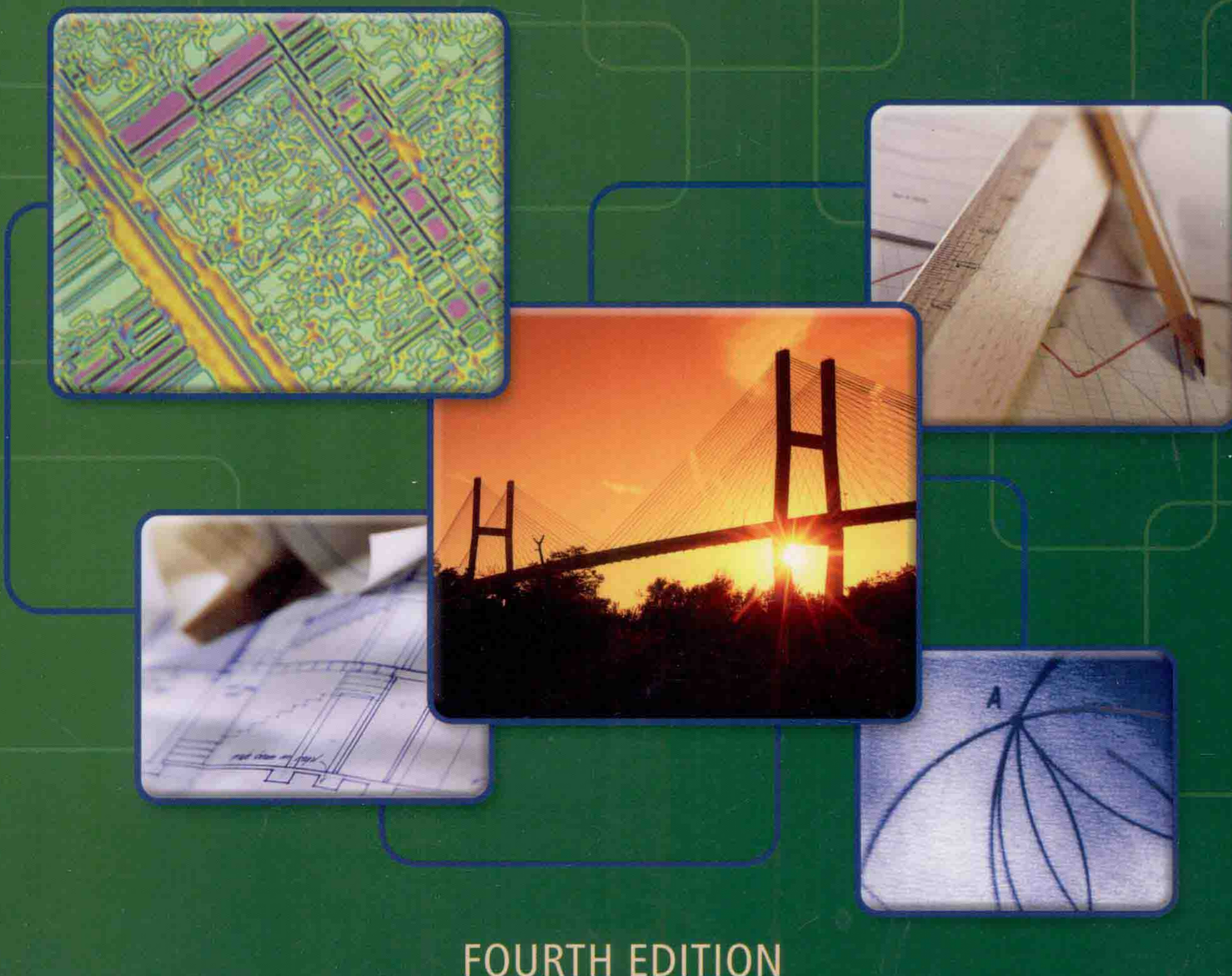
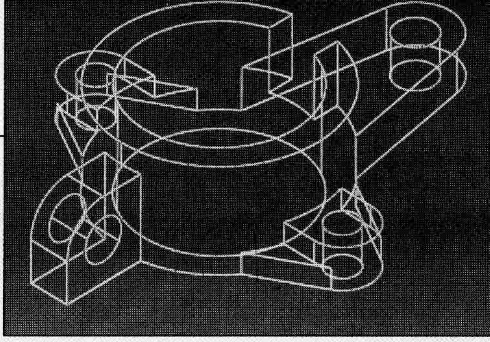
Basic Engineering Series and Tools



FOURTH EDITION

INTRODUCTION TO Graphics Communications for Engineers

GARY R. BERTOLINE



Introduction to Graphics Communications for Engineers

Fourth Edition

Gary R. Bertoline
Purdue University

With Contributions From:
Nathan Hartman, *Purdue University*
William Ross, *Purdue University*

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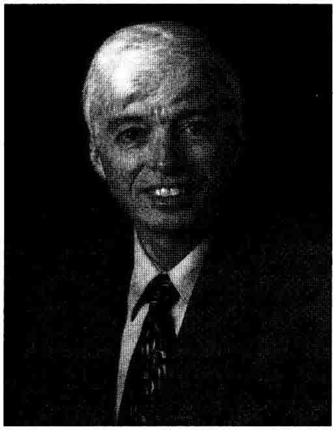

Gary R. Bertoline

Gary R. Bertoline is Professor of Computer Graphics Technology at Purdue University and director of the Envision Center for Data Perceptualization. He earned his B.S. degree in Industrial Technology at Northern Michigan University in 1974, M.Ed. in Industrial Technology at Miami University in 1979, and Ph.D. at The Ohio State University in Industrial Technology in 1987. His graduate work focused on the integration of CAD into engineering graphics and visualization. He has 25 years' experience teaching graphics at all levels from elementary school to senior citizens. Prof. Bertoline taught junior high and high school graphics at St. Henry High School, St. Henry, Ohio; drafting/ design technology at Wright State University, Lake Campus, Celina, Ohio; and engineering graphics at The Ohio State University, Columbus, Ohio.

Prof. Bertoline has authored numerous publications, authored or coauthored 10 textbooks and workbooks, and made over 100 presentations throughout the world. He has won the Frank Oppenheimer Award three times for best paper at the Engineering Design Graphics Division Mid-year Meeting. He has developed many graphics courses, including CAD, solid modeling, multimedia, and virtual reality, and has integrated many modern topics into traditional engineering graphics courses, such as modeling, animation, and visualization. Prof. Bertoline has conducted research in cognitive visualization and was the co-author for a curriculum study in engineering graphics funded by SIGGRAPH. He is on the editorial board for the *Journal for Geometry and Graphics* and is the McGraw-Hill Graphics Series Editor. He was the recipient of the Orthogonal Medal for outstanding contributions to the advancement of Graphic Science by North Carolina State University in 1992, and the 1995 inaugural recipient of the Steve M. Slaby International Award for Outstanding Contributions in Graphics Education. You can contact Dr. Bertoline at bertoline@purdue.edu.

Introduction to Graphics Communications for Engineers, Fourth Edition, is part of the McGraw-Hill's BEST (Basic Engineering Series and Tools), which introduces engineering students to various topics and skills important to their education. This workbook is an introduction to the standard practices used by engineers to communicate graphically. The primary goal of this text is to assist engineering students in learning the techniques and standards of communicating graphically so that design ideas can be clearly communicated and produced.

The text concentrates on the concepts and skills needed to sketch and create 2-D drawings and 3-D CAD models. Engineering graphics has gone through significant changes in the last decade as a result of the use of computers and CAD software. It seems as if some new hardware or software development has an impact on engineering graphics every year. Although these changes are important to the subject of technical graphics, there is much about the subject that has not changed. Engineers still find it necessary to communicate and interpret design ideas through the use of graphical methods such as sketches and CAD drawings and models. As powerful as today's computers and CAD software have become, they are of little use to engineers who do not fully understand fundamental graphics communications principles and 3-D modeling strategies, or who lack high-level visualization skills.

The workbook is divided into six chapters with multiple units of instruction. Chapter 1, "Introduction to Graphics Communications," is an introduction to graphics communications as a language for engineers and describes the tools used and some of the techniques for communicating graphically. Chapter 2, "Sketching and Text," is an introduction to sketching technique, projection theory, visualization, and the use of text on drawings. Chapter 3, "Section and Auxiliary Views," introduces the student to the use of and technique for creating sectioned drawings and models and auxiliary views. Chapter 4, "Dimensioning and Tolerancing Practices," describes how to create and read dimensional drawings. Chapter 5, "Reading and Constructing Working Drawings," describes how to read and produce working drawings. Finally, Chapter 6, "Design and 3-D Modeling," is an overview of 3-D modeling techniques and the engineering design process.

Outstanding features of the fourth edition include:

- **New Design Problems** were developed to provide students an opportunity to exercise the various stages of the design process. The problems provide an ideation stage, a decision-making stage, design creation stage, and the documentation stage. Each problem includes provisions for sketching, 3-D modeling, and documentation of the student's final solution to the problem.
- **Supplemental Solid Modeling Exercise**—A new exercise focusing on 3-D solid modeling for parts and assemblies has been developed. Visual examples for each part and assembly have been created with various solid modeling software packages and are included with engineering sketches to aid students in visualizing part geometry and the modeling process.
- **Design in Industry Boxes,** containing some aspect of design from industry, are featured in this edition. Students will learn how design is done in the real world from these interesting stories presented by practicing engineers and technologists.
- **Practice Problems** are included throughout each chapter in the fourth edition. These problems give students an opportunity to get drawing practice as they work through concepts.
- **End-of-Chapter Sketching Problems** reinforce what students are learning in the chapter.
- **Student-Friendly Pedagogy** includes: a list of objectives at the beginning of chapters, step-by-step instructions on how to draw, and a wide assortment of problems that can be assigned to reinforce concepts.

Sketching worksheets have been integrated into the end of each chapter. These worksheets can be used for sketching assignments to augment assignments using

CAD. After completing the workbook, the student will be able to create design sketches using various projection techniques, create and read 2-D standard engineering drawings, and create and visualize 3-D computer models.

Thanks to James Mohler and Amy Fleck for their work on the illustrations, Jim Leach for some of the drawing problems added in the second edition and Robert Geenlee, University of New Mexico, and Hodge E. Jenkins, Mercer University, for their feedback on the third edition. Special thanks to Professors Nathan Hartman and William Ross from Purdue University for their contributions to this edition of the book.

Gary R. Bertoline, PhD
Professor Computer Graphics Technology
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For Ada, Bryan, Kevin, and Carolyn, who are my motivation and inspiration for all my books.

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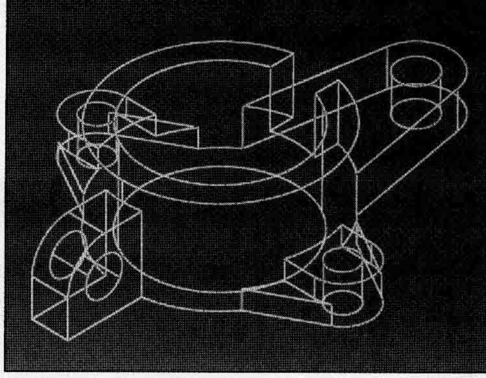
Introduction to Graphics Communications 1



OBJECTIVES

After completing this chapter, you will be able to:

1. Describe why technical drawings are an effective communications system for technical ideas about designs and products.
2. Identify important parts of a CAD system.
3. Identify important traditional tools.
4. Identify standard metric and U.S. drawing sheet sizes.
5. Identify the types and thicknesses of the various lines in the alphabet of lines.

1.1 | INTRODUCTION

Graphics communications using engineering drawings and models is a language—a clear, precise language—with definite rules that must be mastered if you are to be successful in engineering design. Once you know the language of graphics communications, it will influence the way you think, the way you approach problems. Why? Because humans tend to think using the languages they know. Thinking in the language of technical graphics, you will visualize problems more clearly and will use graphic images to find solutions with greater ease.

In engineering, 92 percent of the design process is graphically based. The other 8 percent is divided between mathematics and written and verbal communications. Why? Because graphics serves as the primary means of communication for the design process. Figure 1.1 shows a breakdown of how engineers spend their time. 3-D modeling and documentation, along with design modeling, comprise more than 50 percent of the engineer's time and are purely visual and graphical activities. Engineering analysis depends largely on reading technical graphics, and manufacturing engineering and functional design also require the production and reading of graphics.

Why do graphics come into every phase of the engineer's job? To illustrate, look at the jet aircraft in Figure 1.2. Like

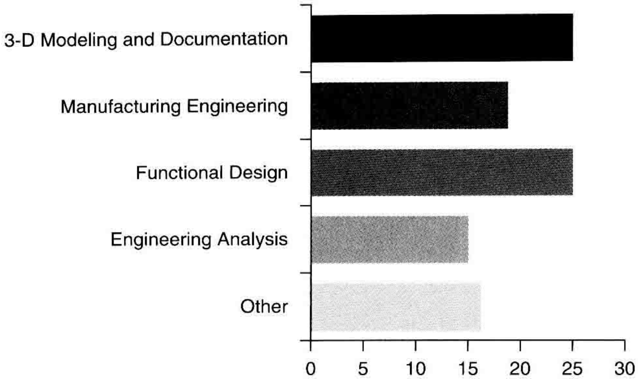


Figure 1.1 **A Total View of Engineering Divided into Its Major Activities**

Graphics plays a very important role in all areas of engineering; for documentation, communications, design, analysis, and modeling. Each of the activities listed is so heavily slanted toward graphics communications that engineering is 92 percent graphically based. (Courtesy of RealD Stereographics)

Figure 1.2

This jet aircraft would be impossible to create without computer graphics models and drawings. Drawings are the road maps that show how to manufacture or build products and structures.
(© Boeing)

any new product, it was designed for a specific task and within specified parameters; however, before it could be manufactured, a 3-D model and engineering drawings like that shown in Figure 1.3 had to be produced. Just imagine trying to communicate all the necessary details verbally or in writing. It would be impossible!

A designer has to think about the many features of an object that cannot be communicated with verbal descriptions (Figure 1.4). These thoughts are dealt with in the mind of the designer using a visual, nonverbal process. This "visual image in the mind" can be reviewed and modified to test different solutions before it is ever communicated to someone else. As the designer draws a line on paper or creates a solid cylinder image with a computer, he or she is translating the mental picture into a drawing or model that will produce a similar picture in the mind of anyone who sees the drawing. This drawing or graphic representation is the medium through which visual images in the mind of the designer are converted into the real object.

Technical graphics can also communicate solutions to technical problems. Such technical graphics are produced according to certain standards and conventions so they can be read and accurately interpreted by anyone who has learned those standards and conventions.

The precision of technical graphics is aided by tools; some are thousands of years old and still in use today, and others are as new and rapidly changing as computer-aided design/drafting (CAD). This book will introduce you to the standards, conventions, techniques, and tools of technical graphics and will help you develop your technical skills so that your design ideas become a reality.

Engineers are creative people who use technical means to solve problems. They design products, systems, devices, and structures to improve our living conditions. Although problem solutions begin with thoughts or images in the mind of the designer, presentation devices and computer graphics hardware and software are powerful tools for communicating those images to others. They can also aid the visualization process in the mind of the designer. As computer graphics have a greater impact in the field of engineering, engineers will need an ever-growing understanding of and facility in graphics communications.

Practice Exercise 1.1

1. Try to describe the part shown in Figure 1.15 using written instructions. The instructions must be of such detail that another person can make a sketch of the part.
2. Now try verbally describing the part to another person. Have the person make a sketch from your instructions.

These two examples will help you appreciate the difficulty in trying to use written or verbal means to describe even simple mechanical parts. Refer to Figure 1.3 and others in this text to get an idea of how complicated some parts are compared with this example. It is also important to note that air and water craft have thousands of parts. For example, the nuclear powered *Sea Wolf* class submarine has more than two million parts. Try using verbal or written instructions to describe that!

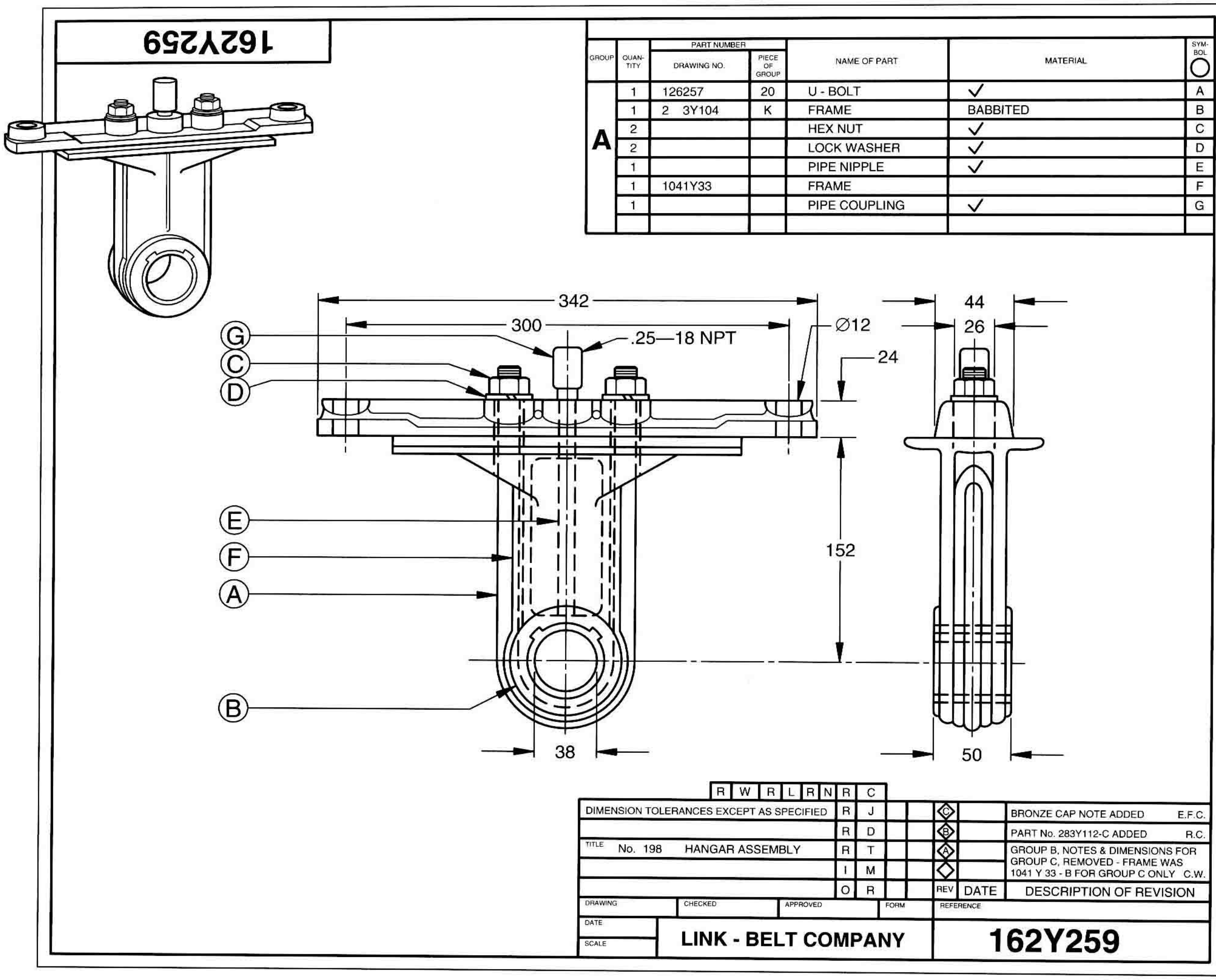


Figure 1.3 Engineering Drawing

Engineering drawings and computer models such as these were needed to produce the hanger assembly shown. The 3-D model is used to design and visualize the hanger. The engineering drawings are used to communicate and document the design process.

1.2 | TECHNICAL DRAWING TOOLS

Just as the graphics language has evolved over the years into a sophisticated set of standards and conventions, so have the tools used to graphically communicate technical ideas. Tools are used to produce three basic types of drawings: freehand sketches, instrument drawings, and computer drawings and models. The tools have evolved from pencils, triangles, scales, and compasses to **computer-aided design/drafting** (**CAD**) systems. **CAD** is computer software and related computer hardware that supplements or replaces traditional hand tools for creating models and technical drawings (Figure 1.5).

Since many industries have not fully integrated CAD into their design offices, it is necessary to learn both traditional and computer design methods. Also, traditional tools are used for sketching, which is one of the most effective methods available to represent design ideas quickly.

Design in Industry
Going Virtual

Virtual reality and simulation software tools hold the promise of drastically slashing product development costs through the elimination of expensive physical prototypes. With costs for the latest virtual reality (VR) tools and simulation systems coming down, automotive and aerospace manufacturers increasingly are seeking to deploy sophisticated, collaborative visualization systems throughout their product development planning organizations, as well as using virtual simulations for designing overall plant layouts and within manufacturing cells.

Although VR tools historically have been the domain of researchers, commercial applications in automotive, aerospace, and medical device manufacturing are becoming much more common. Using VR systems like the CAVE (Computer Automated Visualization Environment), developed in the early 1990s by the Electronic Visualization Laboratory at the University of Illinois at Chicago (EVL, UIC), automakers and aircraft manufacturers can review realistic virtual model prototypes, avoiding the expense of $200,000 for a fiberglass auto prototype to upwards of $3 million for an aircraft prototype.

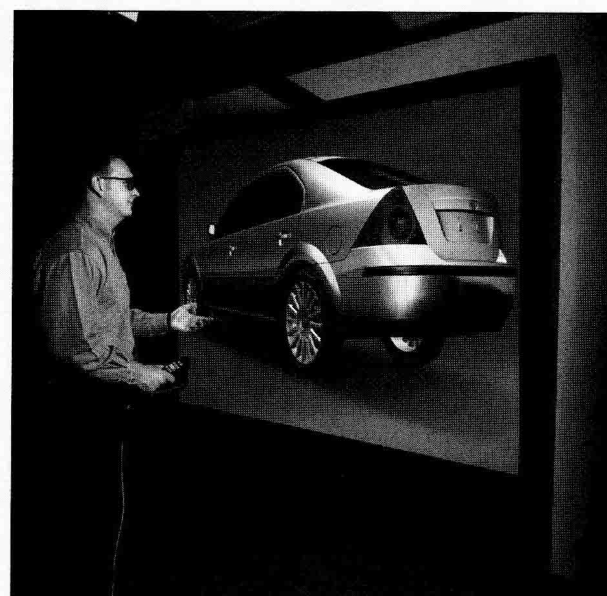
Over the past few years, the addition of more realistic visualization software also has furthered VR's acceptance, with efforts like the partnership between software developer Engineering Animation Inc. (Ames, IA), workstation supplier Silicon Graphics Inc. (Mountain View, CA), and General Motors Corp. (Detroit) offering EAI's VisConcept, a software suite providing a true 1:1, or human-scale, immersive visualization environment. In addition, projection and display technologies have improved to the point where it's possible to easily create high-resolution stereoscopic images—seeing an image in each eye with depth and volume just as in the real world.

Collaborative visualization may represent a new opportunity to manufacturers, particularly in the automotive industry where many major auto manufacturers are trying to persuade their top suppliers to adopt visualization technology. Large-scale displays like the WorkWall enable manufacturing teams to collaborate in much the same way they used to work around drafting tables, but with realistic, full-scale 3-D models.

This article (or excerpts thereof) appear with permission from *Manufacturing Engineering,* the official publication of the Society of Manufacturing Engineers (SME).

With Fakespace Systems' WorkWall, Teams Can View Realistic Stereoscopic Images During Product Development Team Design Reviews.

(Courtesy of Fakespace Systems Inc., A Mechdyne Company)



Users of the Fakespace Wall Can Review Styling and Component Changes on Virtual Models before Committing to Final Product Designs.

(Courtesy of Fakespace Systems, Inc., A Mechdyne Company)

Figure 1.4 Engineering Drawings Used for Communications

Engineering drawings are a nonverbal method of communicating information. Descriptions of complex products or structures must be communicated with drawings. A designer uses a visual, nonverbal process. A visual image is formed in the mind, reviewed, modified, and is ultimately communicated to someone else, all using visual and graphics processes. (© Charles Thatcher/Getty Images)

1.3 COMPUTER-AIDED DRAWING TOOLS

Traditional tools will continue to be useful for sketching and rough layout work; however, good CAD software can create virtually any type of technical drawing. Circle commands replace the compass, line commands replace the T-square and triangles, and editing commands replace the dividers and erasing shield.

A CAD system consists of hardware devices used in combination with specific software. The **hardware** for a CAD system consists of the physical devices used to support the CAD software. There are many different hardware manufacturers and types of hardware devices, all of which are used to create, store, or output technical drawings and models. It is not uncommon in industry to have multiple input, storage, and output devices for a CAD system.

1.4 TRADITIONAL TOOLS

The traditional tools used to create technical drawings have evolved over time. Many tools were originally used in ancient Greece to study and develop geometry. Although computers may someday replace the need for some traditional tools, they are still useful today for drawing, and more importantly, for sketching. **Traditional tools** are devices used to assist the human hand in making technical drawings. The assistance includes drawing lines straighter, making circles more circular, and increasing the speed with which drawings are made. The tools typically used to create mechanical drawings or sketches (Figure 1.6) consist of the following:

1. Wood and mechanical pencils
2. Instrument set, including compass and dividers
3. 45- and 30/60-degree triangles

Figure 1.5 CAD Workstations

Typical CAD workstations used in industry have large color monitors. (© Bill Aron/Photo Edit, Inc.)

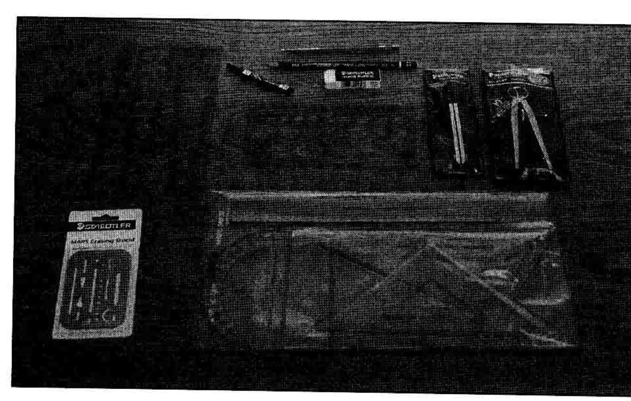


Figure 1.6 Traditional Tools

These are some of the many traditional mechanical drawing tools used for engineering drawings. (Courtesy of Staedtler, Inc.)

4. Scales
5. Irregular curves
6. Protractors
7. Erasers and erasing shields
8. Drawing paper
9. Circle templates
10. Isometric templates

Table 1.1 ANSI Standard Sheet Sizes

Metric (mm)	U.S. Standard	Architectural
A4 210 × 297	A-Size 8.5″ × 11″	9″ × 12″
A3 297 × 420	B-Size 11″ × 17″	12″ × 18″
A2 420 × 594	C-Size 17″ × 22″	18″ × 24″
A1 594 × 841	D-Size 22″ × 34″	24″ × 36″
A0 841 × 1189	E-Size 34″ × 44″	36″ × 48″

1.5 MEDIA

Media are the surfaces upon which an engineer or technologist communicates graphical information. The media used for technical drawings are different types or grades of paper, such as tracing paper, vellum, and polyester film. Tracing paper is a thin, translucent paper used for detail drawings. Vellum is a tracing paper chemically treated to improve translucency. Polyester film, or its trade name Mylar, is transparent, waterproof, and difficult to tear. Mylar can be used for lead pencil, plastic-lead pencil, or ink drawings. Mylar is an excellent drawing surface that leaves no trace of erasure.

Special papers have also been developed for CAD plotters. For example, plotter paper used for fiber-tipped pens has a smooth or glossy surface to enhance line definition and minimize skipping. Often, the paper comes with a preprinted border, title block, and parts list (Figure 1.7).

The American National Standards Institute (ANSI) has established standard sheet sizes and title blocks for the media used for technical drawings. Each paper size is designated by a letter, as shown in Table 1.1, and title block sizes are shown in Figure 1.16 at the end of the chapter.

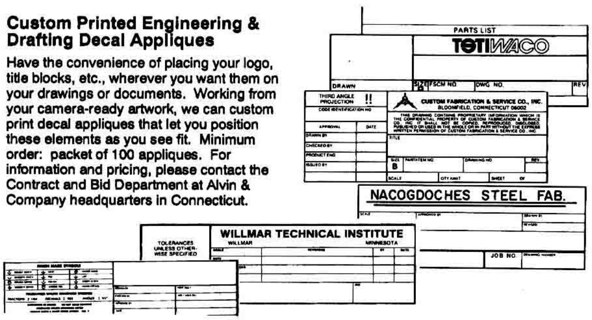


Figure 1.7 Preprinted Title Blocks
Preprinted standard borders and title blocks on drafting paper are commonly used in industry. (Courtesy of Alvin & Company.)

1.6 ALPHABET OF LINES

The **alphabet of lines** is a set of standard linetypes established by the American Society of Mechanical Engineers (ASME) for technical drawing. Figure 1.8 shows the alphabet of lines and the approximate dimensions used to create different linetypes, which are referred to as **linestyles** when used with CAD. ASME Y14.2M-1992 has established these linetypes as the standard for technical drawings. Two line weights are sufficient to follow the standards, a 0.6 mm and a 0.3 mm. These approximate widths are intended to differentiate between thin and thick lines and are not for control of acceptance or rejection of drawings. Thick lines are drawn using soft lead, such as F or HB. Thin lines are drawn using a harder lead, such as H or 2H. Construction lines are very light and are drawn using 4H or 6H lead. A good rule of thumb for creating construction lines is to draw them so that they are difficult to see if your drawing is held at arm's length.

Following are the standard linetypes and their applications in technical drawings:

Center lines are used to represent symmetry and paths of motion and to mark the centers of circles and the axes of symmetrical parts, such as cylinders and bolts.

Break lines come in two forms: a freehand thick line and a long, ruled thin line with zigzags. Break lines are used to show where an object is broken to save drawing space or reveal interior features.

Dimension and extension lines are used to indicate the sizes of features on a drawing.

Section lines are used in section views to represent surfaces of an object cut by a cutting plane.

Cutting plane lines are used in section drawings to show the locations of cutting planes.

Visible lines are used to represent features that can be seen in the current view.

Hidden lines are used to represent features that cannot be seen in the current view.

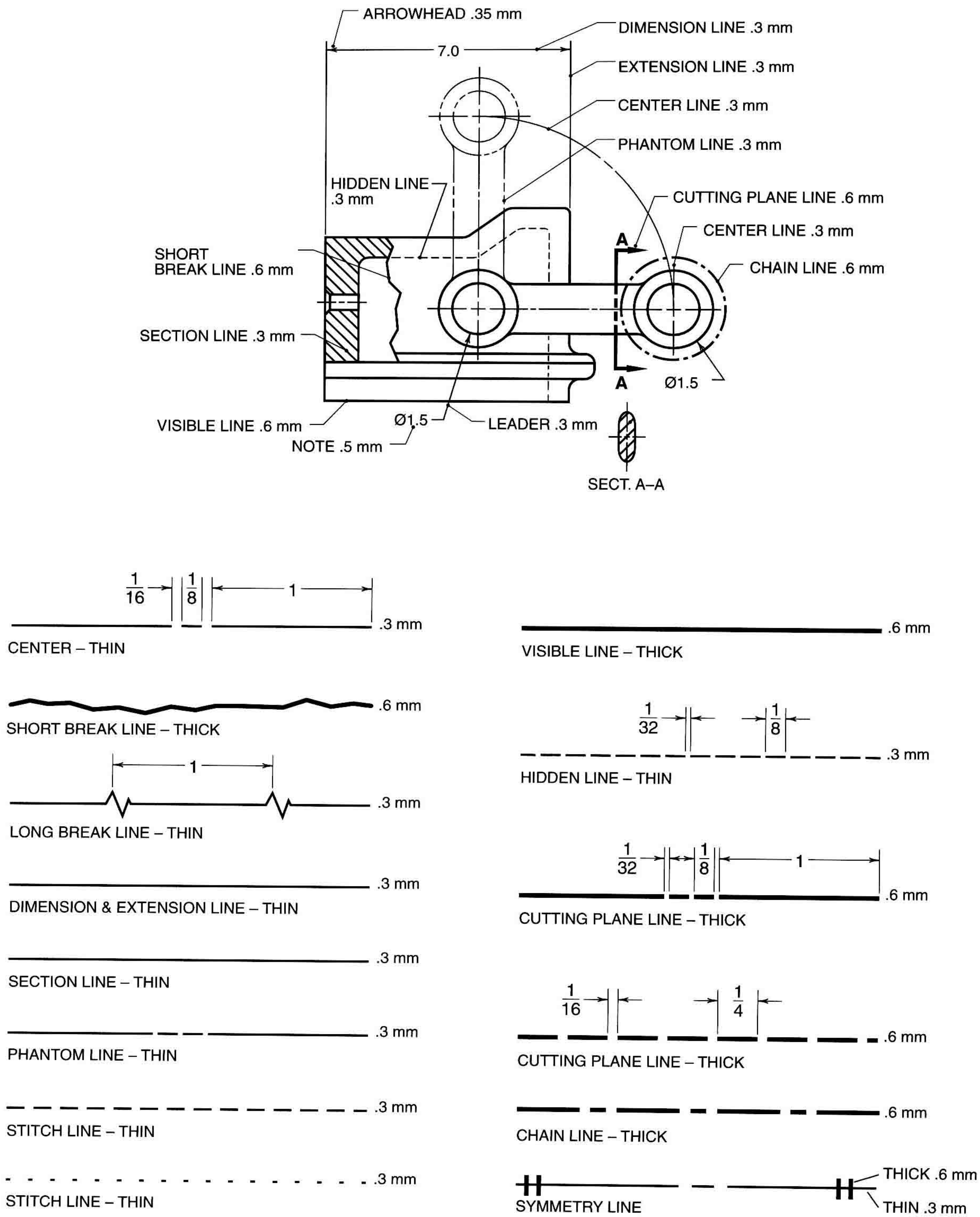


Figure 1.8 **The Alphabet of Lines**

The alphabet of lines is a set of ASME standard linetypes used on technical drawings. The approximate dimensions shown on some linetypes are used as guides for drawing them with traditional tools. The technical drawing at the top shows how different linetypes are used in a drawing.

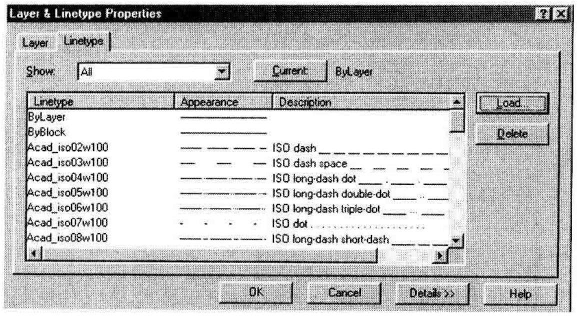


Figure 1.9 **AutoCAD® Linestyle Menu Showing Some of the Linetypes Available**

(Certain images provided courtesy of Autodesk, Inc. © 2004 All rights reserved. AutoCAD is a registered trademark of Autodesk, Inc., in the U.S.A. and other countries.)

Phantom lines are used to represent a movable feature in its different positions.
Stitch lines are used to indicate a sewing or stitching process.
Chain lines are used to indicate that a surface is to receive additional treatment.
Symmetry lines are used as an axis of symmetry for a particular view.

It is important that you understand and remember these different linetypes and their definitions and uses, because they are referred to routinely throughout the rest of this book.

CAD software provides different linestyles for creating standard technical drawings. Figure 1.9 shows the linestyle menu for a typical CAD system. The thicknesses of lines on a CAD drawing are controlled by two different means: (1) controlling the thickness of the lines drawn on the display screen and (2) controlling the plotted output of lines on pen plotters by using different pen numbers for different linestyles, where different pen numbers have different thicknesses, such as a 0.7 mm and 0.3 mm.

1.7 WHAT YOU WILL LEARN

In this text, you will learn the six important areas in technical graphics:

Visualization—the ability to mentally control visual information.
Graphics theory—geometry and projection techniques.
Standards—sets of rules that govern how parts are made and technical drawings are represented.
Conventions—commonly accepted practices and methods used for technical drawings.
Tools—devices used to create engineering drawings and models, including both handheld and computer tools.
Applications—the various uses for technical graphics in engineering design, such as mechanical, electrical, and architectural.

Each chapter in the text will explain the graphics theory important for a topic, integrate the visualization practices, explain the relevant standards and conventions, demonstrate the tools used to create drawings, and apply the topic to engineering design.

Learning to communicate with drawings is very similar to learning to write or speak in a language. For someone inexperienced in technical drawing, the learning process is very similar to learning a new language. There is a set of rules that must be learned in order to communicate graphically or when learning a new language. You will soon find out that graphics is a very effective method of supporting the design process.

1.8 FUTURE TRENDS

The convergence of technology, knowledge, and computer hardware and software is resulting in a number of nontraditional processes that can be used in the engineering design process. These new processes and technologies can extend the circle of people in an organization who are involved in design. Many of these future trends are beginning to combine the design and manufacturing processes into a whole. A few trends even take a more global approach of attempting to control the entire enterprise.

1.8.1 Visualization Tools

The sharing of design ideas has always been important for the engineer. Today, however, the importance of sharing design ideas with others is even more important. One technique that is becoming popular is the sharing of design ideas through various computer graphics techniques. The following is a list in order of realism and interactivity that can be produced with computer graphics tools.

- High-resolution rendered images are a static means of showing initial design ideas (Figure 1.10).
- Computer animations or simulation can also be very effectively used to share design ideas with others.

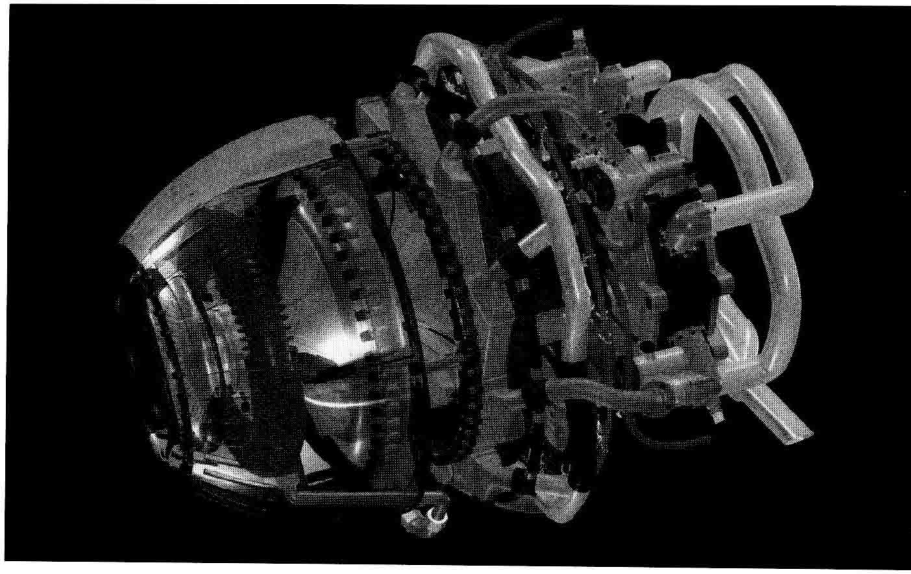


Figure 1.10 **High-Resolution Rendered Image of a CAD Model**
(Courtesy of Simon Floyd Design Group.)

- 3-D stereo graphics can be used to enhance the viewing of static and animated 3-D computer images on the computer screen (Figure 1.11).
- Holographic and volumetric displays of 3-D computer images are being developed that allow designers to literally walk around and through the design as it is being created (Figure 1.12).
- Virtual reality tools can be employed to get an even higher level of realism by immersing the user in a 3-D world (Figure 1.13).
- Rapid prototyping systems are used to create real prototype models directly from CAD models (Figure 1.14).

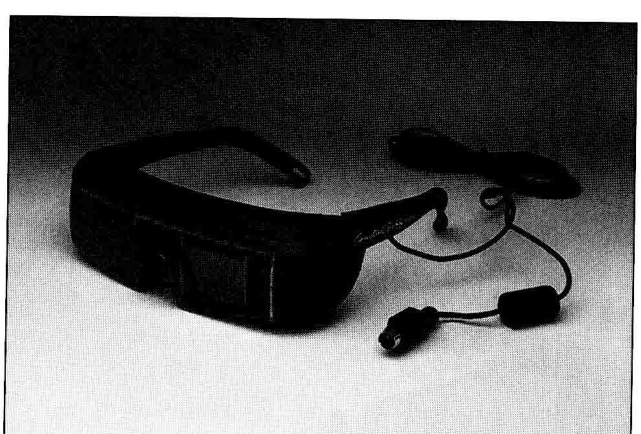


Figure 1.11 **3-D Stereo Glasses Used to Enhance the Viewing of CAD Models**
(Courtesy of Stereographics Corporation)

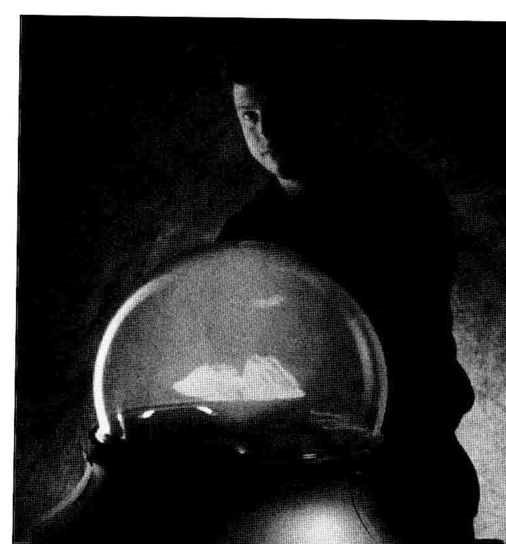


Figure 1.12 **Volumetric Display Device**
(© Lou Jones.)

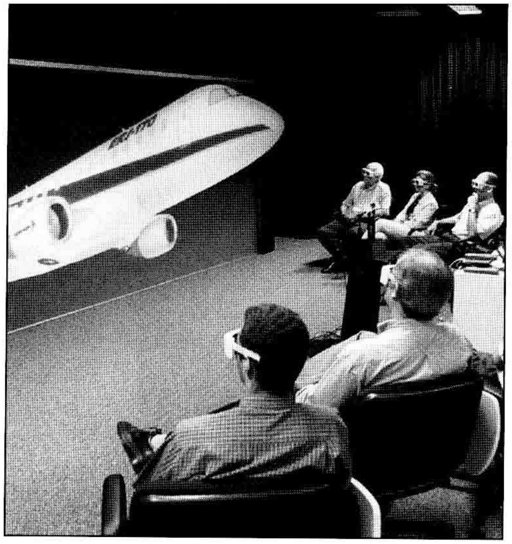


Figure 1.13 **Stereoscopic Imagery Displayed on a Large Display**

(Courtesy of Fakespace Systems, Inc., A Mechdyne Company)

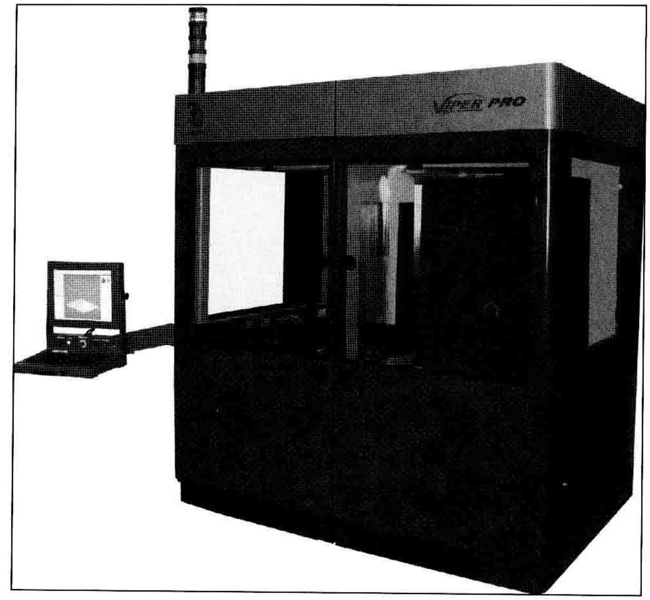


Figure 1.14 **Rapid Prototyping System**

(Courtesy of 3D Systems Corp.)

Problems

Use the worksheets provided at the end of this section to complete the problems.

1.1 Research and report on an important historical figure in engineering design, such as Henry Ford, Thomas Edison, the Wright brothers, or Alexander Graham Bell.

1.2 Identify at least five other individuals who worked as engineers and had an impact on society.

1.3 Research and report on an important historical engineering achievement, such as airplanes, space flight, computers, or television.

1.4 Identify three new products that have appeared on the market in the last five years.

1.5 Research and report on an important historical figure in graphics, such as Gaspard Monge, M. C. Escher, Thomas Edison, Leonardo da Vinci, Albrecht Durer, or Frank Lloyd Wright.

1.6 To demonstrate the effectiveness of graphics communications, write a description of the object shown in Figure 1.15. Test your written description by having someone attempt to make a sketch from your description.

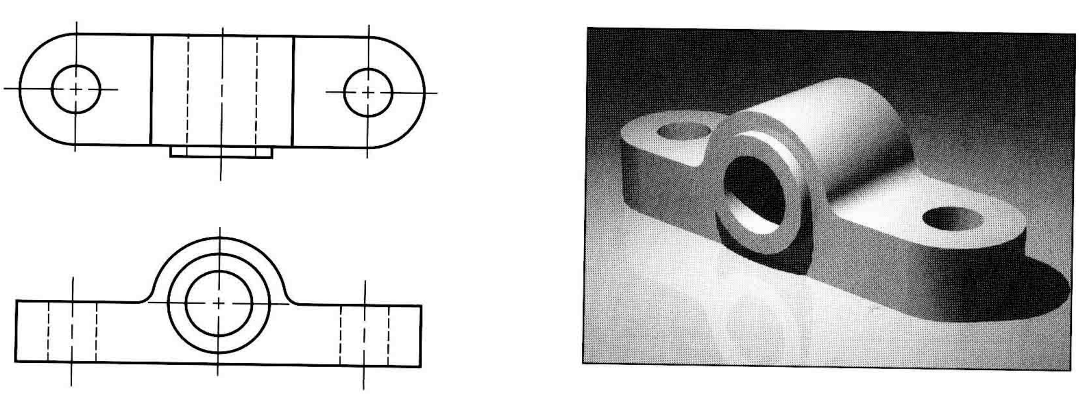


Figure 1.15 **Problem 1.6 Bearing Block to Be Described Verbally**