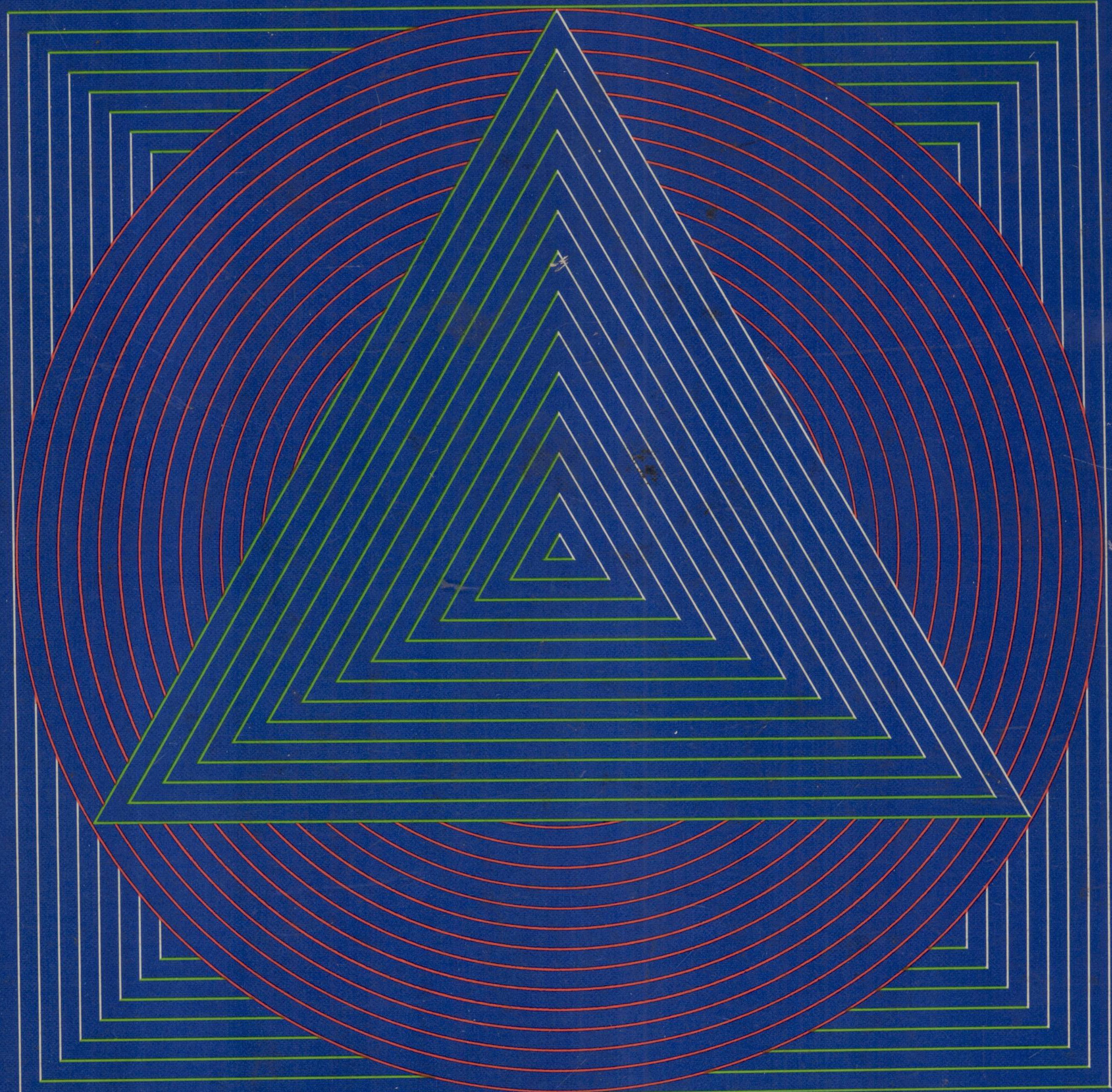
ENGINEERING GRAPHICS

GIESECKE, MITCHELL, SPENCER, HILL, LOVING

SECOND EDITION



engineering graphics

Second Edition

Frederick E. Giesecke

M.E., B.S. in ARCH., C.E., Ph.D., Late Professor Emeritus of Drawing, Texas A&M University

Alva Mitchell

B.C.E., Late Professor Emeritus of Engineering Drawing, Texas A&M University

Henry Cecil Spencer

A.B., B.S. in ARCH., M.S., Late Professor Emeritus of Technical Drawing; Formerly Director of Department, Illinois Institute of Technology

Ivan Leroy Hill

B.S., M.S., Professor of Engineering Graphics, Chairman of Department, Illinois Institute of Technology

Robert Olin Loving

B.S., M.S., Professor of Engineering Graphics Illinois Institute of Technology

Macmillan Publishing Co., Inc.

NEW YORK

Collier Macmillan Publishers

LONDON

Printed in the United States of America

Macmillan Publishing Co., Inc.
866 Third Avenue, New York, New York 10022

Collier-Macmillan Canada, Ltd.

Library of Congress Cataloging in Publication Data

Main entry under title:

Engineering graphics.

1. Engineering graphics. I. Giesecke, Frederick Ernst, (date)
T353.E62 604'.2 73-18769
ISBN 0-02-342720-5

Printing: 5 6 7 8 Year: 7 8 9 0

engineering graphics

Books by the Authors

Basic Problems in Engineering Drawing, Vols. 1 and 2, by J. T. Dygdon, R. O. Loving, and J. E. Halicki (Holt, Rinehart and Winston, 1963)

Basic Technical Drawing, 2nd revised ed., by H. C. Spencer and J. T. Dygdon (Macmillan, 1968)

Descriptive Geometry, 4th ed., by E. G. Paré, R. O. Loving, and I. L. Hill (Macmillan, 1971)

Descriptive Geometry Worksheets, Series A, 3rd ed., by E. G. Paré, R. O. Loving, and I. L. Hill (Macmillan, 1968)

Descriptive Geometry Worksheets, Series B, 3rd ed., by E. G. Paré, R. O. Loving, and I. L. Hill (Macmillan, 1972)

Descriptive Geometry Worksheets, Series C, 2nd ed., by E. G. Paré, R. O. Loving, and I. L. Hill (Macmillan, 1967)

Engineering Graphics, 2nd ed., by F. E. Giesecke, A. Mitchell, H. C. Spencer, I. L. Hill, and R. O. Loving (Macmillan, 1975)

Engineering Graphics Problems, Series I, 2nd ed., by H. C. Spencer, I. L. Hill, and R. O. Loving (Macmillan, 1975)

Technical Drawing, 6th ed., by F. E. Giesecke, A. Mitchell, H. C. Spencer, and I. L. Hill (Macmillan, 1974)

Technical Drawing Problems, Series 1, 4th ed., by F. E. Giesecke, A. Mitchell, H. C. Spencer, and I. L. Hill (Macmillan, 1967)

Technical Drawing Problems, Series 2, 3rd ed., by H. C. Spencer and I. L. Hill (Macmillan, 1974)

Technical Drawing Problems, Series 3, 2nd ed., by H. C. Spencer and I. L. Hill (Macmillan, 1974)

A Group in Design Consultation

Courtesy International Packing Corp.

preface

This revised edition of *Engineering Graphics* is intended as a class text and reference book in both technical drawing and descriptive geometry. It contains a great number of problems covering every phase of the subject, and constitutes a complete teaching unit in itself.

The main purpose of the authors in preparing this new edition is not simply to enlarge the book, although it has been to some extent, but to bring the book completely up to date with the latest trends in engineering education and with the newest developments in industry, especially with the various sections of ANSI Y14 *American National Standard Drafting Manual.* The increased educational emphasis on the design function of the engineer is reflected throughout the text and especially in the chapter on design and working drawings. Much new material has been added to this chapter to help the student to better understand the fundamentals of the design process.

Many of the problems and illustrations have been redrawn or revised to bring them completely up to date. As regards dimensioning, a large number of drawings have been converted to the decimal-inch system now that it had come into extensive use in industry. Many problems in Chapter 14 also present an opportunity for the student to convert dimensions to the metric system.

The book is divided into three parts: "Technical Drawing and Design," "Descriptive Geometry," and "Graphs and Graphical Computation." These comprehensive parts cover the basic principles and applications of *Engineering Graphics.* In addition there is the very complete Appendix taken from the text *Technical Drawing,* Sixth Edition, by Giesecke, Mitchell, Spencer, and Hill, published by Macmillan.

The first eighteen basic chapters on technical drawing and design are the same as the first eighteen chapters in *Technical Drawing,* and the four chapters on graphs, alignment charts, empirical equations, and graphical mathematics are the same as the corresponding chapters in that text.

In addition, this book includes seven chapters on descriptive geometry: "Points, Lines, and Planes"; "Parallelism and Perpendicularity"; "Intersections"; "Developments"; "Line and Plane Tangencies"; "Cartography, Geology, and Spherical Geometry"; and "Graphical Vector Analysis." The content of these chapters is based upon an understanding of the elements of graphic representation and especially upon the fundamentals found in the chapters covering multiview projection, auxiliary views, and revolution. In the chapters on descriptive geometry, the authors have introduced a simplified system of notation consisting of simple arabic numbers. This less time-consuming system will permit the student to devote more time to additional assignments.

This book is intended for use in schools where technical drawing and design, descriptive geometry, and graphs and graphical computation are desired in a single volume, particularly in situations where these subjects are covered in one semester. Nevertheless, the book is so complete in text material and in problems that it can be used equally well in a two-semester arrangement. In this case Part Three, "Graphs and Graphical Computation," may be included in the same semester with technical drawing or with descriptive geometry.

In addition to the problems in the text, a complete workbook has been prepared especially for use with this text: *Engineering Graphics Problems, Series I,* by Spencer, Hill, and Loving, published by Macmillan.

Most of the problems in the book are designed for $8\frac{1}{2}'' \times 11''$ sheets, which are most suitable for filing. All of the workbook sheets are $8\frac{1}{2}'' \times 11''$. However, in the technical drawing portion of the book, particularly in the more advanced chapters, there are many problems which require larger sheets.

An outstanding feature of Part One, "Technical Drawing and Design," is the emphasis on technical sketching. Included is a complete chapter on sketching early in the book. This chapter is unique in integrating the basic concepts of views with freehand technique so that the subject of multiview drawing can be introduced through the medium of sketches.

The chapters on dimensioning and tolerancing are in conformity with the latest ANSI Standard, *Dimensioning and Tolerancing for Engineering Drawings.* The chapters on graphs and graphical computation have been prepared by Mr. E. J. Mysiak, Chief Engineer, Fastener Corporation. The chapter on shop processes was prepared by Professors J. George H. Thompson and John Gilbert McGuire of Texas A&M University. The authors thank Professor H. E. Grant for certain problem material and valuable suggestions, and Mr. David Wong for his assistance with the revision of the many illustrations in Part One.

Every effort has been made to bring this new book completely abreast of the many technological developments that have occured in the past few years. Through the cooperation of leading engineers and manufacturers, this volume includes many commercial drawings of value in developing the subject. The authors wish to express their thanks to these persons and firms, and others too numerous to mention here, who have contributed to the preparation of this book.

The authors invite students, teachers, engineers, and draftsmen to write them concerning any questions that may arise. All comments or suggestions will be appreciated.

Robert Olin Loving
Illinois Institute of Technology
Chicago, Illinois 60616

Ivan Leroy Hill
Illinois Institute of Technology
Chicago, Illinois 60616

PART one

technical drawing and design

contents

1
the graphic language and design

1.1 Evolution of Design. The old saying "necessity is the mother of invention" continues to be true, 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, people will buy it, providing it does not cost too much. Then the questions 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 the officials of a company may elect to go ahead with developing production and marketing plans for the new device 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 conception is usually placed on paper and communicated to others by the way of the *graphic language* in the form of freehand *idea sketches,* Figs. 1.1 and 5.1. These idea sketches are then followed by other sketches, such as *computation sketches,* for developing the idea more fully.

1.2 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 drawings. He must be able to

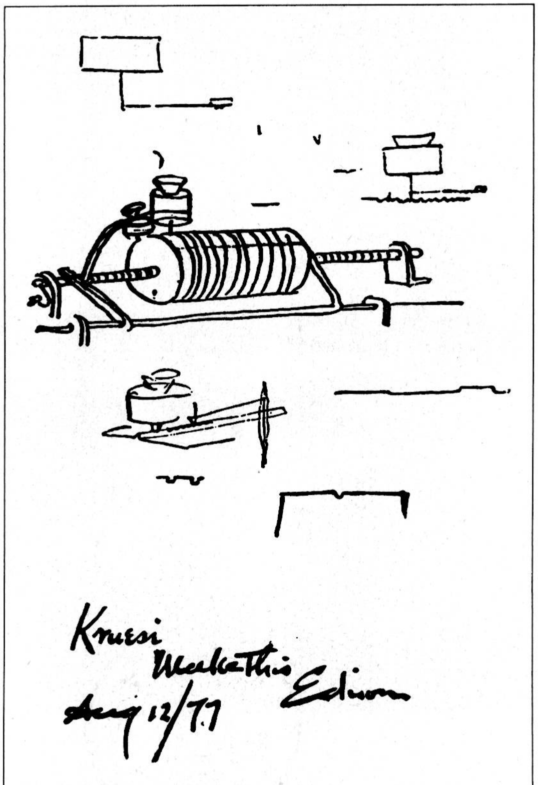


Fig. 1.1 **Edison's Phonograph.***

record and communicate quickly his ideas to his associates and support personnel. Facility in freehand sketching, Chapter 5, or the ability to work with computer-controlled drawing techniques, §14.12, requires extensive training in drawing with instruments and a thorough knowledge of the graphic language.

A typical engineering and design department is shown in Fig. 1.2. Many of the men 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 man to start at a low level and advance to more responsibility as he gains experience. Very much to the point is the following statement by the chief engineer of a large corporation:†

"Many of the engineering students whom we interview have the impression that if they go to work at the drafting board, they will be only draftsmen doing routine work. This impression is completely erroneous, because all of our engineers work at the board at least occasionally. Actually, drawing is only one phase of responsibility which includes site evaluations, engineering calculations, cost estimates, preliminary layouts, engineering specifications, equipment selection, complete drawings (with the help of draftsmen), and follow-up on construction and installation.

"Our policy is to promote from within, and it is our normal practice to hire engineers at the time they finish school, and to give them the opportunity for growth and development by diversified experience. These newly hired engineers without experience are assigned to productive work at a level which their education and experience qualify them to handle successfully. The immediate requirement is for the young engineer to obtain practical engineering experience, and to learn our equipment and processes. In design work, these initial assignments are on engineering details in any one of several fields of engineering study (structural, mechanical, electrical, etc.). Our experience has shown that it is not wise to give a newly graduated engineer without experience a problem in advanced engineering, such as creative design, on the assumption that he can make quick sketches or layouts and then have them detailed by someone else. Rather than start a young engineer at an advanced responsibility level where he may fail or make costly mistakes, we assign him initially to work which requires him to make complete and accurate detail drawings, and his assignments become increasingly complex as he demonstrates the ability to do work of an advanced engineering caliber. If he demonstrates the capacity to assume design responsibility, he is given direction of other engineers with less experience who in turn do detailed engineering for him."

1.3 The Graphic Language.

Many of the troubles of the world are caused by the fact that the various peoples do not understand one another. The infinite number of languages and dialects that contributed to this condition resulted from a lack of intercommunication of peoples widely separated in various parts of the world. Even today when communication is so greatly improved, the progress toward a world language is painfully slow—so slow,

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

†C. G. R. Johnson, Kimberly-Clark Corp.

Fig. 1.2 Section of an Engineering Department. *Courtesy Bell Telephone Laboratories, Indianapolis*

indeed, that we cannot foresee the time when it will be a fact.

Although men have not been able to get together on a world language of words and sentences, there has actually been a universal language in use since the earliest times: the *graphic language.* The idea of communicating thoughts from one person to another by means of *pictures* occurred to even the earliest cave dwellers, and we have examples still in existence to prove it. These earliest men communicated orally, undoubtedly by grunts and other elementary sounds, and when they wished to *record* an idea, they made *pictures* upon skins, stones, walls of caves or whatever materials they could find. The earliest forms of writing were through picture forms, such as the Egyptian hieroglyphics, Fig. 1.3. Later these forms were simplified and became the abstract symbols used in our writing today. Thus, even the letter characters in present word languages have their basis in drawings. See §3.1.

A drawing is a *graphic representation* of a real thing, an idea, or a proposed design for construction later. 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.

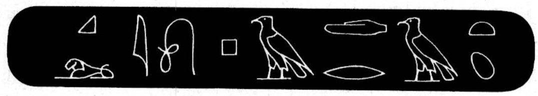


Fig. 1.3 Egyptian Hieroglyphics.

1.4 Two Types of Drawings. Man has developed graphic representation along two distinct lines, according to his purpose: (1) Artistic and (2) Technical.

From the beginning of time, artists have used drawings to express aesthetic, philosophic, or other abstract ideas. In ancient times nearly everybody was illiterate. There was no printing, and hence no newspapers or books as we know them today. Books were hand lettered on papyrus or parchment and were not available to the general public. People

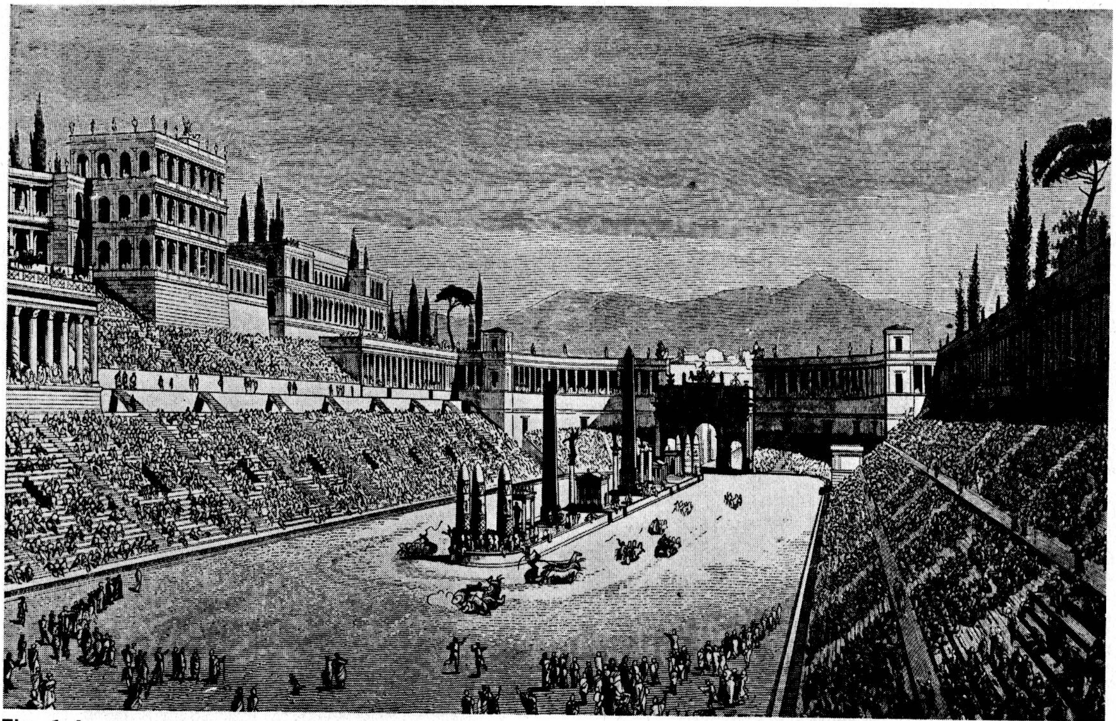


Fig. 1.4 The Circus Maximus in Rome. *The Bettmann Archive, Inc.*

learned by listening to their superiors and by looking at sculptures, pictures, or drawings in public places. Everybody could understand pictures and they were a principal source of information. In our museums and in ruins of antiquity are thousands of examples of storytelling or teaching by means of drawings. If someone wished to preserve his own image or a friend's, he had to have the job done in stone, in bronze, in oil on canvas, or in some other art medium—there were no photographs. The artist was not just an artist in the aesthetic sense—he was 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, man has used drawings to *represent* his design of objects to be built or constructed. Of these earliest drawings no trace remains today, but we definitely know that drawings were used, for man could not have designed and built as he did without using fairly accurate drawings. In the Bible the statement is made that Solomon's Temple was "built of stone made ready before it was brought thither."* Each stone and timber was carved or hewn into shape, brought to the site, and fitted into place. It is evident that accurate drawings were used, showing the exact shapes and sizes of the component parts for the design of the temple.

Moreover, we can see today the ruins of fine old buildings, aqueducts, bridges, and other structures of antiquity that could not possibly have been erected without carefully made drawings to guide the builders. Many of these structures are still regarded as "Wonders of the World," such as the Temple of Amon at Karnak in ancient Egypt, completed in about 980 B.C., which took seven centuries to construct. In sheer mass of stone, this building exceeded any roofed structure ever built, so far as we know, being 1200 feet long and 350 feet wide at its greatest width. Likewise, the Circus Maximus in Rome was a large structure, Fig. 1.4; according to the historian Pliny, it seated a total of 250,000 spectators.

*1 Kings 6:6.

1.5 Earliest Technical Drawings.

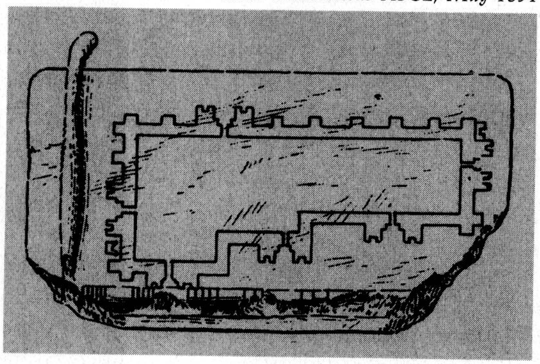
Perhaps the earliest known technical drawing in existence is the plan view for a design of a fortress drawn by the Chaldean engineer Gudea and engraved upon a stone tablet, Fig. 1.5. It is remarkable how similar this plan is to those made by architects today, although "drawn" thousands of years before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

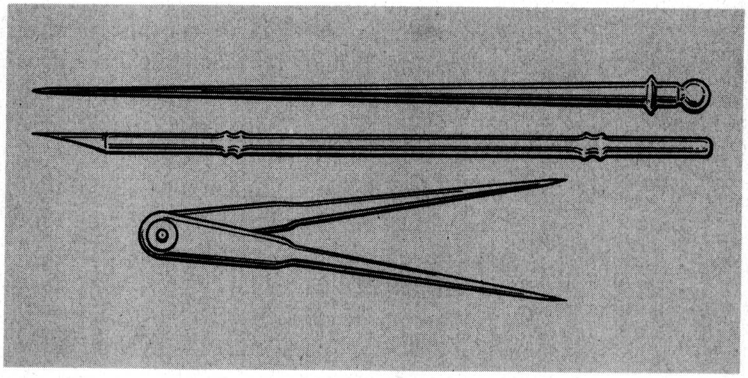
The first written evidence of the use of technical drawings was in 30 B.C. when the Roman architect Vitruvius wrote a treatise on architecture in which he said, "The architect must be skillful with the pencil and have a knowledge of drawing so that he readily can make the drawings required to show the appearance of the work he proposes to construct." He went on to discuss the use of the rule and compasses in geometric constructions, in drawing the plan and elevation views of a building, and in drawing perspectives.

In the museums we can see actual specimens of early drawing instruments. Compasses were made of bronze and were about the same size as those used today. 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 planes of projection (to obtain *views*, §6.1) 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

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*

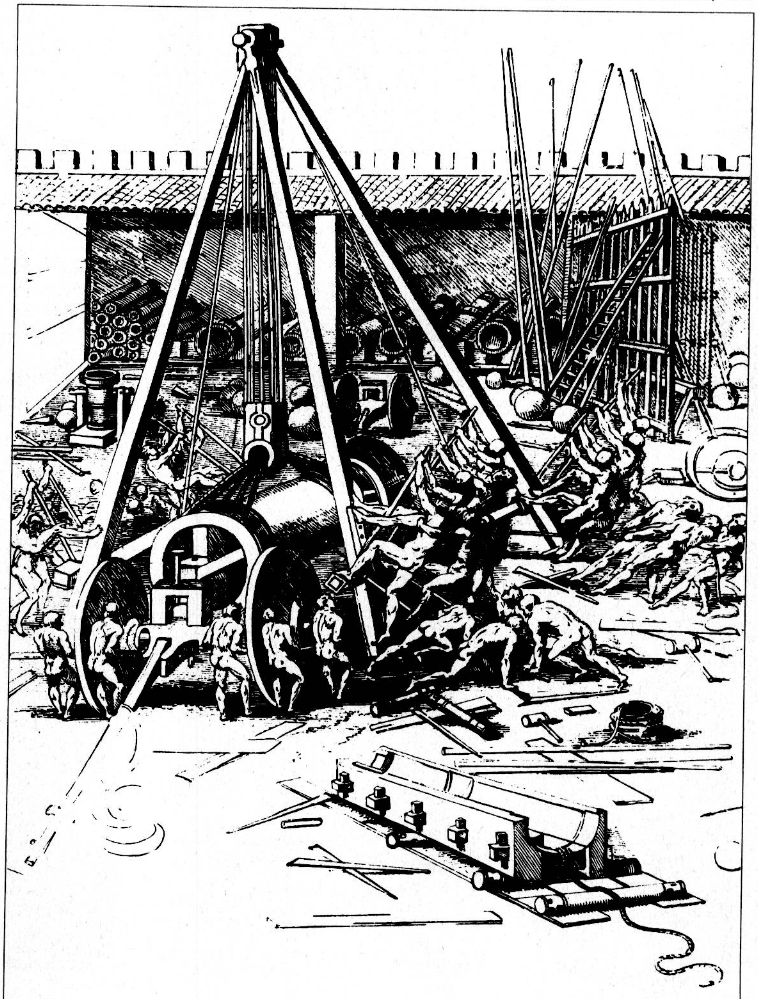




From Historical Note on Drawing Instruments, published by V & E Manufacturing Co.

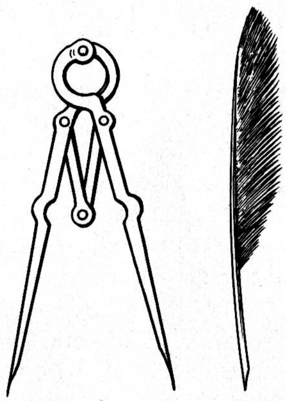
Fig. 1.6 Roman Stylus, Pen, and Compass.

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



used drawings to record and transmit to others his ideas and designs for mechanical constructions, and many of these drawings are in existence today, Fig. 1.7. It is not clear whether Leonardo ever made mechanical drawings showing orthographic views as we know them today, 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.

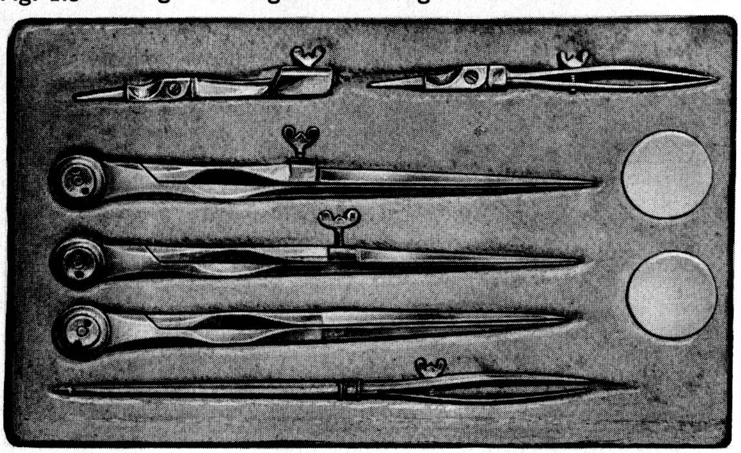
The compass of the Romans remained very much the same during Leonardo's time, Fig. 1.8. Circles were still scratched with metal points, since graphite pencils were not invented until the eighteenth century, when the firm of Faber was established in Nuremburg, Germany. By the seventh century reed pens had been replaced by quills made from bird feathers, usually those of geese (hence: goose-quill pens).



From Historical Note on Drawing Instruments, published by V & E Manufacturing Co.

Fig. 1.8 Compass and Pen, Renaissance Period. Compass after a drawing by Leonardo da Vinci.

Fig. 1.9 George Washington's Drawing Instruments.



From Historical Note on Drawing Instruments, published by V & E Manufacturing Co.

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, and bearing the date 1749. This set, Fig. 1.9, 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.

1.6 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 descriptive 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 today 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 in 1816 from France by Claude Crozet, 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.

1.7 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 this country (Theo. Alteneder & Sons, Philadelphia). In 1876 the blueprint process was introduced in this country 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 plainer to obtain 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 the turn of the nineteenth century throughout the world, drawings were generally made in what is called *first-angle projection,* §6.38, in which the top view was placed *under* the front view, the left-side view was placed at the *right* of the front view, etc. 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 on the subject 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 were aware of the fact that technical drawing was really a *graphic language.* Anthony's *An Introduction to the Graphic Language,* French's *Engineering Drawing,* and this text, *Technical Drawing,* were all written with this point of view.

1.8 Drafting Standards. In all of the above 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 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 will contain twenty-seven or more separate sections when completed. These sections are published as approved standards as they are completed. 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.*

1.9 Definitions. After surveying briefly the historical development of the graphic language and before starting a serious study of theory and applications, the definitions of a few terms should be considered.