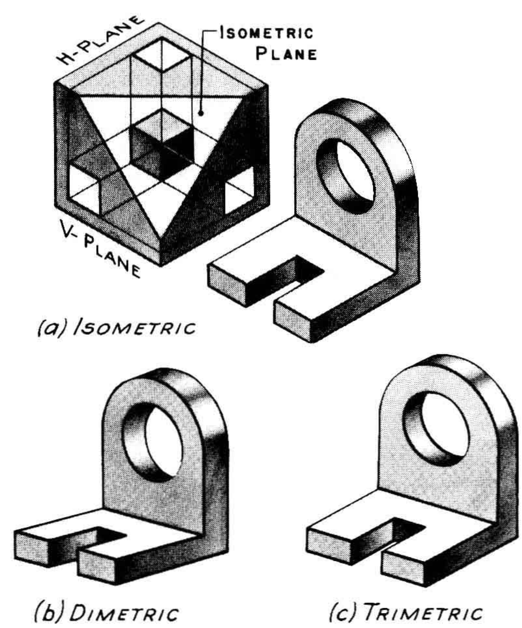


FIG. 1.6. Axonometric projection.

b. ***Cabinet Projection.*** When the angle that the projecting lines make with the plane of projection is such that the scale on the receding axis in the drawing is just one half as long as the other two axis, the result is called a *Cabinet drawing*. See Fig. 1.7*b* and also Chapter 14.

c. ***Clinographic Projection.*** In Cavalier and Cabinet projection, the principal face of the object is made parallel to the plane of projection. For some purposes, however, it may be desirable to turn the object at an angle with the plane of projection. In the fields of minerology and crystallography such a system is used. The angles are shown in Fig. 1.8. For further discussion see Chapter 14.

1.4.2.3 Perspective. When the projecting lines converge to a point the drawing is called a *perspective*. Three kinds of perspectives may be made to serve different purposes. If the principal face of the object is parallel to the plane of projection and there is only one vanishing point, the drawing is called a *parallel* or *one-point perspective*. See Fig. 1.9*a*.

If two faces of the object are at an angle with the plane of projection, while the third face is perpendicular to it, two principal vanishing points occur and the drawing is called an *angular* or *two-point perspective*. See Fig. 1.9*b*.

When all three principal faces of the object are inclined to the plane of projection, the drawing is called an *oblique* or *three-point perspective*. See Fig. 1.9*c*. For further discussion see Chapter 15.

1.4.3 Descriptive Geometry. This is the science of orthographic projection theory underlying all types of projection. It may be noted here that the geometric construction for the kinds of projection mentioned in the preceding paragraphs is based on orthographic projection. The study of descriptive geometry provides a method for solving the problems relation to points, lines, planes, and other surfaces in space. Figure 1.10 illustrates a problem of this kind. See Chapter 7.

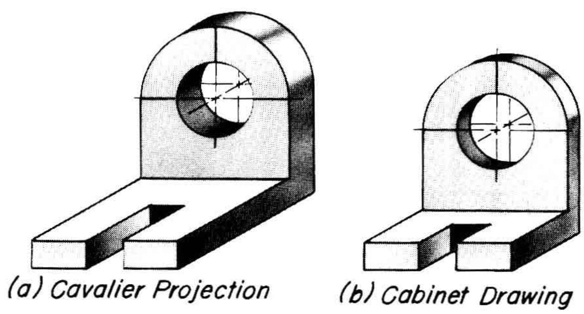


FIG. 1.7. Oblique projection.

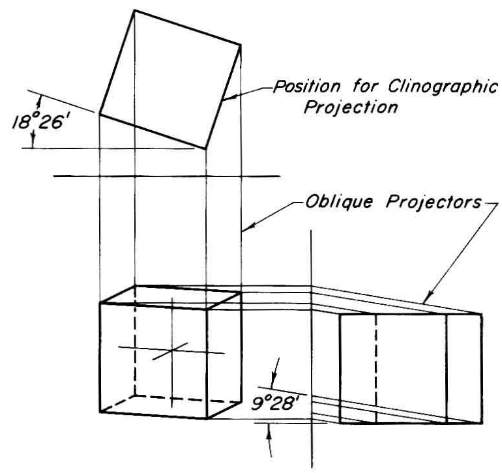


FIG. 1.8. Clinographic projection of a cube.

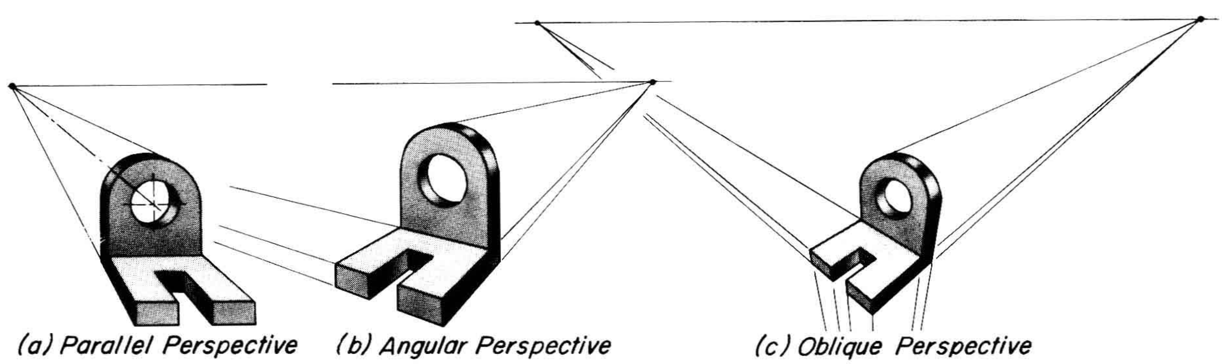


FIG. 1.9. Types of perspective.

1.4.3.1 Space Relationships. Descriptive geometry can be used to solve the relationship between parts of an object, such as the distance from a point to a plane or the true shape of the face of an object. Clearance problems such as the relationship between moving parts or the access to bolts and screws can best be solved by descriptive geometry.

1.4.3.2 Problems of Motion. By means of kinematics, a graphical method closely related to descriptive geometry, the problems of motion can be readily solved on the drawing board. For example, the need to change the rotary motion of a motor to reciprocating linear motion at various speeds and accelerations is a common one.

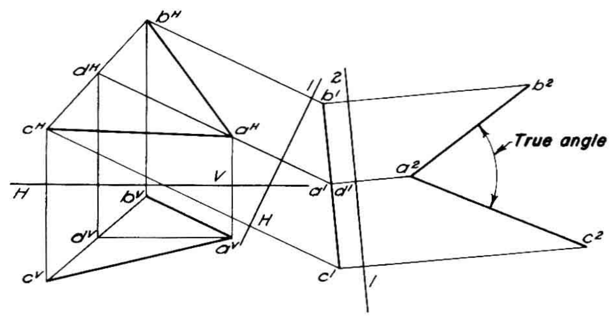


FIG. 1.10. Descriptive geometry.

1.5 SUMMARY

The kinds of projection discussed in this chapter, the relationships of the geometric elements entering into each type of projection, and the classification and name of each special form of projection are summarized in Table 1.1. Each type is discussed in detail in later chapters.

TABLE 1.1 TYPES OF PROJECTIONS

Major Classifications	Subdivision	Number of Planes of Projection	Relation of Lines of Sight to Plane of Projection	Relation of Lines of Sight to Each Other	Location of Point of Sight in Relation to Plane of Projection	Position of Enclosing Cube with Relation to Plane of Projection
Orthographic	Multiple view	As many as necessary	Perpendicular	Parallel	Infinite distance	Faces parallel to planes
	Isometric	One	Perpendicular	Parallel	Infinite distance	Faces equally inclined to plane
	Dimetric	One	Perpendicular	Parallel	Infinite distance	Two faces equally inclined to plane
	Trimetric	One	Perpendicular	Parallel	Infinite distance	Three faces at different angles to plane
Oblique	Cavalier	One	45°	Parallel	Infinite distance	Principal face parallel to plane
	Cabinet	One	63°26′	Parallel	Infinite distance	Principal face parallel to plane
	Clinographic	One	80°32′	Parallel	Infinite distance	Principal face at angle of 18°26′
	General	One	Any angle except those above	Parallel	Infinite distance	Principal face parallel to plane
Perspective	One-point	One	Various angles	Converge at a point	Finite distance	Principal face parallel to plane
	Two-point	One	Various angles	Converge at a point	Finite distance	Two faces inclined and one face perpendicular to plane
	Three-point	One	Various angles	Converge at a point	Finite distance	Three faces inclined to plane

1.6 SHOP AND CONSTRUCTION METHODS

Before one can proceed very far in their profession, the young engineer or technician must become familiar with methods of manufacture in the shop or construction in the field. It is clearly a waste of time and money to make a drawing, however beautiful and accurate, of a part that cannot be made economically in the shop. Since shop courses have almost disappeared from engineering education, the technical students as a part of their training in graphic expression should learn the simpler fundamentals of shop and construction methods as presented in several chapters of this book.

1.7 DIMENSIONING

A shape description of a part shown by one or more projected views is totally inadequate unless dimensions are given showing the exact size of each part and the location of parts in relation to each other. It is this phase of drawing that requires the greatest care and study. Engineers are giving a great deal of attention to the standardization of dimensioning so that there may be no ambiguity. The dimensioning practice given in this book represents the most recently adopted American standards, as set forth in the latest ANSI Y14-5M standard. The letters ANSI mean American National Standards Institute.

1.8 PROFESSIONAL ASPECTS OF DRAWING

The young person who plans to enter a technical industry will frequently find his/her work in one of the specialized fields, such as civil engineering, mechanical engineering, or architecture. In the larger industries and in research institutions the work tends to cross over professional lines. In any event, the fundamental principles of drawings as explained in this book will be the same in all these areas. After training in basic drawing, the student may wish to go further in specialized fields. The difference between these areas of special drawing practices lies in the symbols, conventional practices, standards, and dimensioning methods used in each area.

1.9 STANDARDIZATION OF DRAFTING

In order to establish drafting practice throughout the country on a firm basis so that drawings made anywhere will have clear and unmistakable meaning everywhere, engineers have established standards in drafting. Those standards were set up first in industrial companies, later in engineering societies, and finally in a collective

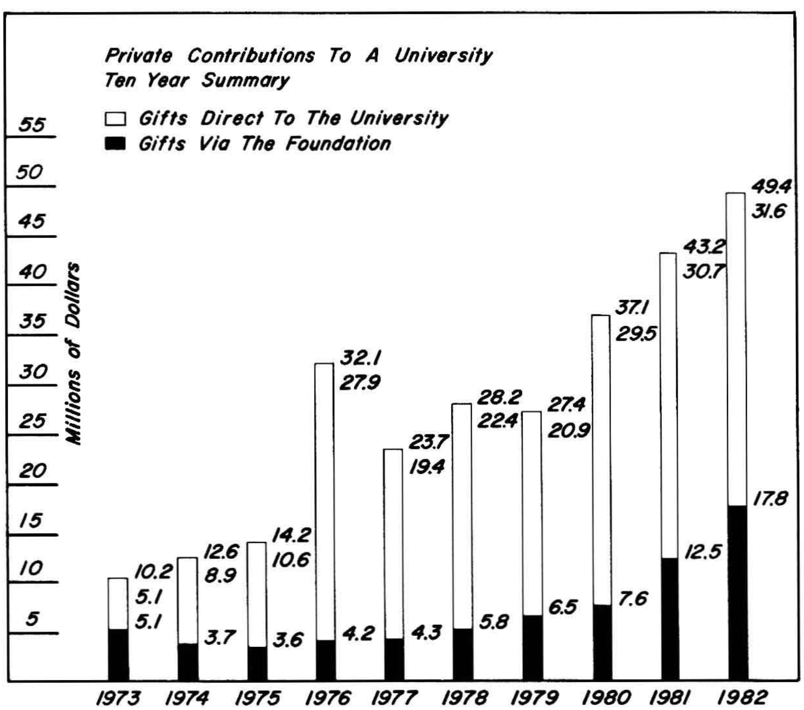


FIG. 1.11. Bar diagram.

effort through the American Standards Association. The drafting procedures shown and recommended in this book reflect the latest revision of these American standards, which are in general agreement with those of Great Britian and Canada.

The student should become familiar with the work of ANSI and that of the professional engineering society with which he is most concerned, for it is only through this standardization that modern mass production is possible.

1.10 NONPROJECTION DRAWING

The following phases of engineering graphics are algebraic in character, rather than geometric, except for certain parts of the first class. The theory of projection is not involved in any of the others.

1.10.1 Charts and Diagrams. These are drawings used to show graphically the relationship between facts. Two variables are usually involved, as shown in Fig. 1.11. A chart involving three variables in pictorial form is shown in Fig. 1.12. Three-dimensional charts of this kind follow the rules for axonometric projection. A three-variable chart may also be made as a plane figure instead of being pictorial in form. In this situation the third variable is shown by a series of curves.

1.10.2 Vector Diagrams. Problems involving the relationship between quantities that have direction as well as size may be solved graphically as shown in Fig. 1.13. This is a stress diagram for a roof truss. The graphical method is rapid, sufficiently accurate for all practical purposes, and self-checking.

1.11 LEGAL ASPECTS

The drawings for buildings, bridges, dams, and other major construction projects have always been the basis for legal contracts in which the builder agrees to erect the structure in accordance with the plans prepared by the engineer for the owner. Such drawings must always be clear and unmistakable in meaning. The drawing, in fact, becomes a legal document. If it is subject to more than one interpretation, litigation may arise causing unnecessary delay and expense.

In the machine industry, modern mass production has brought with it the letting of contracts for the manufacture of machine parts in large quantity. Machine parts, for interchangeable assembly, must be finished very accurately to the dimensions specified. The engineer can seldom go into his/her own shop and tell the supervisor what he/she wants since the part may

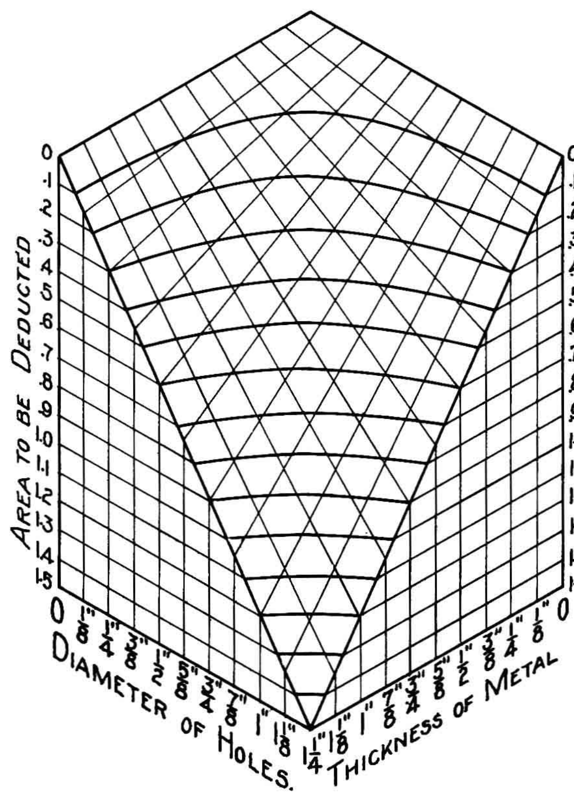


FIG. 1.12. Three-variable chart in pictorial form.

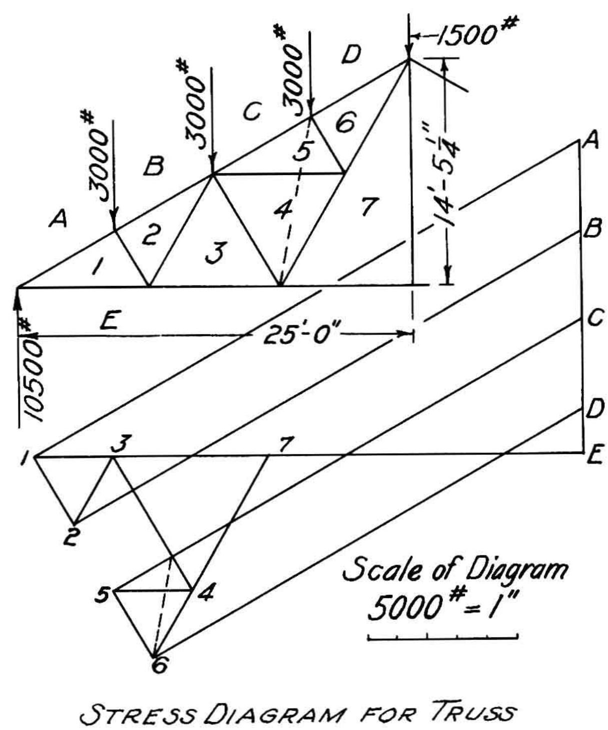


FIG. 1.13. Vector diagram.

be produced in a plant hundreds of miles away. The drawing itself must tell the whole story. It must be made not merely so that it can be understood, but it must be so clear in its meaning that it cannot be misunderstood or misinterpreted by either accident or intention.

This places on the technical person who makes the drawing or directs the work of producing it a heavy responsibility to understand thoroughly both the fundamental theory and the conventional practice of drafting that one studies in engineering graphics courses.

1.12 ENGINEERING DESIGN

Engineering design is the process of creating something new. It may be a new product to be manufactured and sold. It may be a new component that is a part of an old product that will make that product perform more efficiently. Or it may be a new system of some kind, such as the complete water and sanitary system of a large building, that involves new ideas. Essentially, engineering design is a problem-solving process. This may involve mathematical and graphical methods. Ingenuity and imagination are essential in the development of an engineering design. It also involves a familiarity with materials of all kinds, as well as new processes in computation and production.

1.13 ENGINEERING METHOD

The term *engineering method* refers to the manner in which engineers solve the problems presented to them. There is no single standard set of steps that the engineer must follow in solving all problems, but certain broad principles are usually employed in a manner and sequence that are chosen to fit the problem to be solved. A list of these general principles has been outlined in the following paragraphs.

1.13.1 Statement of the Problem. The problem may be clearly stated in the contract that an engineer signs or in the instructions that are given by an employer. If such a statement is not made, the engineer must formulate the problem mentally with a clear vision of what the end product of the work is to be. This may or may not be "spelled out" verbally.

1.13.2 Scientific Principles. After the problem has been clearly stated, the next step is to identify the laws of physical science that might apply to the problem. This is done by a careful analysis, breaking the problem down into its component parts and setting up the necessary mathematical equations that apply to the problem.

1.13.3 Proposed Solution. Most engineering problems have more than one solution. In the solution stage of the engineering method, it is necessary to make some assumptions, determine the limiting conditions of the problem, and make the calculations that will produce the answer. Such items as factors of safety, building code requirements, and the economics of the situation have to be taken into consideration.

1.13.4 Evaluation. When more than one solution is feasible, the various solutions must be compared and a selection made of the solution that best fits all of the conditions of the problem. For larger engineering projects the scope is often too wide to be considered here.

1.13.5 Checking. After a solution has been chosen, the entire problem must be checked from beginning to end:

a. To see that all limiting conditions have been satisfied.
b. To see that any public laws that may apply have been duly met.
c. To see that all computations are correct.
d. To see that all drawings involved are correct and cannot be misinterpreted.
e. To see that the latest development in new materials, especially suited for the project, have been employed.
f. To see that the best methods of production can be used.

1.13.6 Report. Finally, a report of some kind must be presented. This may require written specifications and detailed drawings, or it may be an informal discussion, with drawings submitted, by a younger person to their superior officer in a company.

1.14 ENGINEERING GRAPHICS AND DESIGN

The student should realize that engineering graphics is an integral part of the whole process of engineering design from the point where computation begins to the end result of the project represented by drawings. Many computations can be made graphically and the end product is almost always described by one or more drawings.

For the beginner, drawing is an excellent tool for testing and developing the imagination. Many problems in engineering graphics can have more than one solution. These are sometimes referred to as *open-ended problems*.

1.15 COMPUTER AIDED DESIGN

Today the computer is used widely to solve engineering problems and to generate engineering drawings. The use of the computer in manufacturing is widely accepted. The so-called CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) interface will be more important in the future than it is today.

The form of the information now supplied on drawings will continue to change. One thing that will remain the same will be the need for the engineer to be able to visualize in a three-dimensional way the projects being worked on. Therefore, it becomes even more important for the engineer to understand the fundamental theories of projection as are developed in the chapters that follow in this book.