SECOND EDITION

fundamentals of Modern Drafting

PAUL ROSS WALLACH

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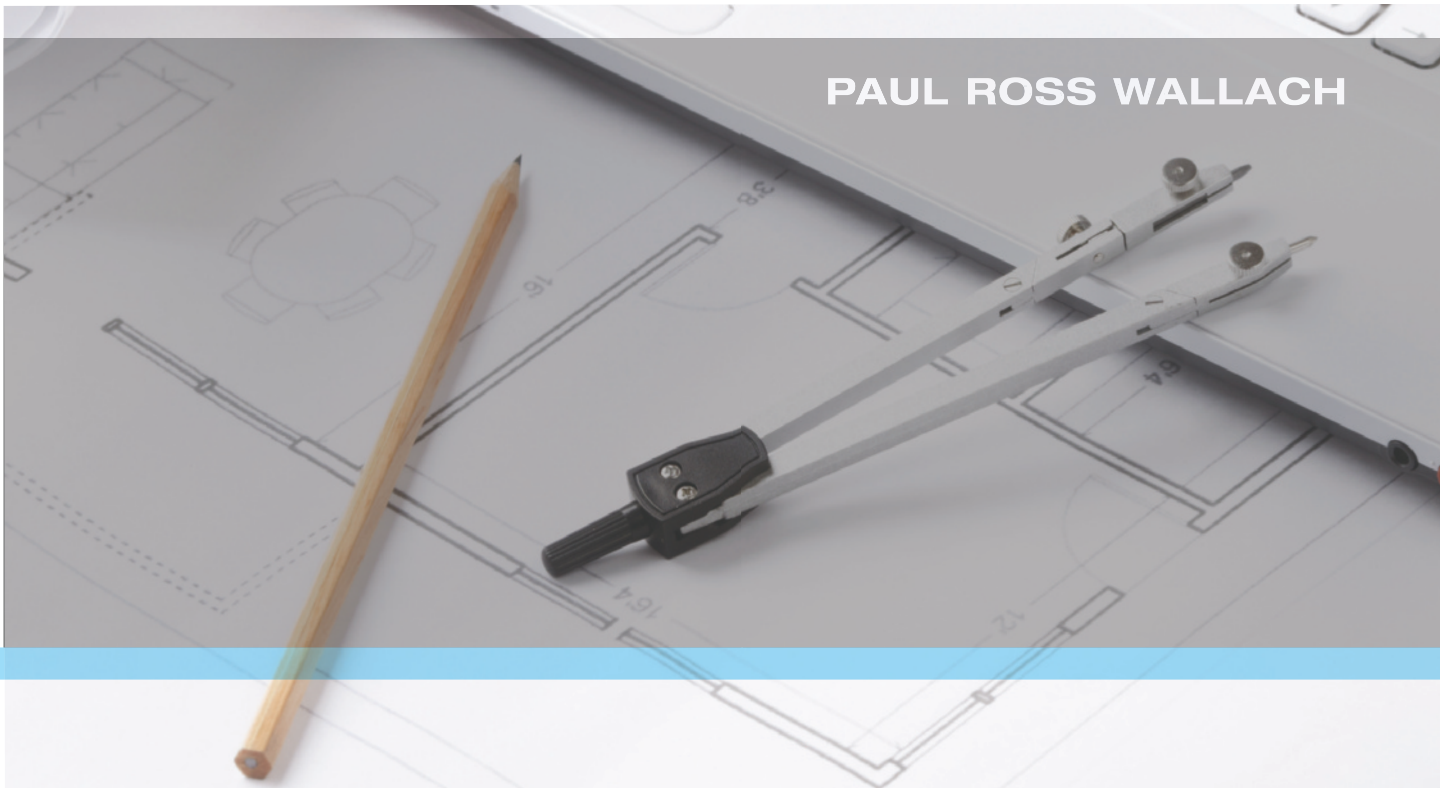

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PREFACE

A Word from the Author

With the increasing development of industry and new breakthroughs in technology, there will always be a large demand for qualified engineers and drafters. With this demand comes the need for qualified schools and instructional materials to provide students with the skills they need to compete in today's workplace.

I would like to welcome you to this student-oriented engineering drawing textbook. *Fundamentals of Modern Drafting* provides the basic information and skill-building procedures of modern design and drafting techniques. The many drafting and design exercises in this text may be performed with either manual drafting, CAD, or freehand sketching techniques. Each chapter is designed to teach basic drafting concepts and skills in a logical order using the latest ASME conventions. The concepts and drawing exercises for each chapter progress from simple to complex. This will ensure beginning students a degree of success and offer sufficient materials for more advanced students. Many of the drafting concepts are presented with visual step-by-step illustrations.

The last chapter contains concise but complete instructional materials and exercises to design and draw residential working drawings.

Note to Instructors

It is critical that the students understand the design and drawing concepts of engineering and architectural drawing *before* they start creating drawings with a CAD system. Designing and drawing with a CAD system without this basic knowledge will not create any good-quality or useful working drawings.

Supplements

The Instructor's Companion Web Site to Accompany Fundamentals of Modern Drafting offers free resources for instructors to enhance the educational experience. The Web site contains the following features:

- Slides created in PowerPoint, which outline key concepts from each chapter
- Test bank to evaluate student learning

Features of this Text

Fundamentals of Modern Drafting fulfills the need for an instructional drafting text that will teach the fundamentals of engineering drawing through sketching, instrument drafting, and introductory CAD skills. Some of the special features include the following:

- Each chapter opens with objectives and sets the stage for clear and concise learning.
- Over 1,300 illustrations and photographs help clarify the content and aid students in reading two-dimensional and three-dimensional working drawings.
- Step-by-step procedural illustrations take the students through the concepts of drafting, design, and layouts.
- Key terms are highlighted within the text and listed at the end of each chapter to reinforce important concepts and terminology.
- Each chapter will develop and strengthen specific technical concepts, allowing the student to develop proficiency in solving drafting problems.
- All chapters are organized in a logical sequence; however, each chapter may be used as a stand-alone unit of instruction.
- No previous drafting knowledge is required to use this textbook.
- Exercises at the end of each chapter start with simple concepts and become progressively more complex.
- Students use the following methods to solve end-of-chapter exercises:
  - Freehand sketching
  - Instrument drafting
  - CAD system drawings
  - Special design exercises
  - Engineering change orders (ECOs)
  - Inch-decimal, inch-fraction, and metric units of measure

Chapter Overview

Chapter 1 presents an introduction to modern industry. Specific careers related to drafting also give the students an insight into occupational options.

Chapters 2 through 7 give the student the background needed to learn and draw the basic drafting concepts with: sketching, instruments, drafting supplies, lettering, formats, conventions, and an overview of CAD. The latest ASME standards are used throughout the text. Chapter 5 offers instruction on how students can use their creativity and drafting skills in a design team.

Chapters 8 through 15 teach the students the concepts of mechanical drafting required to design and draw finished multiview drawings, dimensioning, tolerancing, sectional drawings, auxiliary drawings, revolutions, descriptive geometry, development drawings, and pictorial drawings.

Chapters 16 through 24 teach students how to prepare finished working drawings that are required for production: fasteners, drafting systems, working drawings, welding drawings, gear drawings, cam drawings, piping drawings, electronics drawings, jig and fixture drawings, green planning in industry, and architectural drawings.

Standards

The language of drafting is a uniform and standardized system that is used throughout the world. The standards for the U.S. Customary system are developed by the American Society of Mechanical Engineers (ASME). The standards for the metric system are developed by the International Organization for Standardization (ISO). Careful attention was given to the dimensioning and tolerancing chapters (ASME Y14.5).

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Harrison, Tennessee

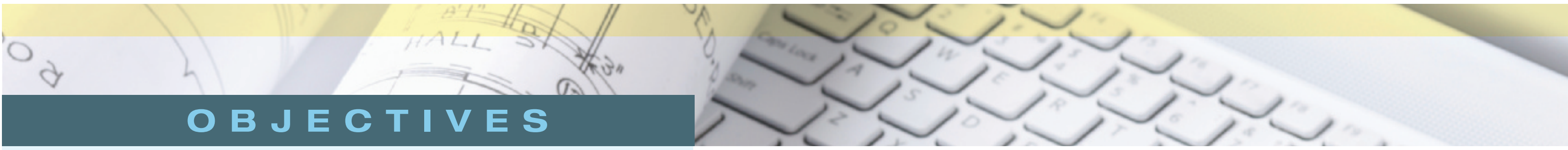
John Scheblein
Suffolk Community College
Selden, NY

Ed Wheeler
University of Tennessee at Martin
Martin, Tennessee

"This textbook is dedicated to Mike Robbins"

1

Introduction to Contemporary Drafting



OBJECTIVES

The student will be able to:

- Relate to the historical development of drafting
- State the importance and need for drafting as a technical communication skill
- State how drafting is used in different industrial fields as the major source of communication
- Identify the roles and responsibilities of various drafting specialists
- Recognize the levels of education, training, and experience required for the various professional and drafting positions

History

Prehistoric people drew crude drawings in the soil and cave walls long before people were able to write (**Figure 1-1**). Drawings have been used throughout history as an art form and a method of communication. As time progressed, drawing instruments and drawing surfaces, such as stone and clay tablets, limestone, wood and **parchment** made from the papyrus plant, were developed and refined. During the years of 3,600 BC. the first Egyptian pyramid was built using detailed construction drawings (**Figure 1-2**). Other historical buildings that used construction drawings for their construction was the **Parthenon** in Greece in 447 BC. (**Figure 1-3**), and the Roman Coliseum in 72 BC. (**Figure 1-4**). These are only a few of the very early structures designed and constructed with detailed drawings on parchment. By the first century AD, Romans were using detailed instrument drawings that were dimensioned for their building projects of roadways, aqueducts, and buildings. It was not until the fifteenth century that two-dimensional working drawings were used to produce products. Note a few of Leonardo da Vinci's (1452–1519) drawings of his inventions from 500 years ago (**Figure 1-5**). Can you tell what their functions are?

Figure 1-1 *Early humans drew crude pictures on cave walls.*

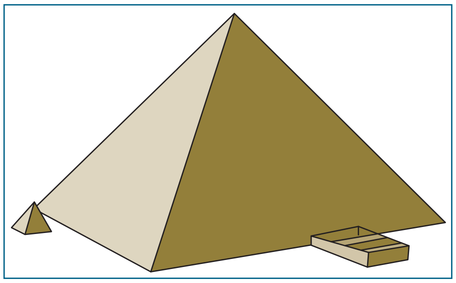


Figure 1-2 *Egyptian Pyramid.*

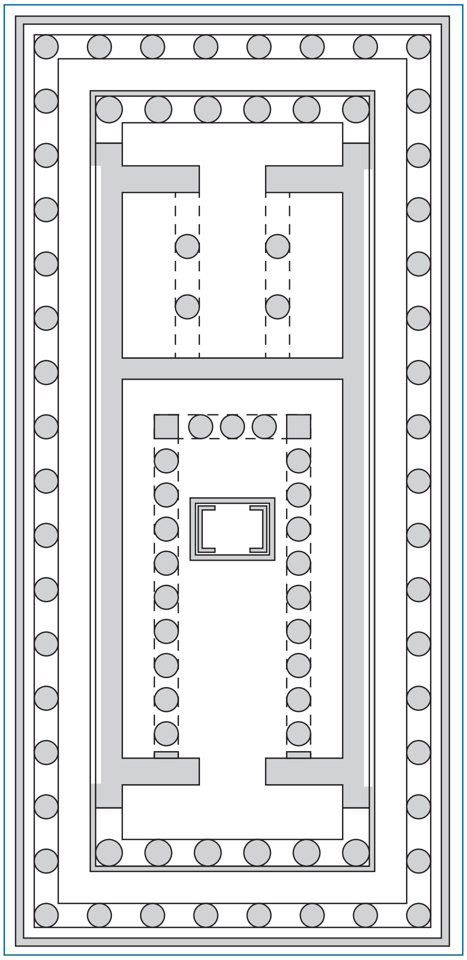


Figure 1-3 *Floor plan of the Greek Parthenon.*

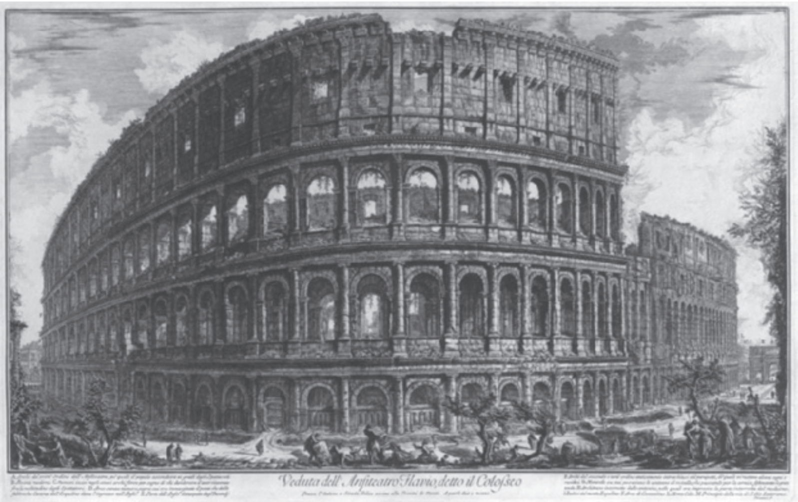


Figure 1-4 *Roman Coliseum.*

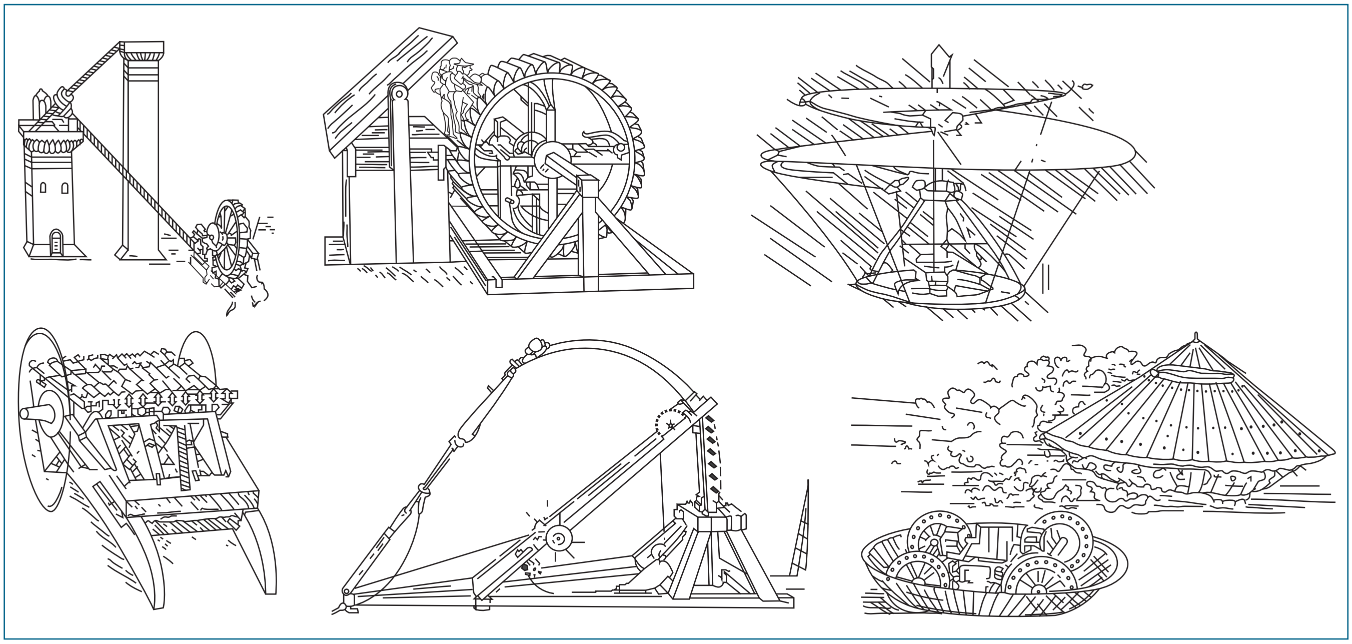


Figure 1-5 *Inventions and drawings by Leonardo Da Vinci.*

The Graphic Language

Human beings routinely communicate with each other through speech, written words, body movements, and an assortment of artistic and technical drawings. Verbal, written, and body language are very effective in communicating personal and social ideas or emotions. Only drawings, not language, are effective in describing the precise shape, size, and form of objects. To illustrate this point, verbally describe the spinning wheel in **Figure 1-6** to a friend. Now show the picture to your friend. How good was your verbal description? This exercise should clearly illustrate the Chinese proverb, "A picture is worth a thousand words."

Drafting is the basic technical form for visual communication. It is the universal language of industry and construction. It will translate the technical ideas, sketches, and the data of engineers and designers into clear, easy-to-read working drawings. Drafting is the basic technical form for visual communication.

Figure 1-6 *The spinning wheel was invented in the 13th Century AD.*

Today's Technical Working Drawings

Most of the aspects of technical graphics (drawings) are common to all the industrial areas of drafting. The major types of drawings are:

- **Multiview drawings** are two-dimensional (2D) views of the object drawn using orthographic projection (See Chapter 8). The complete shape of the item with its dimensions and details is shown with multiview drawings (**Figure 1-7**).

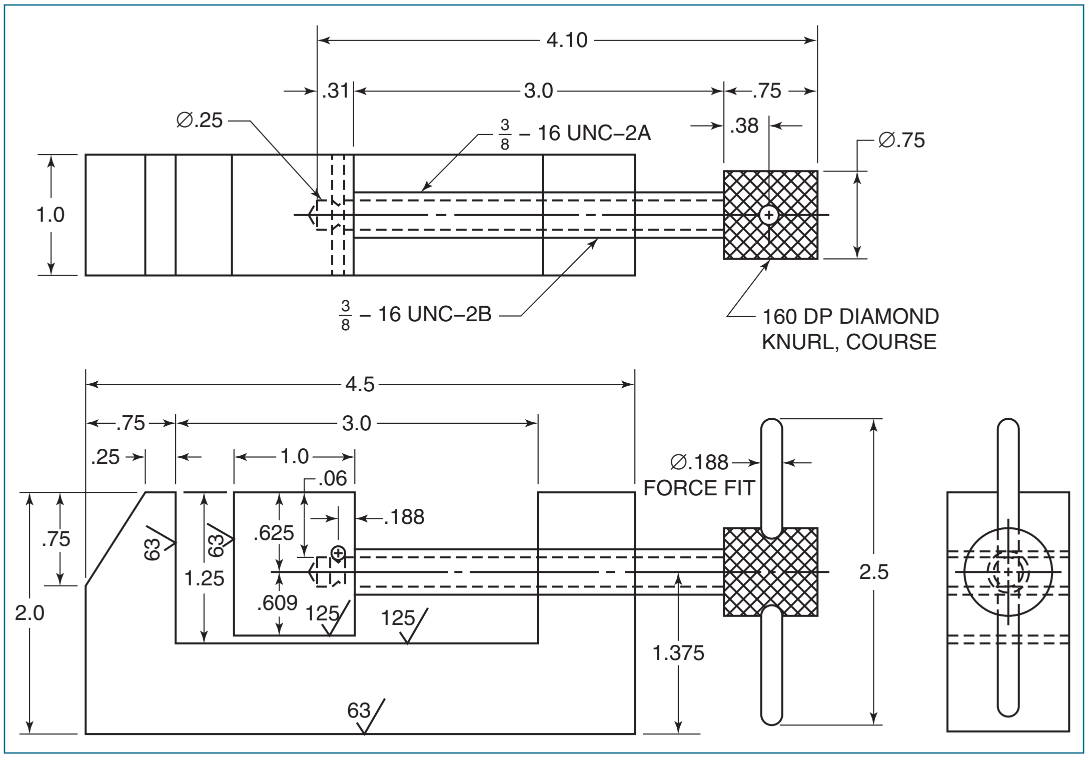


Figure 1-7 *Multiview drawing of a machinist vise.*

- **Pictorial drawings** are three-dimensional (3D) drawings that show an object as in a photograph (**Figure 1-8**). Usually three adjacent surfaces are shown in one drawing (See Chapter 15).
- **Schematic drawings** (See Chapter 22) use symbols and lines to show the flow of energy or fluids (**Figure 1-9**).
- **Block diagrams** are used to show the flow of a working process (**Figure 1-10**).

The use of **American Society of Mechanical Engineers (ASME)** standardized symbols and engineering drawing conventions makes it possible for technical drawings to be interpreted in all countries regardless of the language barriers. All manufactured products and structures, regardless of simplicity (**Figure 1-11**) or complexity (**Figure 1-12**), will still require a technical working drawing. Complex products may require many hundreds of working drawings (**Figure 1-13**).

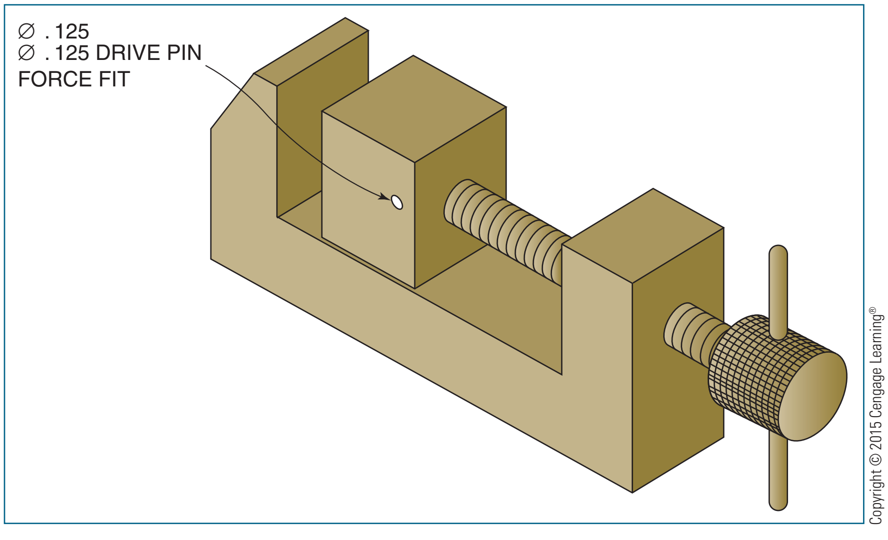


Figure 1-8 *Pictorial drawing.*

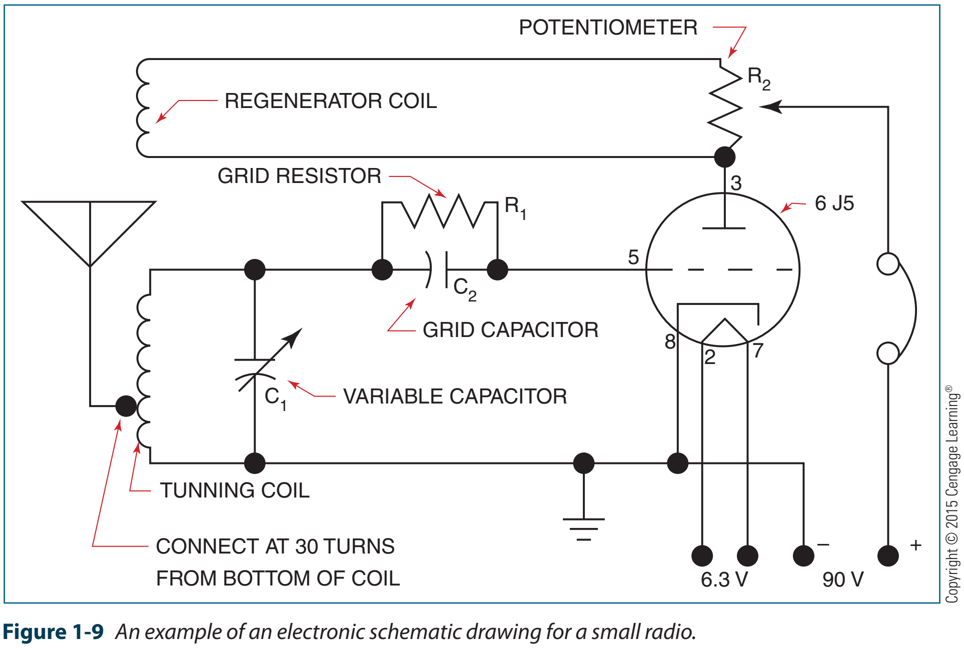


Figure 1-9 *An example of an electronic schematic drawing for a small radio.*

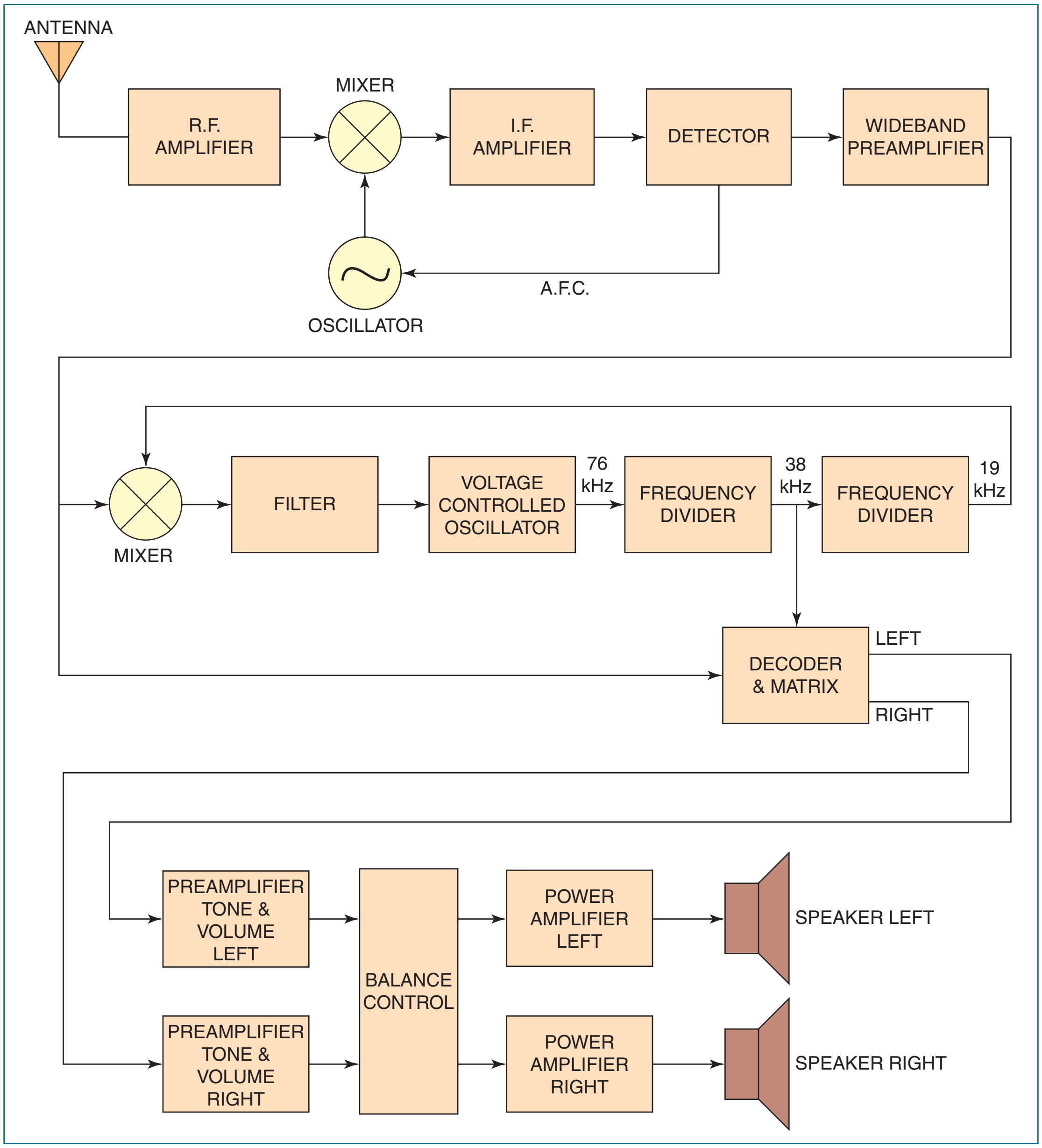


Figure 1-10 *An example of a block diagram for a sound system.*

Today's drafters must possess a broad understanding of the drafting knowledge and skills covered in this text. In addition, drafters must gain the specific knowledge of the manufacturing methods and standards in the specific industry where they work. Regardless of the level of responsibility or the drafting specialization, all drafters must:

- Understand the basics of drafting and design
- Be familiar with the basic types of engineering drawings (**Figure 1-14**).
- Clearly communicate ideas with freehand sketches
- Be proficient with computer-aided drafting and design systems
- Have some skill with manual drafting instruments

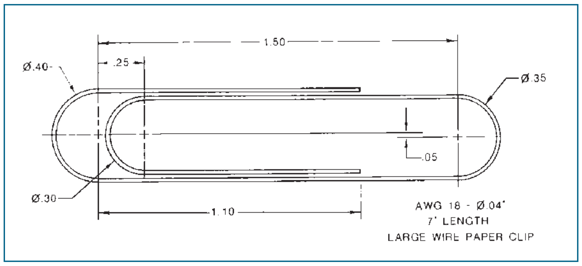
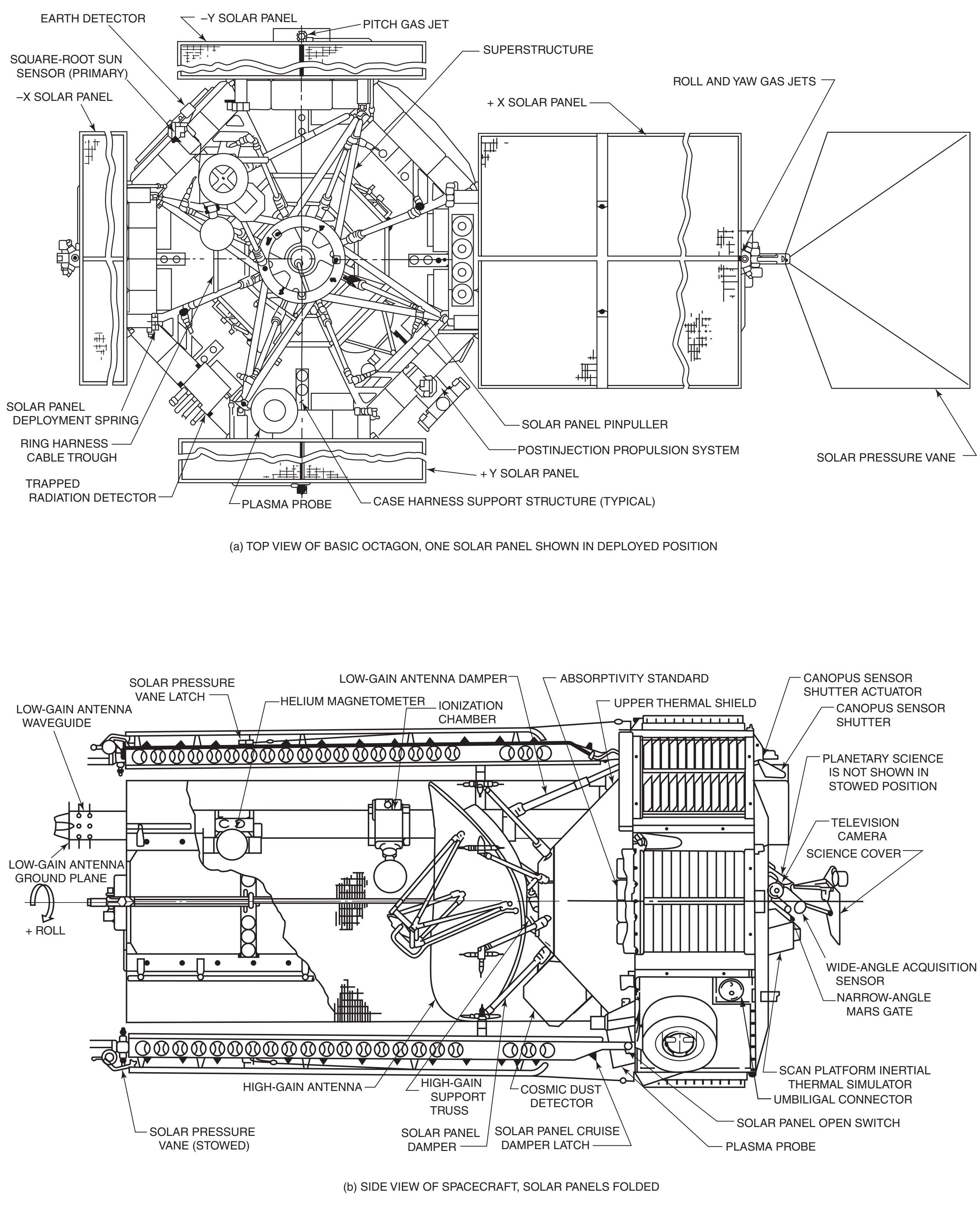


Figure 1-11 *The design and manufacture of a simple paper clip requires technical working drawings.*



Courtesy of the NASA FOIA program

Figure 1-12 *Mariner-Mars Space Craft.*

The Graphic Creators

Because each industry is highly specialized, the drafters in each industry must have the knowledge to correctly design and draw each part for manufacture. The personnel involved with designing and producing the working drawings may be placed into three general categories according to their formal education, knowledge, creativity, experience, and work ethics. These categories are top-level professionals, midlevel drafters, and intern-level drafters.

Regardless of the level an individual may reach, she or he should concentrate during the high school years on classes in math, physics, science, and drafting. This will provide a good background to start a formal education or an intern-level position in industry.


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Figure 1-13 *It will take many working drawings to accurately manufacture this robot welder.*

THE TOP-LEVEL PROFESSIONAL

The formal education for all top-level professionals is a college degree (BA, MA, or PhD). Often an internship and a state license in a specialty is required. These professionals have the responsibility for the successful designing and manufacturing operations. That is why they draw the largest salaries. Following is a brief description of several professional areas:

- The **aeronautical** and **astronautical engineers** perform a variety of work related to the research, planning, designing, manufacturing, and testing of airplanes, satellites, rockets, and spaceships.
- The **architect** does the planning, designing, environmental study, structural engineering, and supervising of the construction for all types of construction.
- The **cartographer** does the planning and drawings for all types of maps.
- The **civil engineer** plans does the planning, designing, and supervision for roads, airports, harbors, dams, tunnels, and most construction systems that are not inhabited buildings.
- The **chemical engineer** plans the research to develop new and improved industrial chemicals for manufacturing processes and production procedures.
- The **developmental engineer** does the data research for the development of new ideas and new products.
- The **drafting/engineering supervisor** coordinates all the workers involved with the production of all the working drawings for specific projects. It is her or his responsibility to get well-designed and error-free working drawings finished on schedule.
- The **electrical/electronics engineer** does the planning, designing, and supervising of the manufacturing of electrical and electronics components such computer systems, and all other types of electrical/electronic systems.
- The **environmental engineer** does the research and study of the materials and the effect a product may have on the environment. Also called green engineering.

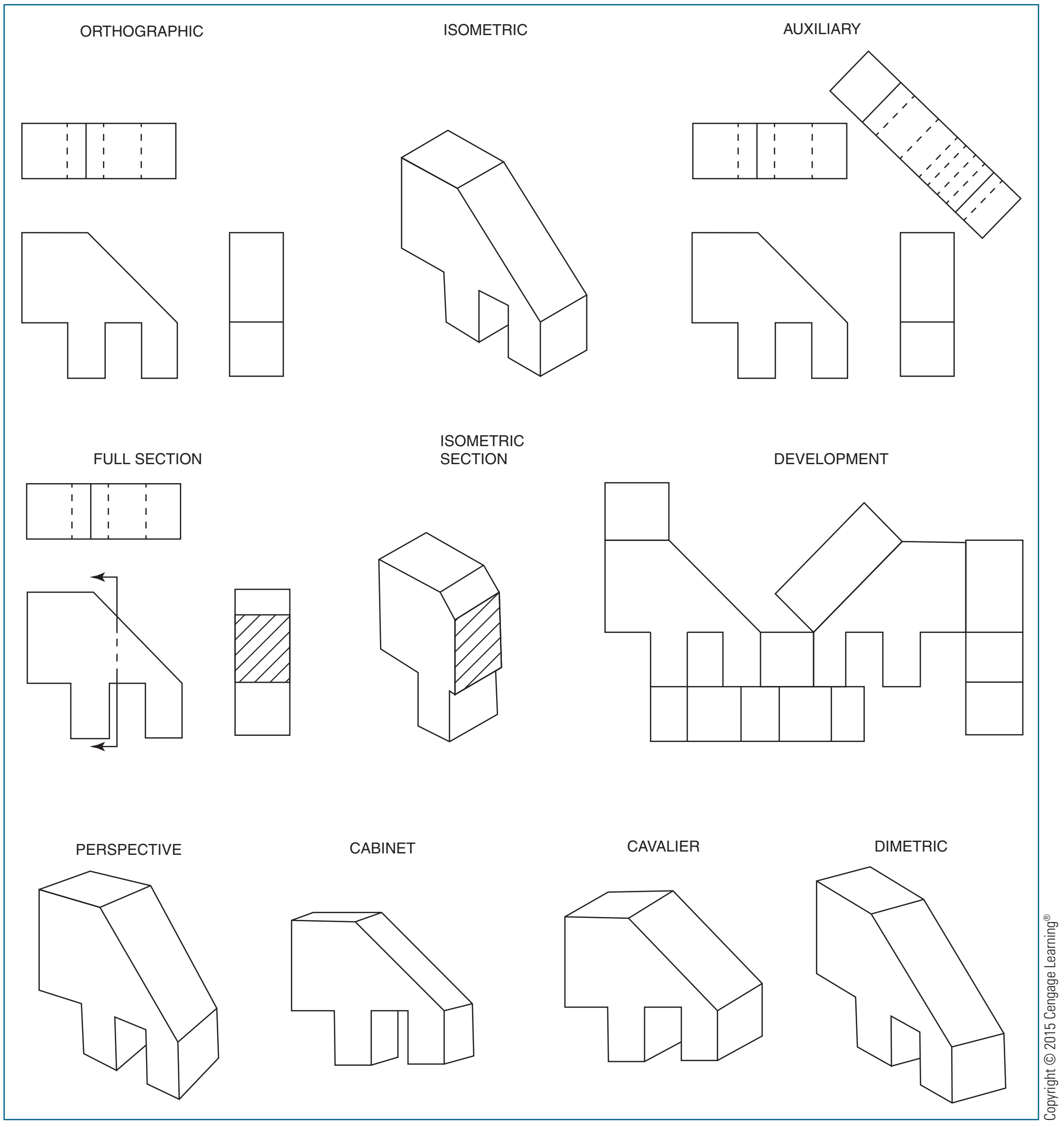


Figure 1-14 *Types of engineering drawings.*

- The **industrial designer** is a creative person who will use new ideas and materials to design a functional and attractive external package for industrial products.
- The **industrial engineer** and **mechanical engineer** works in all areas of industry, applying the math and physics to machines and parts so they will function properly and safely.
- **Instructor of engineering** or **drafting** is a rewarding position for people who enjoy working with helping others. Teaching positions in secondary schools, technical schools, colleges, and universities are open to people with degrees and/or teaching credentials with industrial experience.
- The **molecular** and **nanotechnology engineers** research and develop products on a molecular level that are used in the medical field and often in industrial products.

- The **robotics engineer** specializes in the design of robotic tools for industry and miscellaneous items such as toys.
- The **tool designer** plans and designs the tools used to produce the manufacturing systems, machinery, and tools for all areas of the industrial production.

MIDLEVEL DRAFTERS

Midlevel drafters are the technicians. It is recommended that they obtain an AA degree from a technical school. They should have a broad and diversified job classification, depending on their education, knowledge, creativity, drafting skills, and attitudes. They are classified as semi-professionals. Most will be supervised by the top-level professionals. Some technicians, even though they do not have a college degree, are highly capable and may perform the top-level job activities, but they will not reach the top salary levels.

Following is a brief description of some of the positions for midlevel drafters:

- The **checker** is an experienced drafter whose responsibility is to see that all the drafters' working drawings are properly drawn and are error-free. This is critical, because correcting an error during production is very expensive.
- The **chief /senior drafter** supervises the drafting personnel and sets the parameters for the standards, practices, schedules, and drawing procedures for the project's set of working drawings.
- The **commercial artist** prepares attractive illustrations for magazines, books, posters, and so on, to help promote recognition and sales of the manufactured item.
- The **design technician** combines design skills and drafting ability, usually working from the top-level sketches.
- The **senior detailer** is skilled in understanding the engineer's concepts and can produce complex working drawings needed for manufacture.
- The **technical illustrator** creates three-dimensional drawings from the working drawings. The drawings are used to view a complicated part for a better understanding, or to show an exploded drawing of all the individual parts to simplify its assembly.

INTERN-LEVEL DRAFTERS

Intern-level drafters do not require a formal technical education, but receive on-the-job training. However, it is recommended that they have some training from a two-year or technical college with drafting and CAD training. Many engineers and technicians will have interns working with them.

The following is a brief description of some intern-level drafting positions:

- The **computer-aided drafting operator (CAD)** must have the CAD skills that are important for all designers and drafters. These are an asset in gaining employment and advancement in the workplace.
- The **junior detailer** prepares simple working drawings from the sketches of the senior detailer and corrects drawing errors marked by the checker.

- The **junior drafter** should have good manual drafting and lettering skills and be trainable on a CAD system. He or she starts with simple working drawings and is closely supervised.
- The **printing operator** makes reproductions of working drawings on various types of equipment such as copy machines, cameras, and printers connected to a computer or from a CD.
- The **tracer** is the most basic entry level position. This job requires good drafting and lettering skills because it involves the copying or recopying sketches or quick drawings from the engineers and designers who did not take the time to do a neat drawing.

The Design Process

The design process will involve all levels of personnel involved. Each industry will vary in its design process, but the goal of an efficient product remains the same. A typical design process from beginning to end might be:

1. Recognition of needs
2. Scientific investigation
3. Proposal of concept
4. Layout and development drawings
5. Conceptual design reviews and analysis
6. Component testing of a prototype
7. Final design review
8. Detail design drawings
9. Quality assurance
10. Manufacturing
11. Assembly
12. Final testing
13. Sales
14. Planning for the second-generation upgrade

Nearly every phase of the 14-step design process will require some degree of freehand sketching, manual drafting and CAD for the development of ideas and working drawings.

Conclusion

With today's advancing technologies, we are continually improving existing industries and creating new ones. All industries will require a degree of graphic drawings for manufacturing, assembly, maintenance, and sales.

There are now over one million women and men working in the drafting, design, and related positions. As more products are developed and manufactured, and more buildings are designed and constructed, the need for personnel with high levels of drafting skills and knowledge will continue to increase.

DRAFTING EXERCISES

1. Select one of the professional positions that you find interesting and write a short paper on the education, training, and the type of work it involves.
2. Select one of the midlevel drafting positions that you find interesting and write a short paper on the education, training, and the type of work it involves.
3. If you had to go to work directly from high school, what type of intern position would you prefer? Write a paper on how you would prepare yourself for the internship.
4. Interview a college counselor and list the high school prerequisites needed for acceptance into an college engineering program.
5. Interview a technical or community college counselor and list the recommended high school classes needed for enrollment in a technical program.
6. Talk to high school counselor about applying for a scholarship or educational grant.
7. Practice writing a resume to use to apply for an internship drafting position.
8. Visit an industry using a CAD system. Interview the CAD operator and take notes on her or his background, education, training, and work performed on the CAD system.
9. Observe the Mainer-Mars spacecraft drawing in **Figure 1-12**. List the personnel involved with its design and drawings.
10. Discuss the concepts of the jet's multiview drawings in **Figure 1-15**.

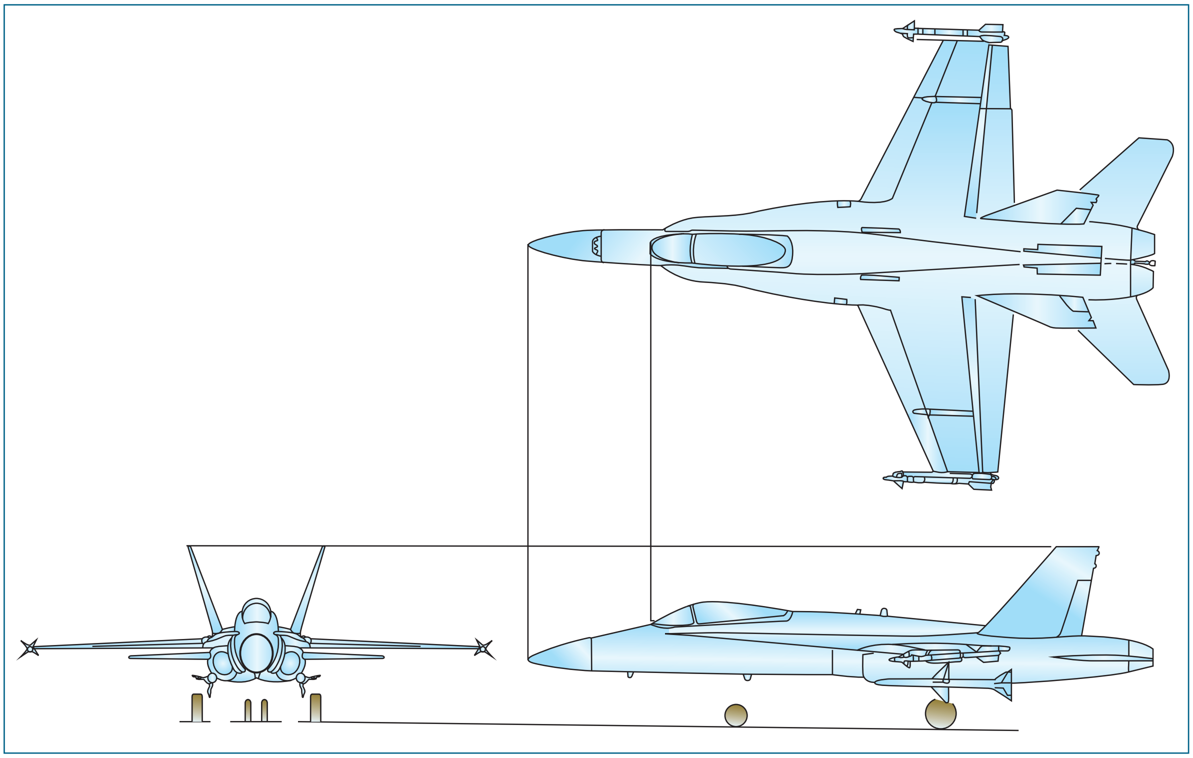


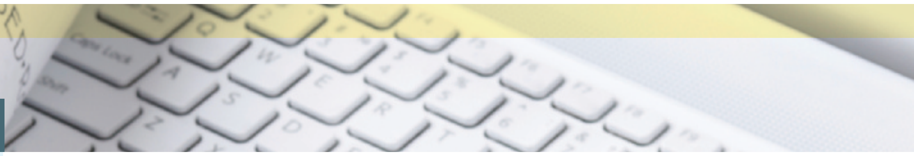
Figure 1-15 *Discuss the concepts of the jet's multiview drawings.*

KEY TERMS

- Aeronautical engineer
- Architect
- Astronautical engineer
- American Society of Mechanical Engineers (ASME)
- Block diagram
- Cartographer
- Checker
- Chief/senior drafter
- Chemical engineer
- Civil engineer
- Commercial artist
- Computer-aided drafting operator
- Design technician
- Developmental engineer
- Drafting/engineering supervisor
- Electrical/electronics engineer
- Environmental engineer
- Industrial designer
- Industrial engineer
- Instructor of engineering/drafting
- Junior detailer
- Junior drafter
- Mechanical engineer
- Molecular/nanotechnology engineers
- Multiview drawing
- Parchment
- Parthenon
- Pictorial drawing
- Printing operator
- Robotics engineer
- Schematic drawing
- Senior detailer
- Technical illustrator
- Tool designer
- Tracer

2

Drafting Equipment and Supplies



OBJECTIVES

The student will be able to:

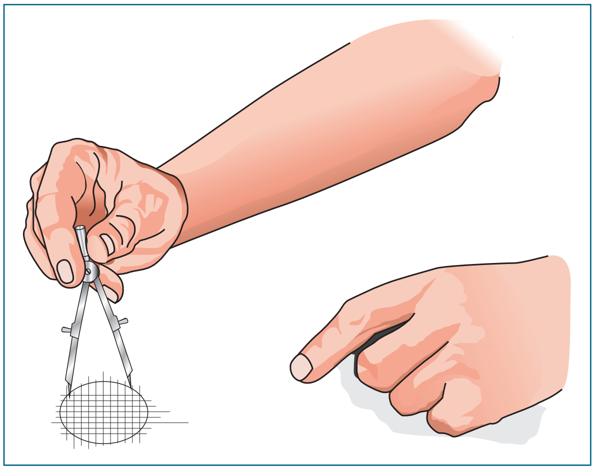
- Understand the function of manual drafting instruments and supplies
- Complete a pencil drawing using drafting instruments
- Measure with a civil engineer's scale
- Measure with a mechanical engineer's scale
- Measure with a metric scale
- Measure with an architect's scale

Introduction

There are three basic forms of drafting procedures. They are:

1. Freehand sketching (**Figure 2-1**)
2. Manual drafting (**Figure 2-2**)
3. Computer-aided drafting (CAD) (**Figure 2-3**)

The drafter must be familiar with all three methods so he or she can select the best method to fit the needs for the design requirements. Note the variations of drawing times with the three drafting



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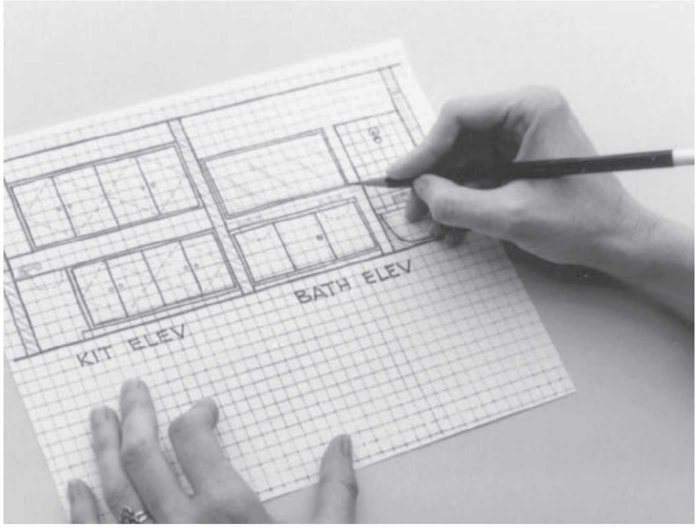

Courtesy of Ann Ross Wallach

Figure 2-1 *Freehand sketching on quarter-inch grid paper.*

© Steven Morris/E+/Getty Images

Figure 2-2 *Manual drafting.*

methods in **Figure 2-4**. The final drawings must be dimensionally correct, accurate, and easily readable using the correct standards. It is, therefore, critical when enrolled in an engineering or architectural drawing and design class to first obtain knowledge of the concepts of the subject, *before,* learning how to operate a CAD system. Without this knowledge, your CAD drawings will be useless in industry.

The successful drafter, designer, engineer, or architect should be skilled with freehand sketching and manual drafting for the following reasons:

- A CAD system may not always be available.
- Not all companies can or will supply CAD systems to every drafter.
- Field drawings and instructional sketches might have to be completed in environments hostile to computers.
- Creative design in many areas is still done in pencil.
- There may be times when the CAD system cannot create a specific type of detail. It would be expedient to make a print of your drawing and complete the detail with manual drafting instruments.

Manual Drafting Supplies

This section described manual drafting supplies (**Figure 2-5**).

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Figure 2-3 *This CADD workstation has a computer, keyboard, mouse, and flat-panel monitor.*

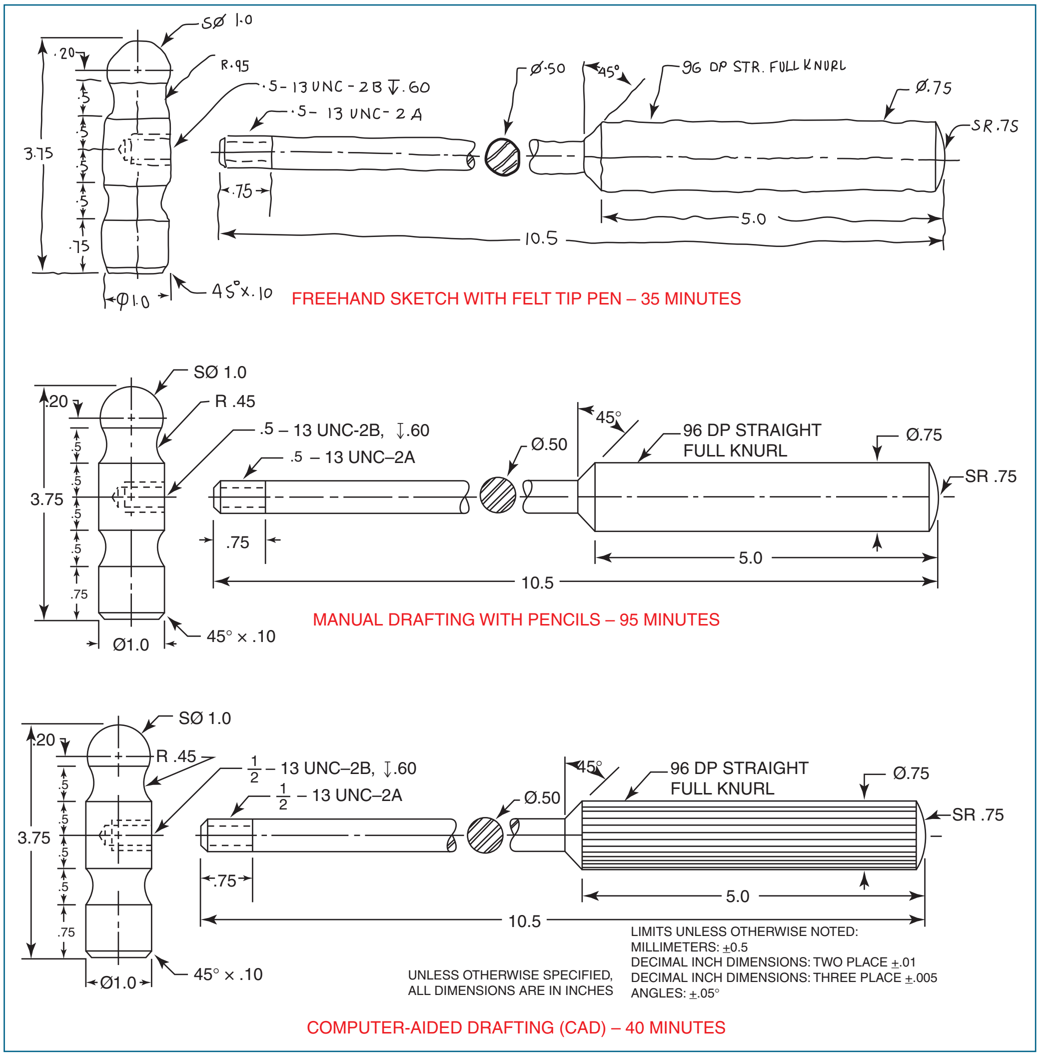


Figure 2-4 *Drawing times for Ball-peen hammer.*

Figure 2-5 *Manual drafting supplies.*

DRAWING BOARDS

Drawing boards come in many different sizes to fit large drawing formats. The typical size for a manual drafting class is 20" × 26" basswood drafting board, as shown in **Figure 2-6**.

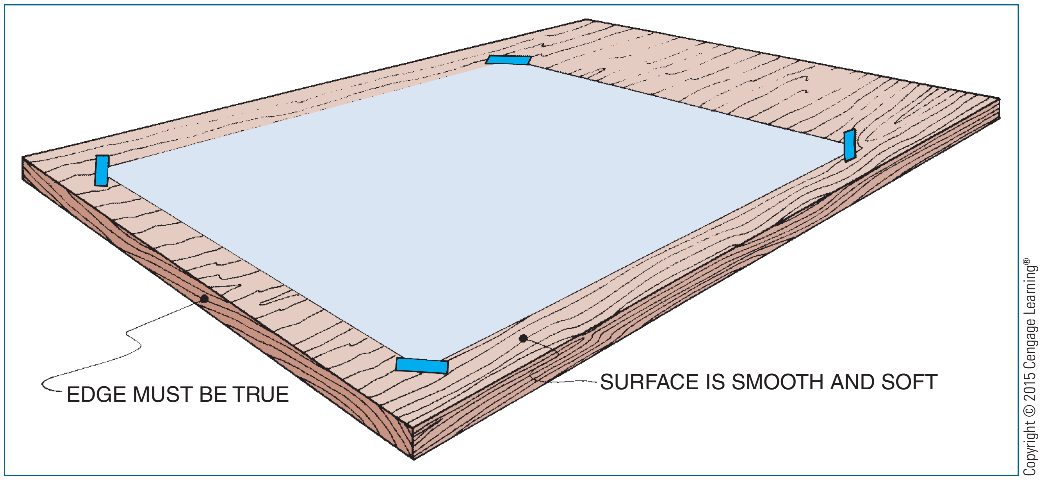


Figure 2-6 *Drawing board qualities.*

DRAWING PAPERS

Drawing papers include a variety of materials that may be used for drafting:

- **Opaque drawing paper** is a heavy paper that comes in white, buff, and light green.
- **Tracing paper** is a thin, transparent, inexpensive paper that is usually used for sketching ideas. It tears easily when handled or erased. It is not used for permanent type of drawings.
- **Vellum** is a transparent paper that is treated with oils and chemicals to make it heavier and durable.
- Polyester **film** is a transparent and indestructible media. Because of its smooth surface, only a black plastic led pencil or ink can be used to draw on its smooth surface (**Figure 2-7**).
- **Grid paper** is printed with various patterns. The grid paper used for engineering drawing is usually the inch divided into 10 parts or 2 millimeters for metric drawings. Architects use the 1/8" or 1/4" graph paper (**Figure 2-8**).

All drafting papers come in rolls or cut sheets (**Figure 2-9**). Standard cut sheet paper sizes are shown in **Figure 2-10**. Drafting tape is used to hold the paper to the drafting board (**Figure 2-11**).

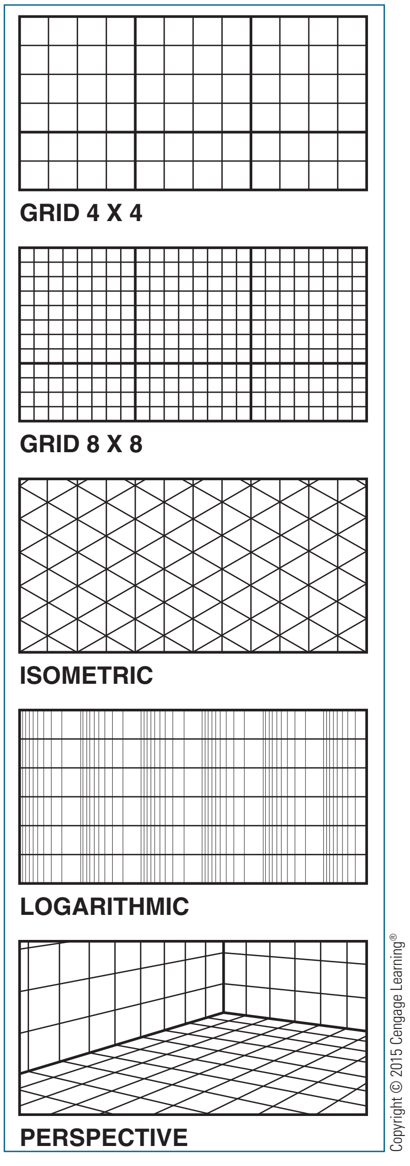


Figure 2-8 *Examples of grid paper.*

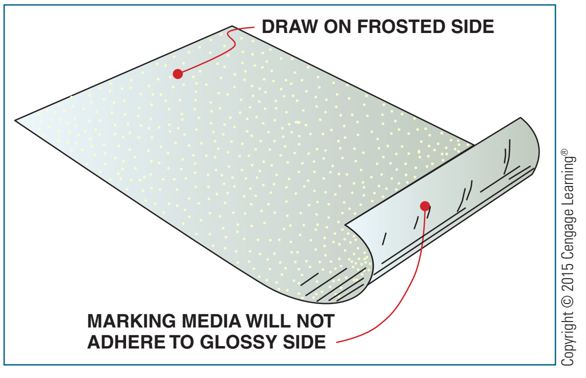


Figure 2-7 *Drawing on polyester drafting film.*

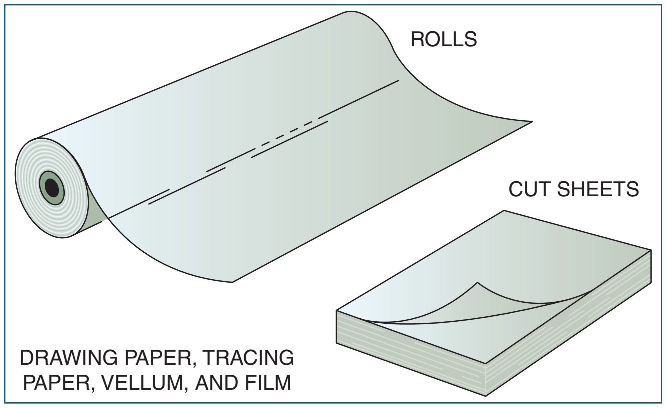


Figure 2-9 *Paper is manufactured in rolls and sheets.*

LETTER SIZES	STANDARD SIZES	
A	9 × 12	8.5 × 11
B	12 × 18	11 × 17
C	18 × 24	17 × 22
D	24 × 36	22 × 34
E	36 × 48	34 × 44
F	28 × 40	

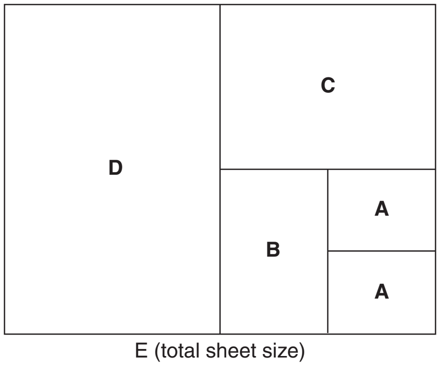


Figure 2-10 *Standard cut paper sizes.*

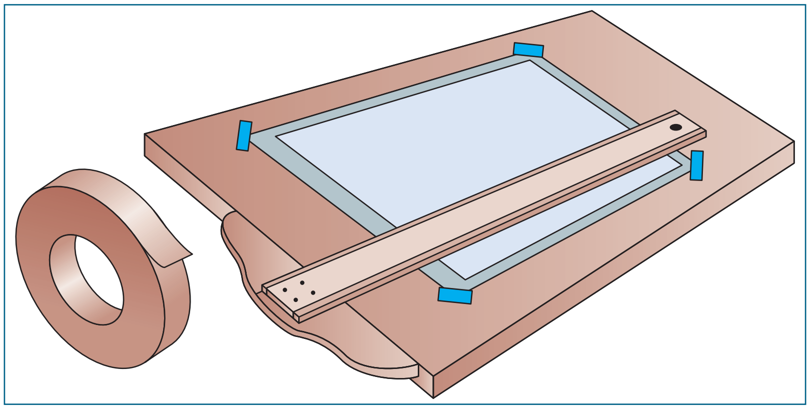


Figure 2-11 *Drafting tape is the most efficient method to attach drawing media to the drawing board's surface.*

DRAFTING PENCILS

The two most common **drafting pencils** are wood and thin-lead mechanical pencils. The graphite leads are in various degrees of hardness and softness (**Figure 2-12**). The recommended pencils for drafting are shown in **Figure 2-13**. Sharp points produce fine lines, while round or dull points produce broad lines. Sharpening devices for drafting pencil points include hand or electric rotating sharpeners, cylindrical lead pointers, and sandpaper for hand-pointing leads.

Thin-lead mechanical pencils do not require either sharpening or pointing. Leads for mechanical holders are available in all grades; fine-line leads are available in thicknesses of 0.3, 0.5, 0.7, and 0.9 mm. Drafting leads are made of graphite, not lead. However, some drafting leads are made of plastic specially designed for use on drafting film. After drawing with any graphite lead, remember to brush the surface periodically with a dusting brush to remove the accumulation of foreign matter and eraser leavings.

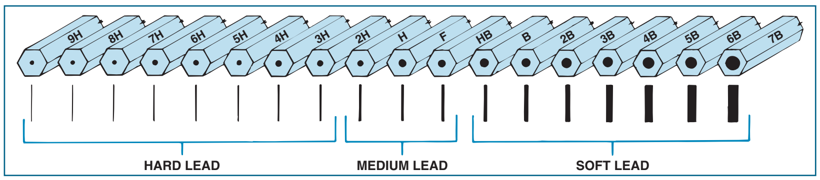


Figure 2-12 *The various degrees of draftiung pencils and their graphite lead widths.*

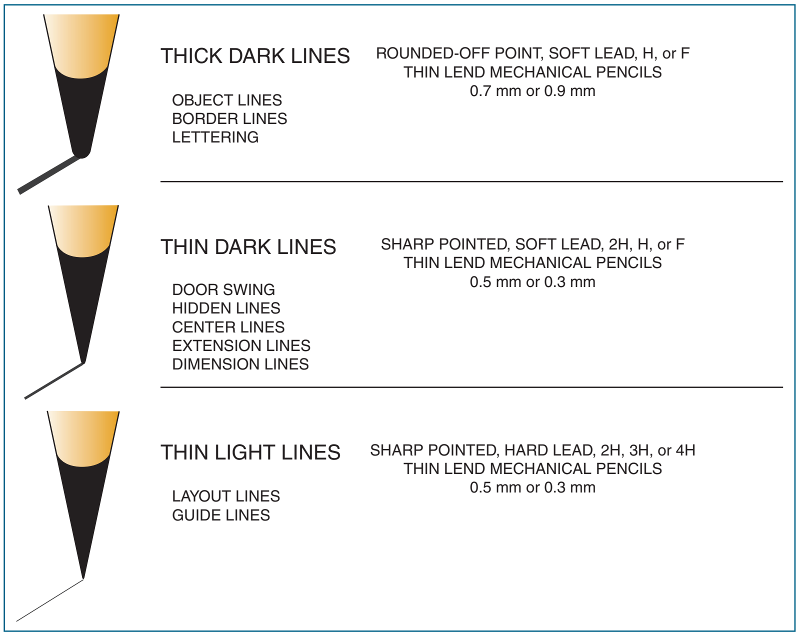


Figure 2-13 *Recommended pencils for manual drafting.*

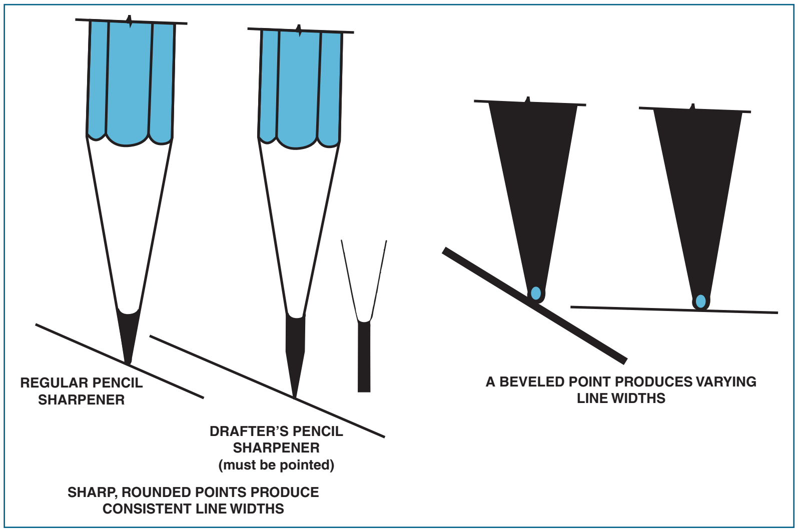


Figure 2-14 *Pointing the drafting pencil.*

When drawing, it is important to rotate the pencil so the point does not become beveled, because it will produce different line thicknesses (**Figure 2-14**).

ERASERS

An eraser is used to eliminate construction lines, drafting errors, and graphite smudges from the drawing surface. A rubber eraser is best for most line work. A soft vinyl eraser is good for light lines and smudges. When using an eraser it is often helpful to use an erasing shield to ensure that only the desired line area is erased (**Figure 2-15**).

T SQUARES

The **T square** comes in various lengths to fit different sized formats. For the 20" × 26" drawing board, a 24" T square is recommended. Keep the T square firmly against the left side of the drawing board when drawing horizontal lines (**Figure 2-16**).

TRIANGLES

The two drafting **triangles** used with manual drafting are the 30-60-degree and the 45-degree triangles (**Figure 2-17**). They are available in several sizes. The recommended sizes are 10" for the 30-60-degree triangle, and 8" for the 45-degree triangles. Be certain to hold the T square and the triangles firmly with one hand when drawing the lines (**Figure 2-18**).

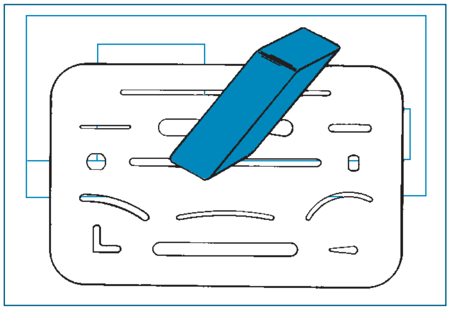


Figure 2-15 *The erasing shield protects lines not to be erased.*

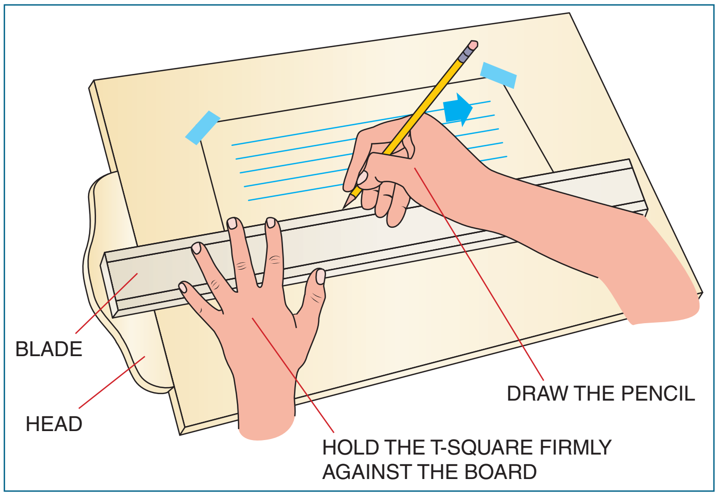


Figure 2-16 *Drawing horizontal lines.*

Incremental angles of 15 degrees may be drawn with the two triangles (**Figure 2-19**). An adjustable triangle (**Figure 2-20**) can be set at any required angle.

COMPASSES

Compasses are used to draw circles and arcs. The **bow compass** is usually used for drafting (**Figure 2-21**). It is important to adjust the shoulder needle and sharpen the graphite lead on a rough surface before using it (**Figure 2-22**).

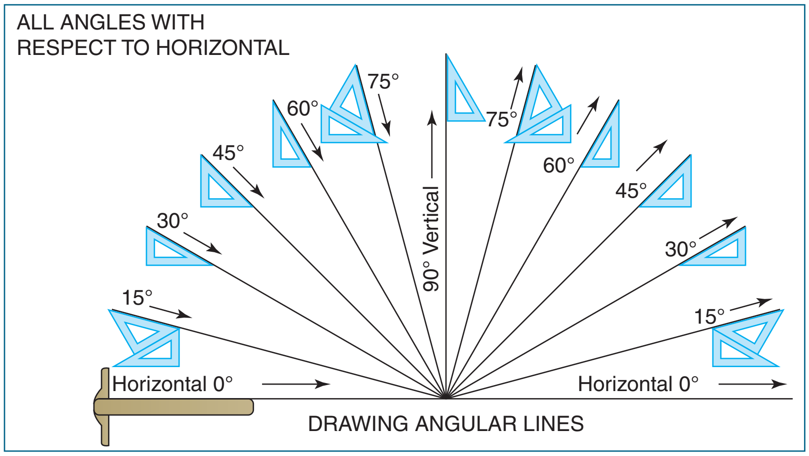


Figure 2-19 *Drawing angles at 15° increments.*

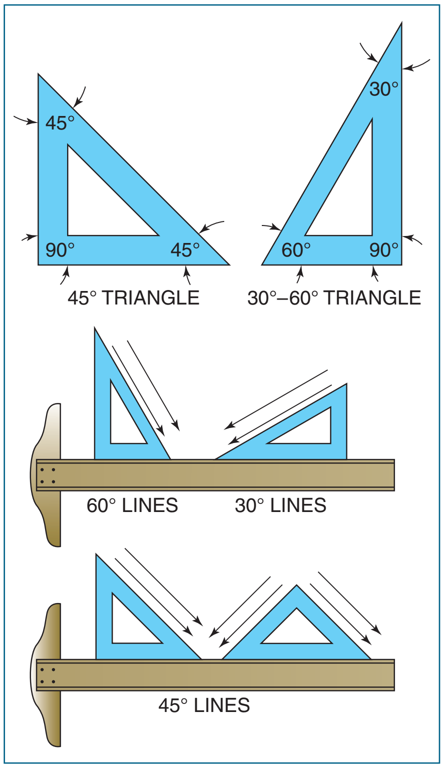


Figure 2-17 *Drawing 45°, 30°, and 60° lines.*

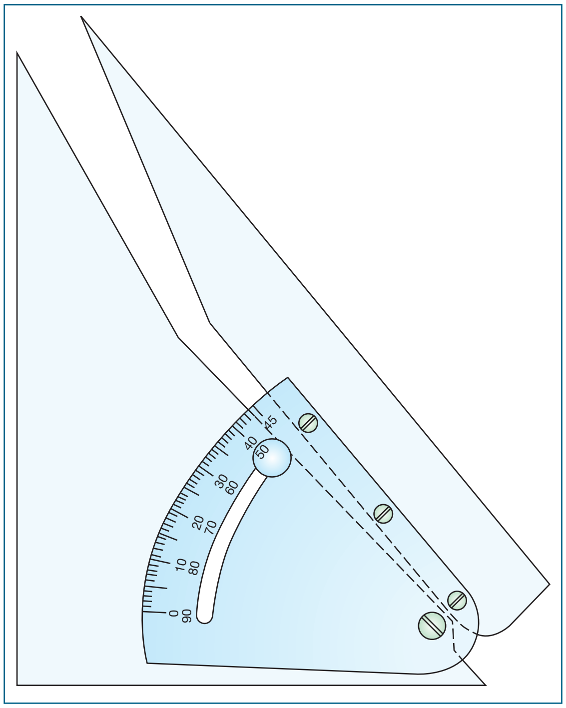


Figure 2-20 *Adjustable triangle.*

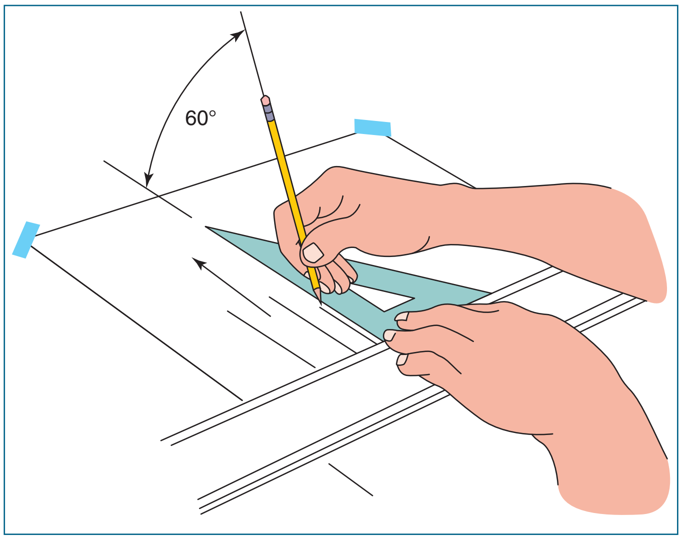


Figure 2-18 *Drawing with a T-square and triangle.*

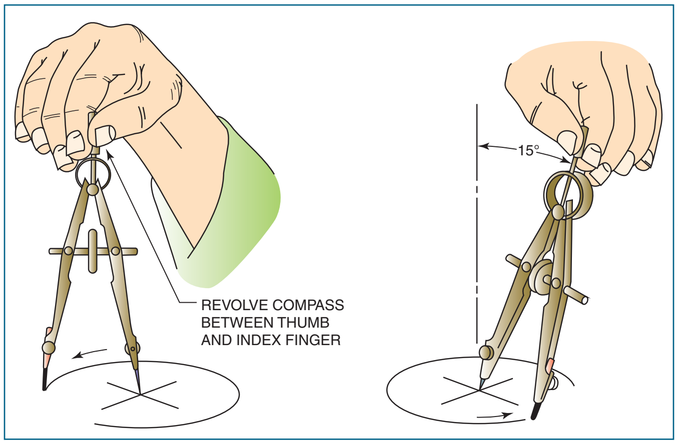


Figure 2-21 *Drawing procedure for handling a bow compass.*

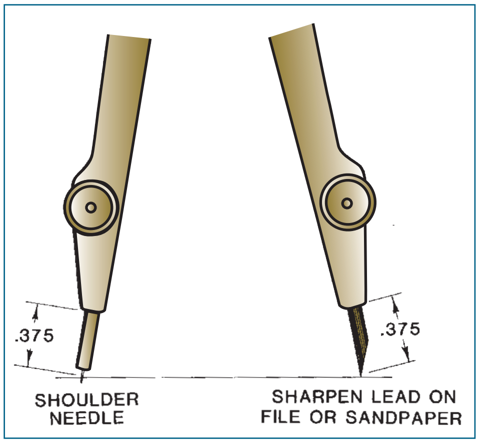


Figure 2-22 *The compass point and the compass lead.*

DIVIDERS

Dividers are similar to compasses except that both tips are pointed. They are very helpful to divide a line or transfer distances from one drawing to another (**Figure 2-23**).

PROTRACTORS

A **protractor** is used to lay out a specific angle on a drawing or measure an existing angle (**Figure 2-24**).

IRREGULAR CURVES

All drawings are composed of straight lines, circles, arcs, and irregular lines. All these lines must be drawn with drafting instruments. An **irregular curve**, also called a French curve, is used to draw the irregular lines (**Figure 2-25**). Only the lettering on a manual drawing is done freehand.

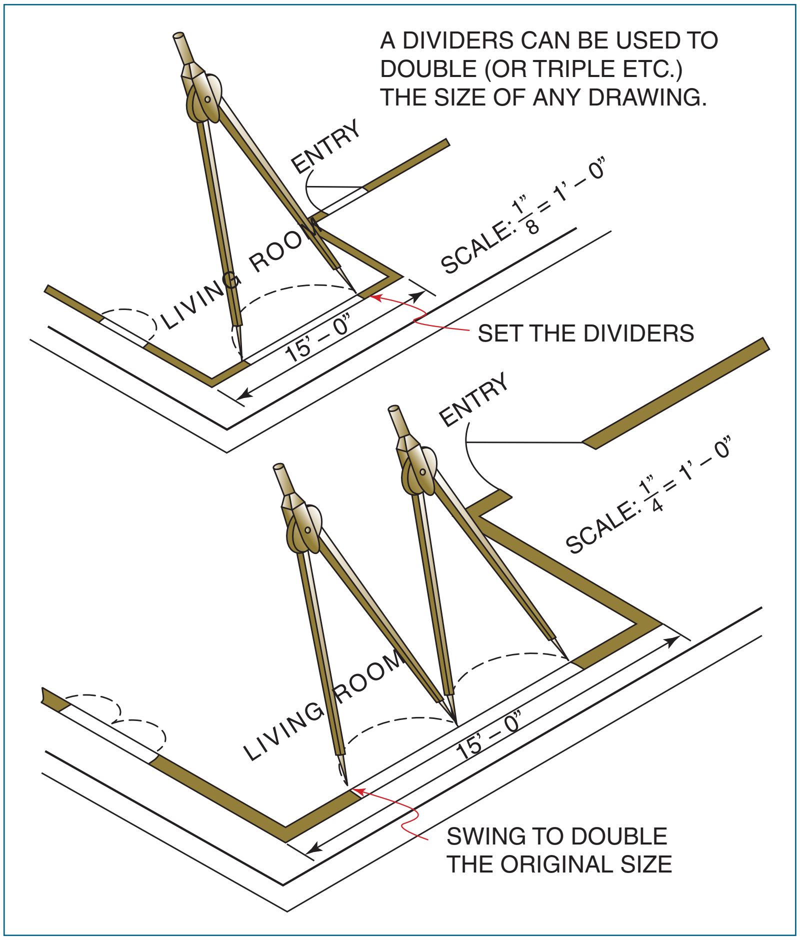


Figure 2-23 *Stepping off dimensions with the dividers.*

TEMPLATES

Templates for drawing symbols and geometric figures are available for all areas of engineering and architectural drawing. An electronics template is shown in **Figure 2-26** and an architectural template in **Figure 2-27**. As small circles are difficult to draw with a compass, a circle template will be required (**Figure 2-28**).

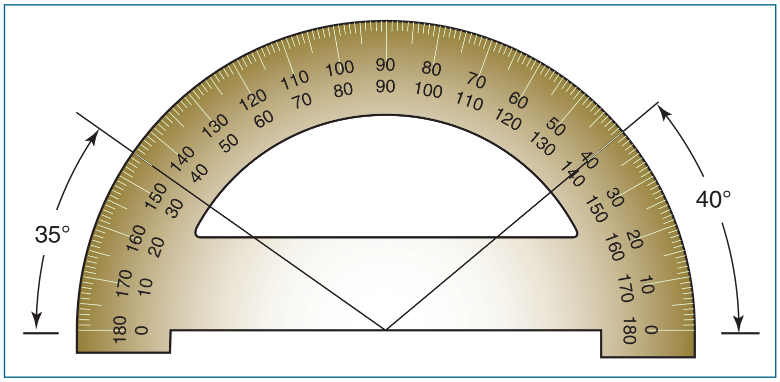


Figure 2-24 *Protractor.*

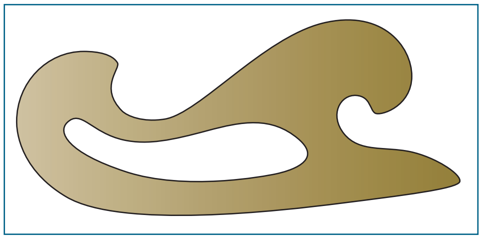


Figure 2-25 *Irregular curve.*

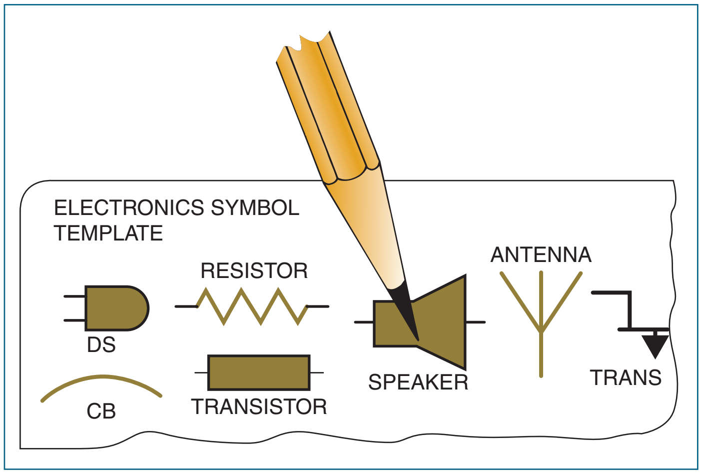


Figure 2-26 *Line up and position the graphic symbol on the schematic drawing and trace around the inside of the cut-out symbol.*

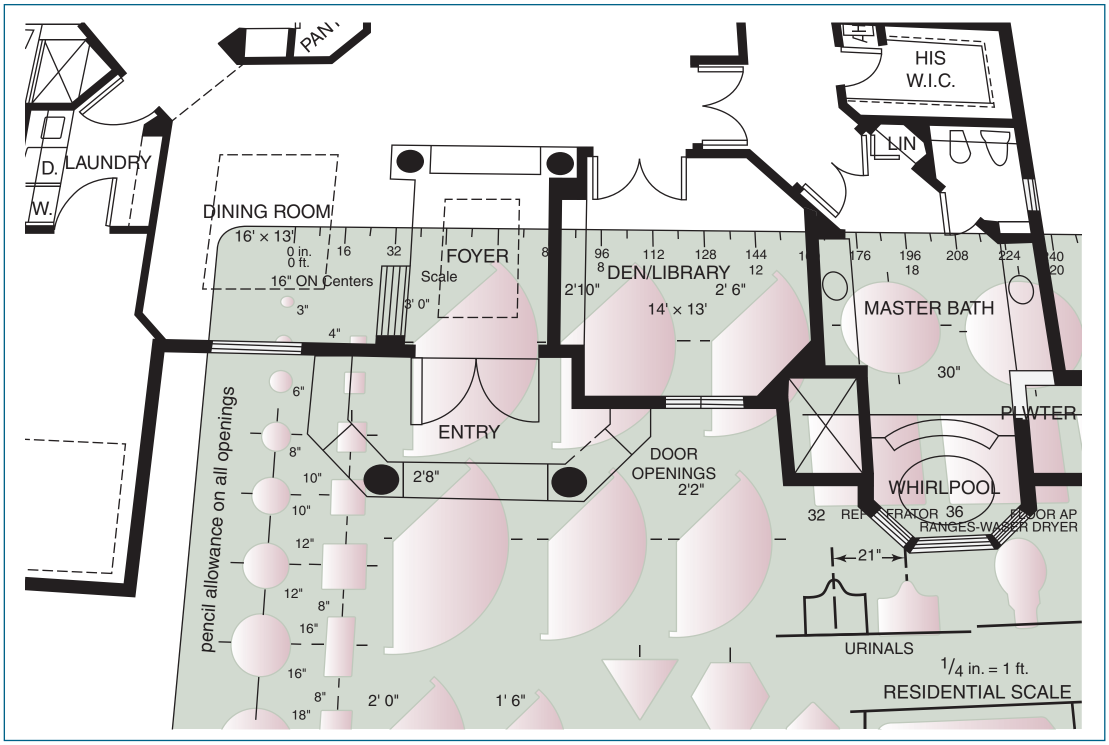


Figure 2-27 *Architectural template.*

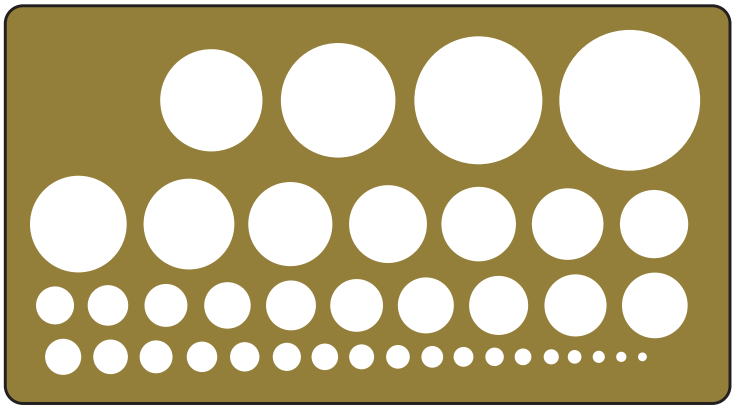


Figure 2-28 *Circle template.*

DRAFTING SCALES

Whether you draw with manual equipment or with a CAD system, an understanding of different scales is essential. Scales are available in several different shapes **(Figure 2-29)**. Scales allow drafters to create accurate drawings that are proportioned to the actual size of the object being drawn. Scales are based on either the **U.S. customary system** or the **metric system**. Scales used in drafting include the mechanical engineer's scale, the civil engineer's scale, the architect's scale, and the metric scale.

The **mechanical engineer's scale** uses a U.S. customary inch-fraction unit of measure **(Figure 2-30)**. Scale subdivisions include 1/32", 1/16", 1/8", 1/4", 3/8", 3/4", 1/2", and 1" units.

The **civil engineer's scale** uses a U.S. customary inch-decimal unit of measure **(Figure 2-31)**. The inch-decimal unit is used by most industries using the U.S. customary system. Civil engineer's scale subdivisions include 10, 20, 30, 40, 50, and 60 parts per inch.

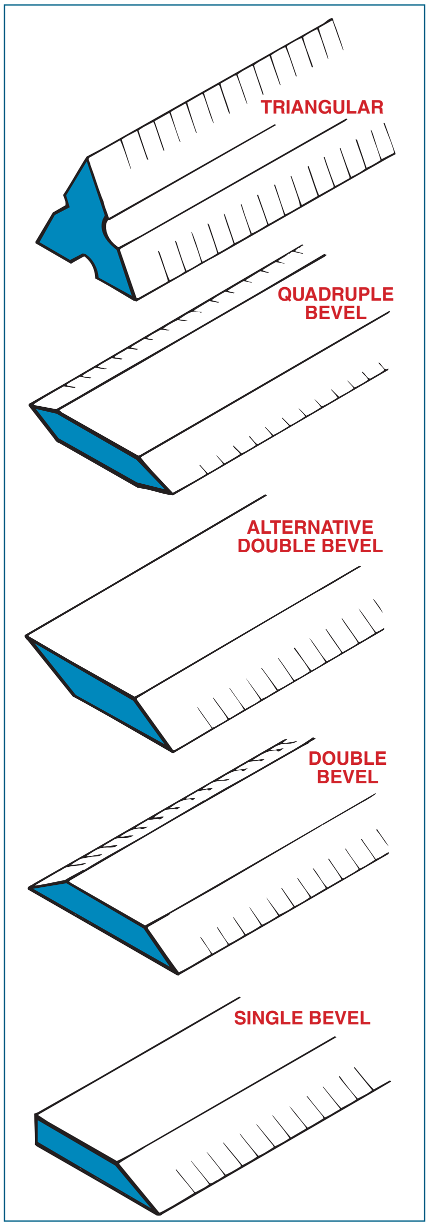


Figure 2-29 *Various scale shapes.*

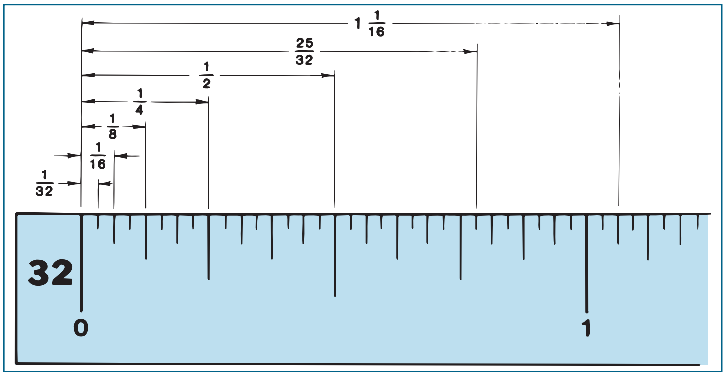


Figure 2-30 *The mechanical engineer's scale uses inch-fraction units of measure.*

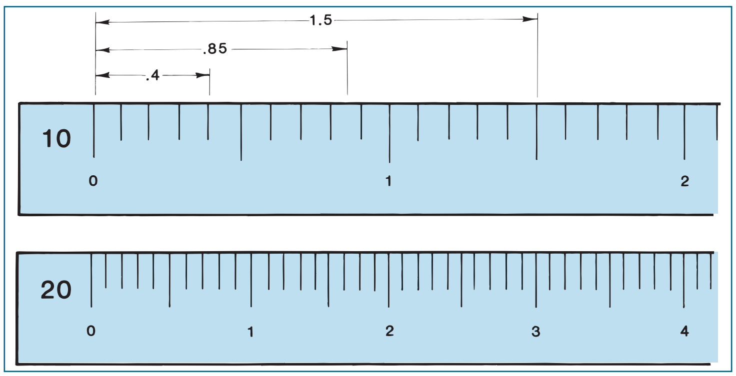


Figure 2-31 *The civil engineer's scale uses inch-decimal units of measure.*

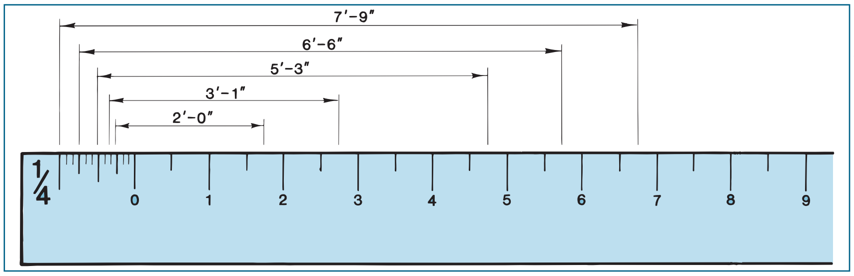


Figure 2-32 *The architect's scale uses foot-inch units of measures. The most often used architect's scale is 1/4″ = 1′–0″.*

The **architect's scale** is used to prepare plans for structures. The foot is divided into twelve parts, so inches on a drawing can equal the actual inch or feet dimensions of a building **(Figure 2-32)**. For example, most architectural drawings are prepared to a scale ¼" = 1'–0". This means that a ¼" line on a drawing represents one foot on a building. Thus, at ¼" = 1'–0" scale, an 8' wall would appear 2" long on the drawing. The various architect's scales are 3⁄32", 3⁄16", ⅛", ¼", ⅜", ¾", ½", 1", 1½", and 3".

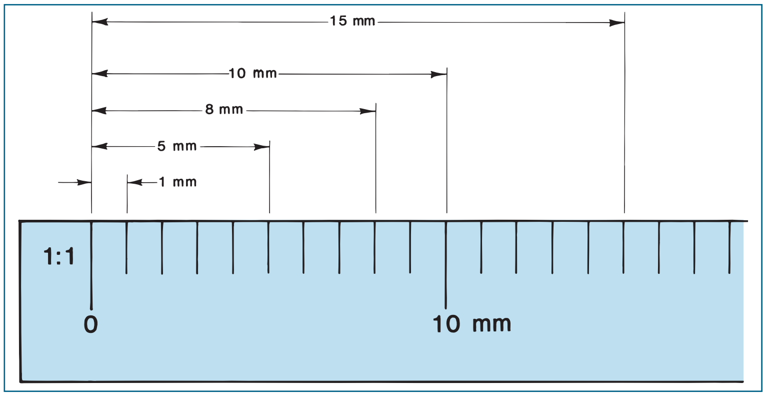


Figure 2-33 *The basic unit of measure for metric scales is the millimeter (mm).*

The basic unit of measure for metric scales is the **millimeter (mm)** **(Figure 2-33)**. The abbreviation mm is not used in metric drawings since all dimensions are in millimeters. All countries except the United States use the metric system for technical drawing and manufacturing, although we are gradually converting.

Drafting scales are either **open-divided** or **full-divided** **(Figure 2-34)**. Only one major unit of open-divided scales is graduated with a full-divided unit. It is adjacent to the zero. Full-divided scales contain full subdivision lines throughout the entire length of the scale. In selecting the proper scale for each drawing, the drafter must consider the amount of space available, the readability of the finished drawing, and ease of drawing. **Figure 2-35** provides some basic guidelines for proper scale selection. In selecting a scale, remember that a decimal or fractional part of an inch can be made equal to any unit of measure such as an inch, foot, yard, or mile.

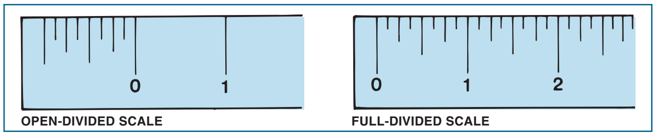


Figure 2-34 *Drafting scales are either open-divided or full-divided.*

SCALE SELECTIONS FOR ENGINEERING DRAWING			
Types of Drawings	**Mechanical Engineer's Scale**	**Civil Engineer's Scale**	**Metric Scale**
The object to be drawn must be smaller than the drawing format. All the drawings, dimensions, and notations will fit at actual size.	Full Size (1:1)	1:1	1:1
The object to be drawn is larger than the drawing format and must be reduced by half to fit the format.	1/2" = 1"	1:2	1:2
The object to be drawn is much larger than the drawing format and must be reduced eight to ten times in size to fit the drawing format.	1/8" = 1"	1" = 10" 1:10	1:10
The object to be drawn is very large, such as a building, and must be reduced at least fifty times in size to fit the drawing format.	1/4" = 1'–0" (1:48)	1:50	1:50
The object to be drawn is small and cannot easily be drawn full size. Doubling the drawing size makes the drawing easier to draw and interpret.	1" = 1/2" (2:1)	2:1	2:1
The object to be drawn is very small. For ease of drawing and interpreting, the original size must be increased eight or ten times.	1" = 1/8" (8:1)	10:1	10:1
When an industrial product is extremely small, such as circuitry chips, the drawings must be drawn approximately 100 to 500 times larger.	Not used	100:1 500:1	100:1 500:1

Figure 2-35 *Typical scale selection for engineering drawings.*

Manual Drafting versus CAD

As computer-aided drafting becomes more prevalent in schools and industry, a decision must be made as to how many CAD stations and how many manual drafting stations should be installed. The decision will depend on the needs, goals, and budgets of each school, industry, and business.

DRAFTING EXERCISES

Exercises are provided for freehand drawing, manual drafting, and CAD.

1. Divide a "B" (11" × 17" or 12" × 18") drawing format into 11 parts as shown in **Figure 2-36**. Practice sketching the line work with drafting pencils.
2. Divide a "B" drawing format into 11 parts (**Figure 2-36**). Practice drawing with instruments and drafting pencils.

   Measure each line in **Figure 2-37** with these scales:

   full size—inch-decimal

   full size—inch-fraction

   ½" = 1"

   1" =10'

   full size—metric (millimeters)

   ¼" = 1'–0"
3. Practice drawing the line work in **Figure 2-38** with drafting instruments, freehand, and with a CAD system.

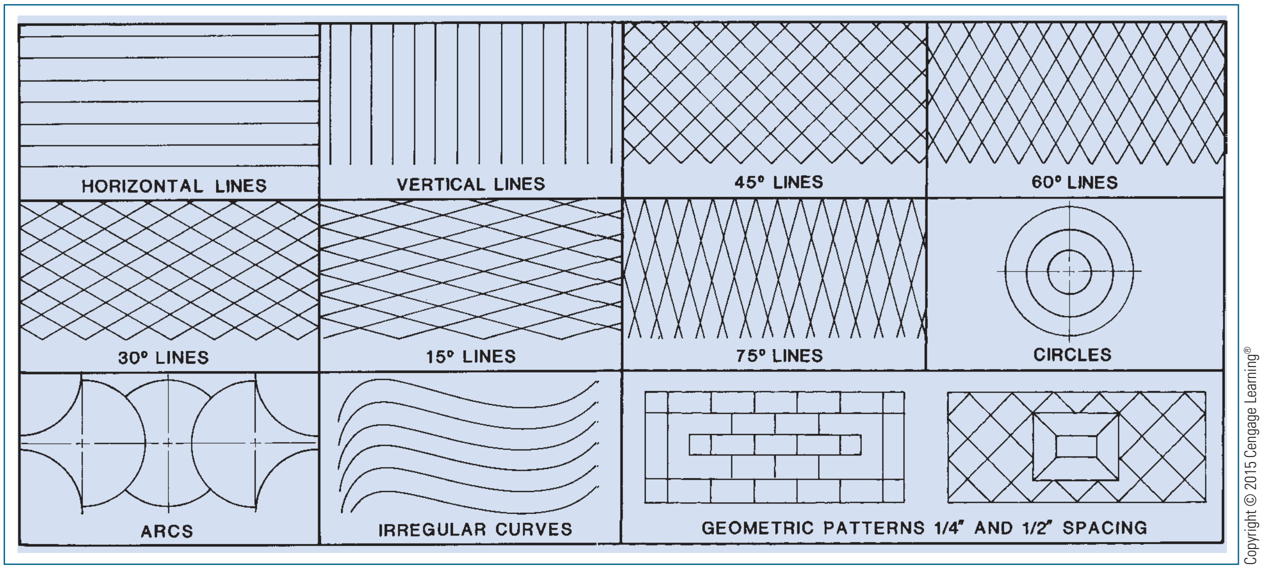


Figure 2-36 *Divide four B-size drawing formats into eleven parts as shown. Practice the line work with pencil sketching, drawing instruments and pencil, drawing instruments and a CAD drawing.*

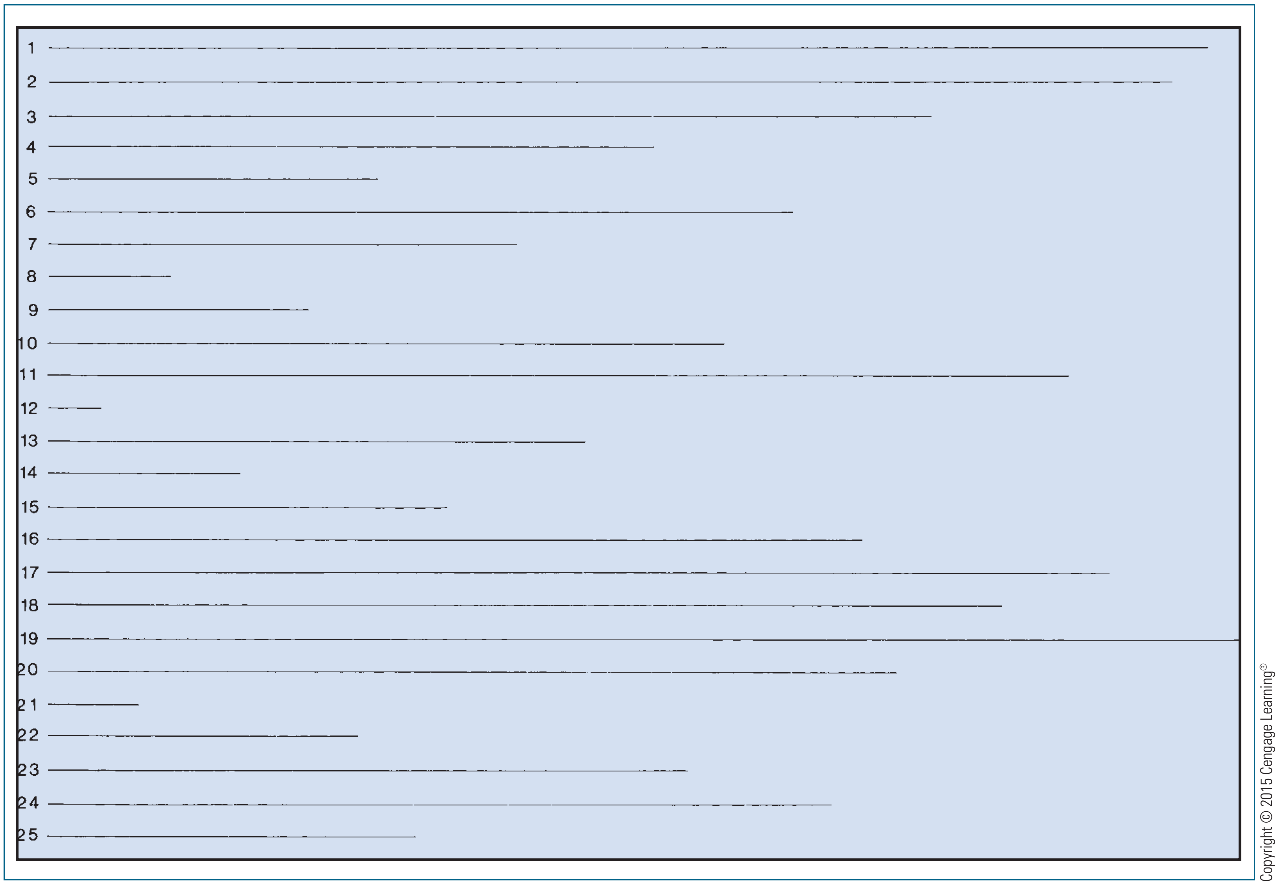


Figure 2-37 *Measure each line with as many different scales as are available.*

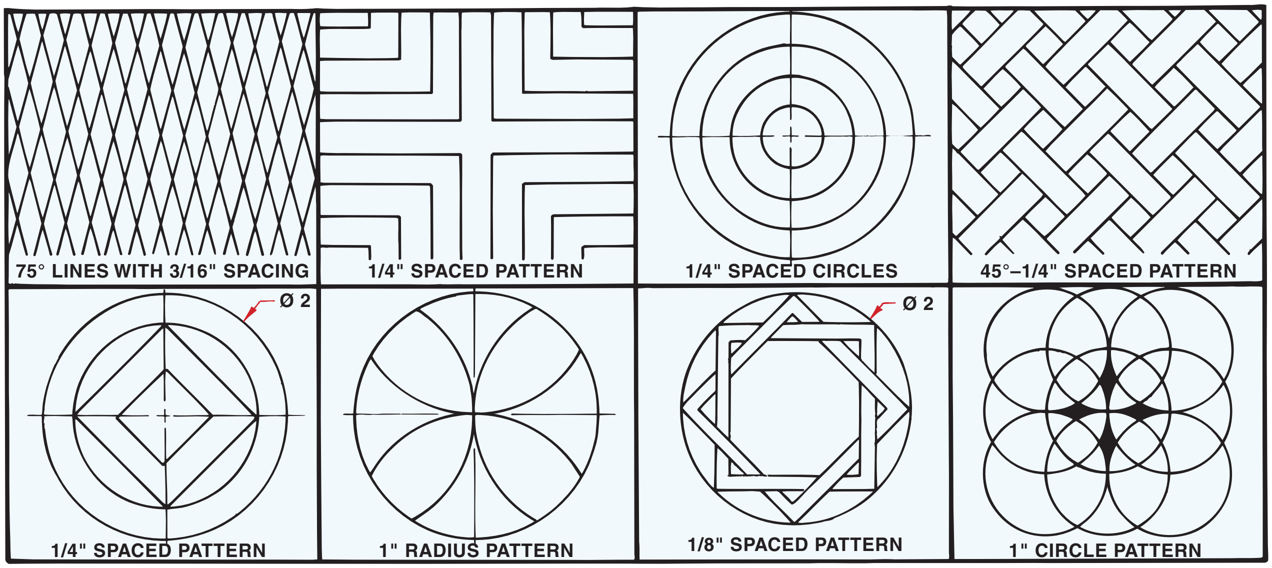


Figure 2-38 *Practice drawing the line work.*

DESIGN EXERCISES

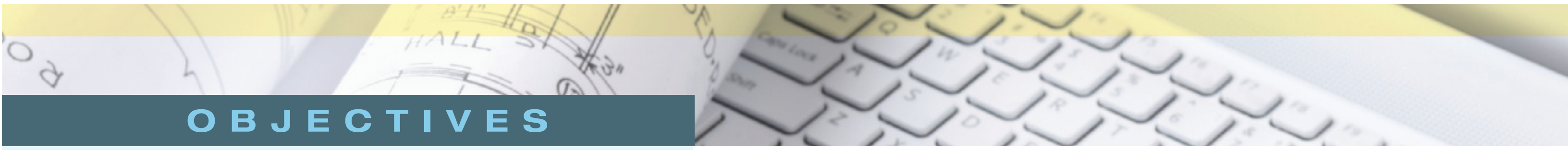
1. With your drafting instruments, make a geometric design of your initials about 3" in height.
2. Design a dart board target with the scoring values.
3. Design a rifle range target.
4. With your drafting instruments, design and cut out a puzzle on stiff paper.

KEY TERMS

- Architect's scale
- Bow compass
- Civil engineer's scale
- Dividers
- Drafting pencils
- Film
- Full-divided scale
- Grid paper
- Irregular curve
- Mechanical engineer's scale
- Metric system
- Millimeter (mm)
- Opaque drawing paper
- Open-divided scale
- Protractor
- T square
- Template
- Tracing paper
- Triangle
- U.S. customary system
- Vellum

3

Sketching and Lettering



OBJECTIVES

The student will be able to:

- Use proper line weights to sketch and letter
- Complete a two-dimensional sketch of simple objects
- Complete a three-dimensional sketch of simple objects
- File a record of sketched ideas
- Select and sharpen sketching and lettering pencils
- Keep sketches in proportion
- Dimension a sketch
- Shade a sketch
- Letter clearly on a sketch

Introduction

Highly developed manual drafting skills are not required for the preparation of CAD drawings (**Figure 3-1**); however, a competent CAD operator must possess a thorough understanding of the principles of drafting and be skilled in technical sketching.

Observe how the sketch (**Figure 3-2**) is used to describe the object shown in **Figure 3-3**. Try describing a pair of pliers to a person who has never seen one. You will now understand the proverb "a picture is worth a thousand words."

Supplies

Sketching supplies consist of a wide variety of pencils, erasers, and drawing media. Soft pencils in the range shown in **Figure 3-4** are used for sketching. Pencil points (**Figure 3-5**) are rounded for sketching compared to the sharp points used for instrument drawing. However, sharp points on soft pencils are used for layout and lettering guide line sketching. Chisel points are used for shading. Sketching pencils are sharpened with a mechanical sharpener, with a knife and file, or with sandpaper to shape the point.

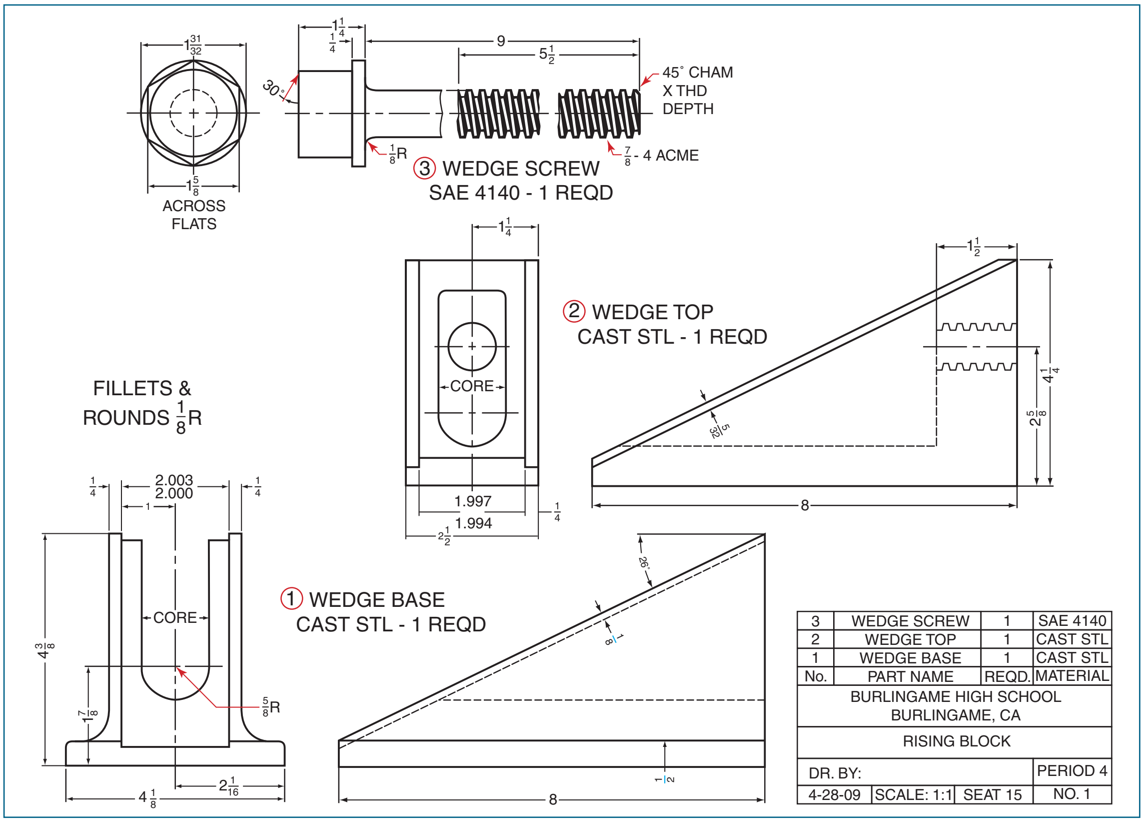


Figure 3-1 *As a CAD system is only another drafting tool, it is important that the CAD operator have a knowledge of engineering drawing.*

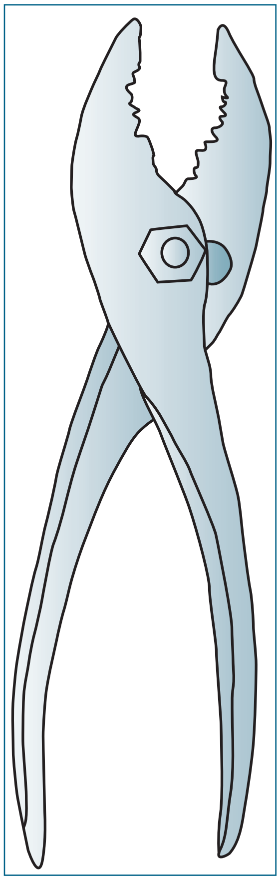


Figure 3-2 *A freehand sketch is worth a thousand words.*

Figure 3-3 *A pair of pliers.*

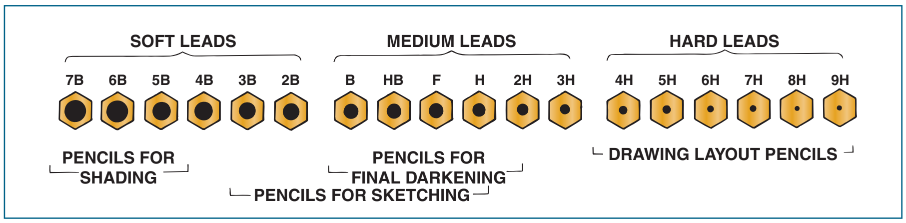


Figure 3-4 *Recommended pencil grades for sketching.*

Although many types of drawing media are used for technical sketching, grid paper is the most practical and easy to use **(Figure 3-6)**. Grids provide **guide lines** for rough scaling and proper alignment of perpendicular and parallel lines. Use light-colored surfaces if sketches are to be photocopied, and use translucent surfaces if diazo prints are to be made. Translucent surfaces are also helpful if progressive design sketches are to be traced.

Working Drawings

Working drawings are sketches used as the major design reference in manufacturing and construction. Sketches are also used as working drawings when time and conditions preclude the preparation of instrument or CAD working drawings. These sketches are usually orthographic multiview drawings, but they are sometimes prepared as pictorial drawings. An **orthographic projection** shows several views of an object on a drawing surface that is perpendicular to both the view and the lines of projection. A **pictorial drawing** shows an object's depth; three sides of an object can be seen in one view.

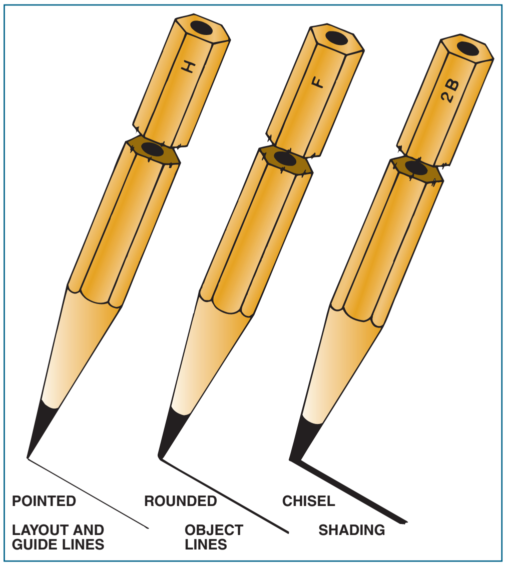


Figure 3-5 *Recommended pencil points for sketching.*

ORTHOGRAPHIC MULTIVIEW DRAWINGS

Multiview drawings provide the greatest amount of detail for manufacturing and construction. **Figure 3-7** shows the steps recommended to complete a multiview sketch. As with manual drafting (see Chapter 18), blocking in the overall outline before completing the internal details is the key to maintaining correct scales, angles, and proportions.

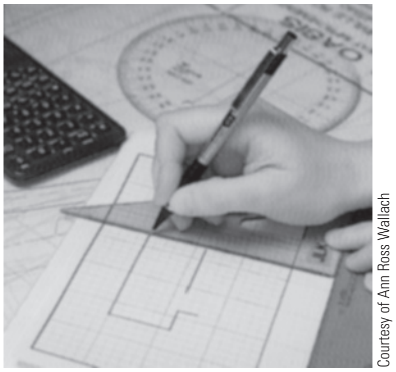


Figure 3-6 *Drawing on grid paper is faster and neater.*

PICTORIAL DRAWING

Blocking in the basic outline is also the recommended procedure for pictorial drawings. There are three types of pictorial drawings: isometric, oblique, and perspective.

Isometric drawings are prepared by establishing a vertical corner line and projecting receding lines 30° **(Figure 3-8)**. As with multiview drawings, always block in the entire outline of the object before cutting corners or adding surface details such as holes and projections.

Oblique drawings are sketches that recede on only one side of an orthographic view. In preparing an oblique drawing, first draw a front view of the object (**Figure 3-9**), then extend lines from each corner upward at 45° or 30°. Connect the ends of these lines with lines that are parallel to the lines of the front view. Oblique drawings are easy to dimension since the width and length of the front view are drawn to actual scale. Only the depth dimension is foreshortened by the receding lines.

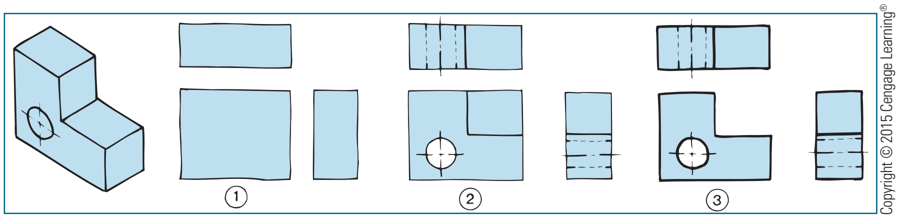


Figure 3-7 *Steps to sketch a multiview drawing.*

Perspective drawings are sketches that contain receding sides designed to approximate the actual appearance of an object. There are three types of perspectives: one-point, two-point, and three-point.

1. **One-point perspective** sketches are similar to oblique drawings, except the receding lines do not follow a consistent angle. Receding lines are connected to a **vanishing point.** A vanishing point represents the point at which all receding lines appear to come together. It is similar to road or train tracks

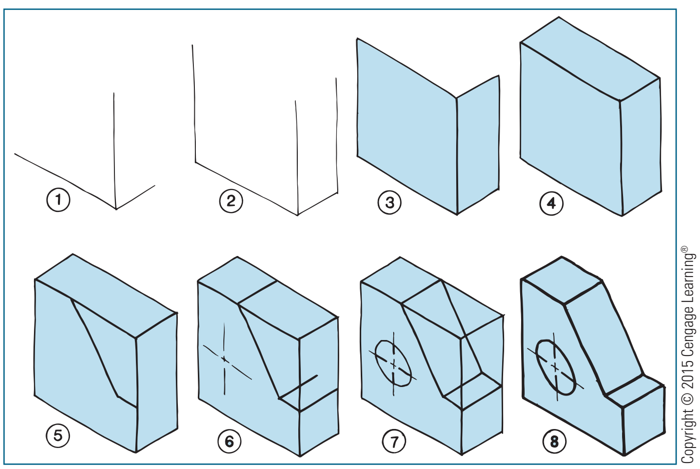


Figure 3-8 *Steps to sketch an isometric drawing.*

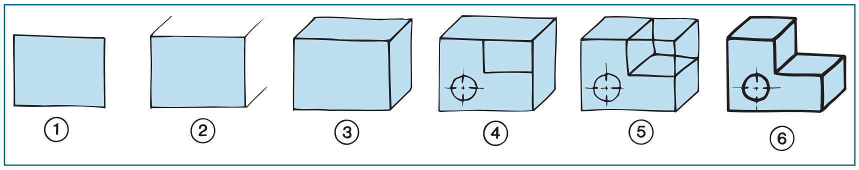


Figure 3-9 *Steps to sketch an oblique drawing.*

disappearing on the horizon. In sketching a one-point perspective, first outline the front view, as in oblique sketching. Establish a vanishing point and sketch lines from each corner to this point **(Figure 3-10)**. Sketch lines representing the back of the object parallel to the lines on the front view. This blocks in the sketch. Now any angular cuts and details can be added.

2. **Two-point perspective** sketches are similar to isometric sketches, except the side lines recede to two vanishing points. First, sketch the front vertical corner **(Figure 3-11)**. Establish two vanishing points above or below the front corner line, and connect the top and bottom of the front corner line to each of these points. Vanishing points on two-point perspective sketches must always be located on a horizontal line representing the horizon. Next, establish the depth of the sides and connect the back corner lines also to the vanishing points. In two-point perspectives, vertical lines are all parallel.

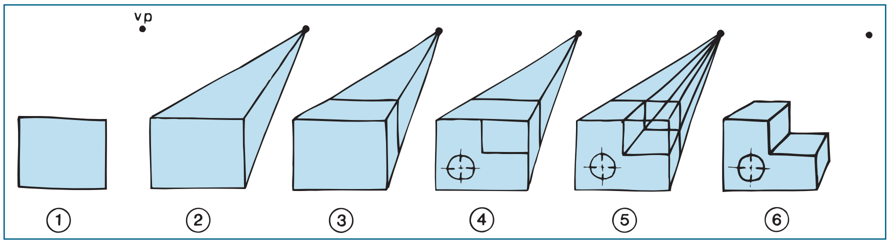


Figure 3-10 *Steps to sketch a one-point perspective drawing.*

3. In **three-point perspectives**, vertical lines are projected to a third vanishing point that is aligned with the vertical front corner line. Three-point perspectives are usually used for architectural sketches, and rarely for technical drawings.

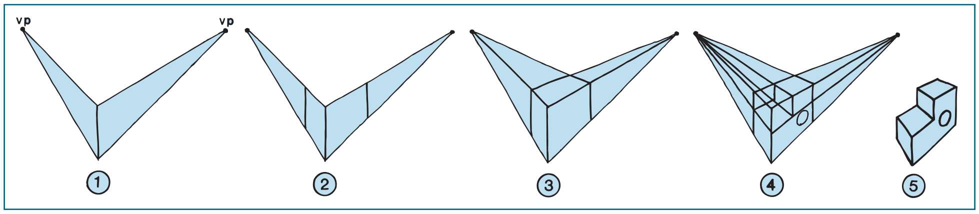


Figure 3-11 *Steps to sketch a two-point perspective drawing.*

Sketching Guidelines and Procedures

Line conventions and lettering for technical sketches are similar to those used for instrument drawings (**Figure 3-12**). Sketching standards differ only in the degree of line raggedness. Lines are dark and wide for object lines, dark and thin for dimension and center lines, and thin and light for layout and guide lines. **Figure 3-13** shows the application of line conventions to a technical sketch.

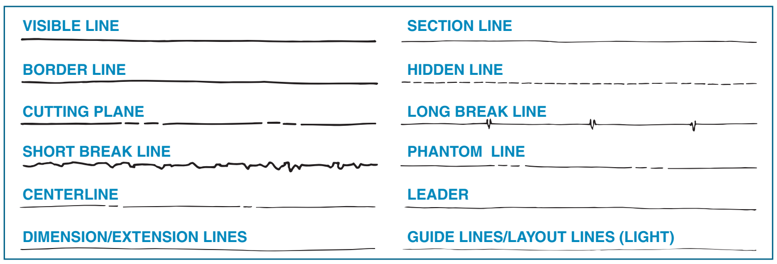


Figure 3-12 *Line conventions for sketching working drawings.*

All sketches are composed of straight lines, circles and arcs, irregular curves, and letters and numerals (**Figure 3-14**). Sketches cannot be prepared with the precision and accuracy of an instrument or CAD drawing. Care must be taken to ensure that dimensions are relatively proportional. If dimensional proportions are grossly inaccurate, the sketch will misrepresent the actual appearance of the object (**Figure 3-15**).

When sketching straight lines, squares, and rectangles, use short strokes. Do not attempt to draw continuous lines. Right-angle lines, unless sketched on grid paper, should be laid out and sketched (**Figure 3-16**).

Circles and arcs can be accurately and symmetrically sketched by following the sequence shown in **Figure 3-17a**. Just as the circle was derived from the square in **Figure 3-17a**, all fillets and rounds should first be blocked in square, as shown in **Figure 3-17b**. By following this procedure, proper proportions and symmetry can be maintained.

The procedure and sequence for sketching ellipses is similar to circle sketching (**Figure 3-18**). Sketching accurate angles, other than right angles (90°), can be difficult without using a triangle or protractor. However, by estimating and dividing a right angle into even angles, you can achieve an acceptable level of accuracy (**Figure 3-19**).

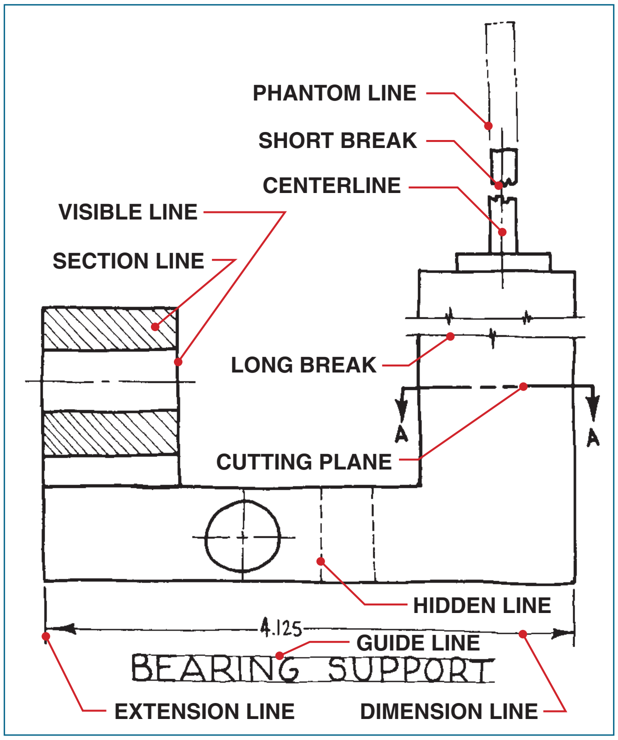


Figure 3-13 *Using line conventions on a working drawing.*

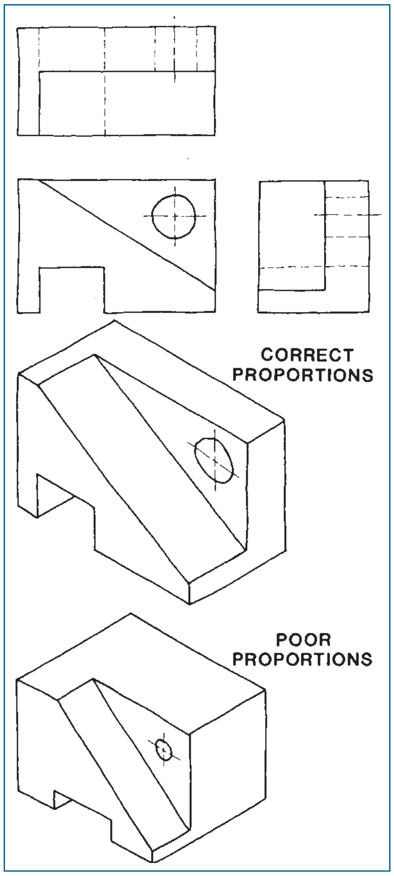


Figure 3-15 *Well-proportioned drawings have superior communications.*

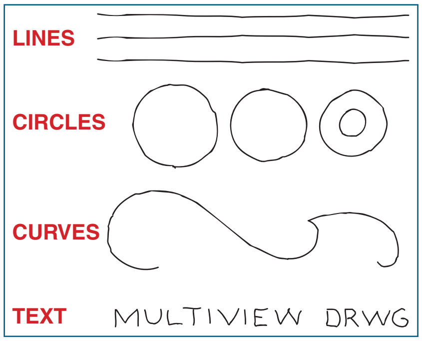


Figure 3-14 *Four basic drawing forms make up all drawings.*

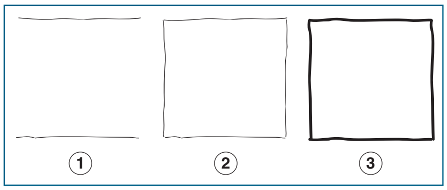


Figure 3-16 *Sketching straight lines, squares, and rectangles.*

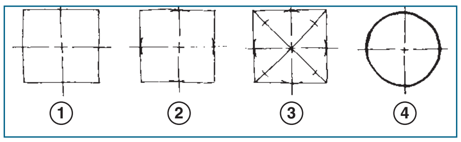


Figure 3-17a *Sketching circles.*

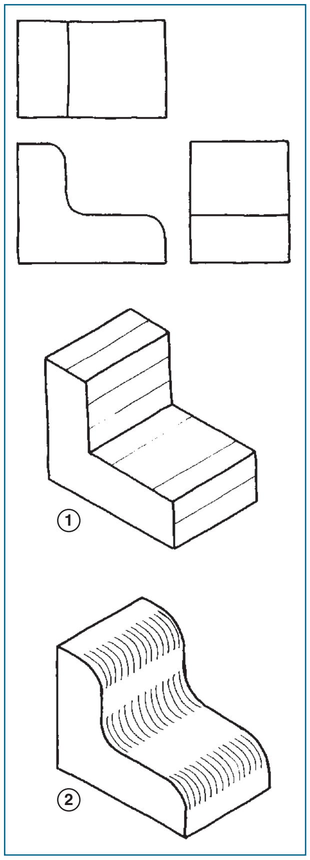


Figure 3-17b *Sketching fillets and rounds.*

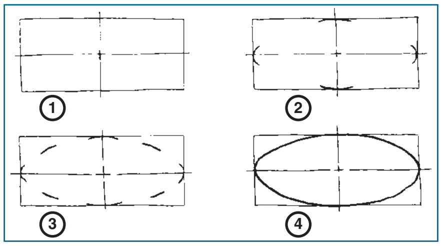


Figure 3-18 *Sketching ellipses.*

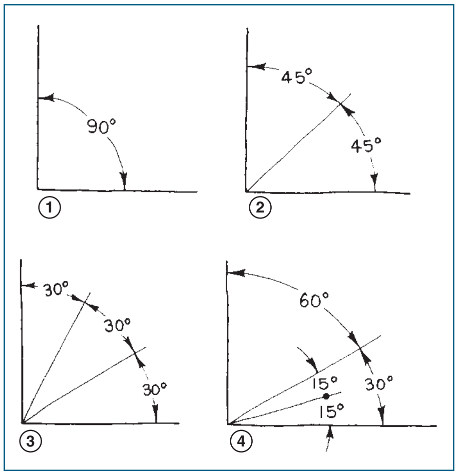


Figure 3-19 *Sketching and estimating angles.*

When sketching, hold the pencil comfortably (**Figure 3-20**) and pull it (**Figure 3-21**), never push it. To maintain a consistently rounded point and avoid wearing a flat chisel point, rotate the pencil frequently (**Figure 3-22**). When erasing soft pencil sketches, use a good quality medium-soft eraser.

SHADING

Surfaces exposed to a major light source will appear bright. Conversely, surfaces not directly exposed to a light source will be shaded; therefore, adding shading to sketches creates realism (**Figure 3-23**). In **Figure 3-23**, the light source is located above and to the left of the object. The opposite areas are shaded because direct light is blocked from these surfaces. **Figure 3-24** shows techniques for shadowing (shading) these areas.

Surfaces are rarely totally hidden from a light source. Some surfaces are very light, very dark, or appear in a variety of shadow grades depending on the position, intensity, and number of light sources. **Figure 3-25** shows an object with three light levels: light, medium, and dark. In addition, this figure shows a separate shadow cast by the object.

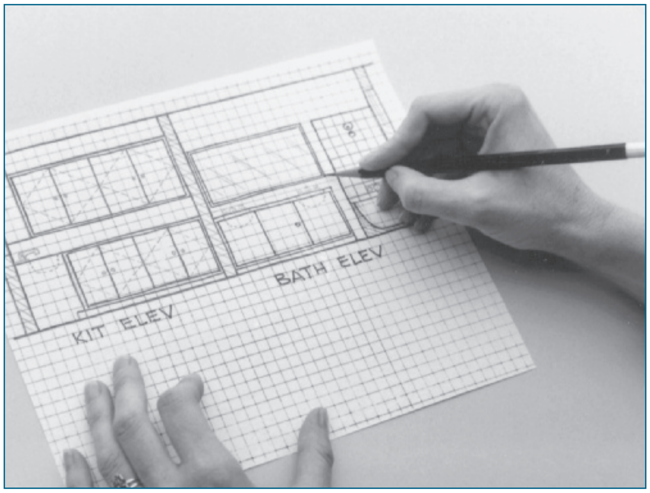


Figure 3-20 *Use a comfortable pencil grip for sketching.*

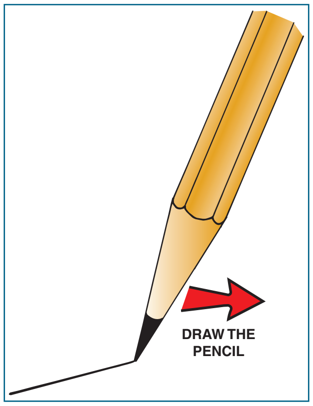


Figure 3-21 *Always pull the pencil—never push it.*

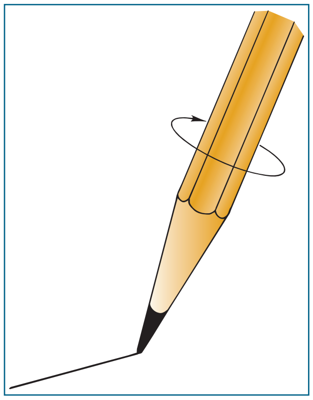


Figure 3-22 *Rotate the pencil frequently for rounded points.*

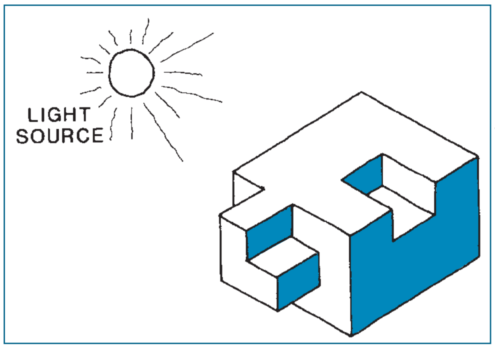


Figure 3-23 *Shade (darken) the surfaces opposite the light source.*

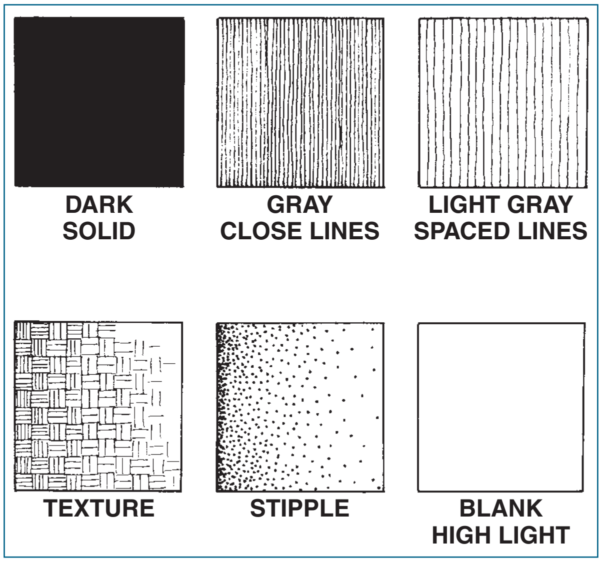


Figure 3-24 *Shading techniques.*

Light travels in a straight line and cannot bend around corners unless reflected; therefore, light intensity on surfaces always changes at the corners of objects. **Figure 3-26** shows several methods of sketching these differences to add realism to a sketch. On objects without corners, such as spheres and cylinders, light and dark areas change gradually. **Figure 3-27** shows several methods of shadowing a cylinder sketch to add realism.

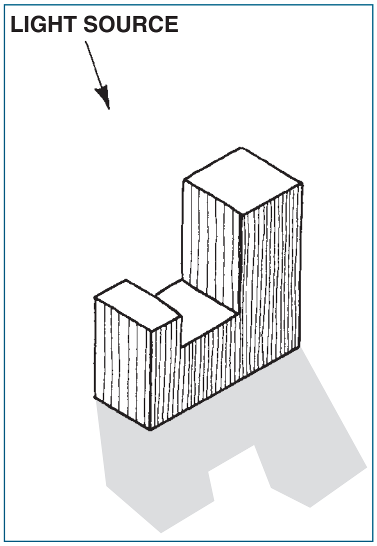


Figure 3-25 *The light source dictates the position of the shadows.*

DIMENSIONING

When sketches are used for instruction, manufacturing, or construction, dimensions are usually necessary to adequately describe the object. When sketches are dimensioned, the overall width, depth, and height dimensions are placed on the outside of the **location dimensions** (**Figure 3-28**). These are known as **overall dimensions**. Dimension lines are sketched parallel to object lines and connected to the object with extension lines and arrows. Location dimensions show the location of parts of an object. **Size dimensions** show the size of any hole or projection on the object and are placed between the object and the overall dimension lines. Dimensions are usually shown on multiview sketches. Pictorial sketches (**Figure 3-29**) are normally used only to show the general appearance of products and do not require dimensions.

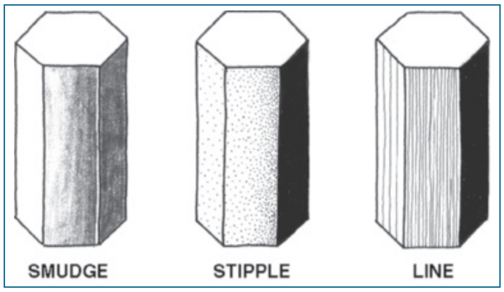


Figure 3-26 *Freehand shading of short corners.*

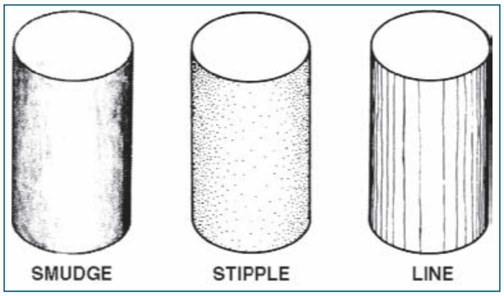


Figure 3-27 *Freehand shading of rounded surfaces.*

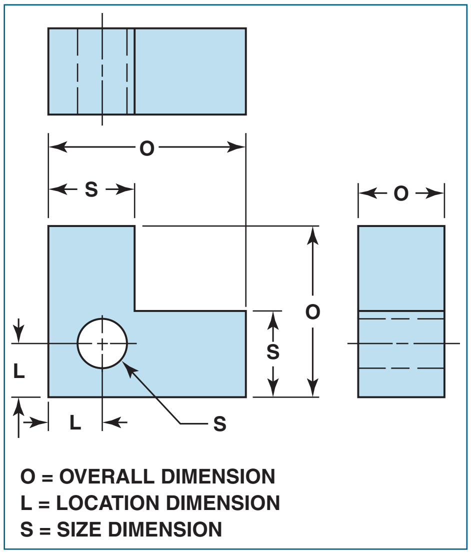


Figure 3-28 *Types of dimensions.*

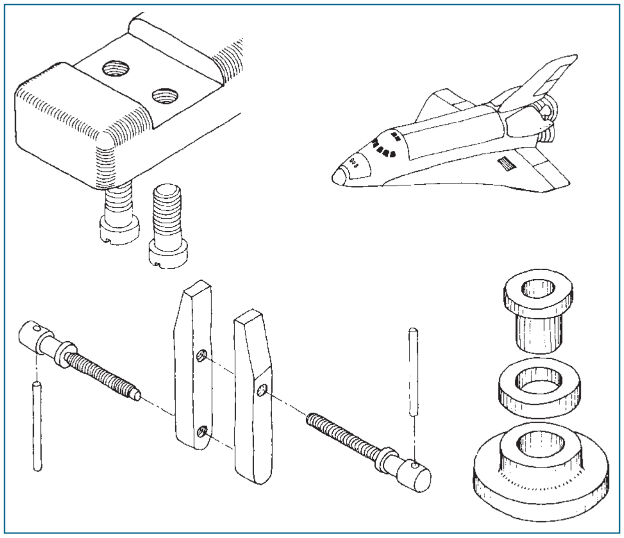


Figure 3-29 *Examples of pictorial sketches.*