

DOCUMENT RESUME

ED 083 372

CE 000 302

TITLE General Drafting. Technical Manual.
INSTITUTION Department of the Army, Washington, D.C.
REPORT NO TM-5-581A
PUB DATE 3 Oct 72
NOTE 223p.; This document supersedes TM-5-230, October 29, 1962
AVAILABLE FROM Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. 20402 (488-579/19)
EDRS PRICE MF-\$0.65 HC-\$9.87
DESCRIPTORS *Drafting; Engineering Drawing; Engineering Graphics; Geometric Concepts; Instructional Materials; Manuals; *Military Personnel; Reprography; *Technical Illustration
IDENTIFIERS *Military Occupation Specialty; MOS

ABSTRACT

The manual provides instructional guidance and reference material in the principles and procedures of general drafting and constitutes the primary study text for personnel in drafting as a military occupational specialty. Included is information on drafting equipment and its use; line weights, conventions and formats; lettering; engineering charts and graphs; geometrical construction; intersections and developments; multiview projections; pictorial drawing and sketching; dimension and notes; and methods of reproduction. The appendixes are lists of references, abbreviations, and illustrations and tables. There is also a subject index. (AG)

TM 5-581A



TECHNICAL MANUAL

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GENERAL DRAFTING

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GENERAL DRAFTING

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* This manual supersedes TM 5-230, 29 October 1962.

CHAPTER 1

INTRODUCTION

1-1. Purpose and Scope

a. This manual provides instructional guidance and reference material in the principles and procedures of general drafting. This manual is the primary study text for personnel in this military occupational specialty. The career pattern for soldiers in this specialty is described in AR 611-201.

b. This manual contains the information required in applying the general draftsman military occupational specialty (MOS). It covers types of drafting equipment and their use; line weights, conventions, and formats; methods of lettering; preparation of charts and graphs; geometrical construction; surfaces and projections; drawing and sketching; dimensioning drawings; and methods of reproduction.

1-2. Duties

The general draftsman's military occupational specialty is the basic entry MOS into the career fields of construction draftsman, cartographic draftsman, map compiler, illustrator, and model maker. The duties of the general draftsman include but are not limited to the following. He draws a variety of general drafting details such as diagrams, graphs, and charts; and assists personnel engaged in construction drafting, cartographic drafting, map compilation, model making and related art and drafting activities. He prepares graphic sections of organizational charts, statistical reports, and visual aids. He letters drawings, plans, artwork, and other related material by freehand or mechanical devices. He compiles and enters information such as dimensions, specifications, and legends on appropriate section of drawings.

1-3. Drafting a Graphic Language

Engineer drawing has been called the graphic language of the engineer. It has definite rules of usage to insure that it has the same meaning wherever it is used. Anyone who learns the rules can read engineering drawings. Engineering

drawing must present information such as size, shape, location, material, and so forth, meeting certain requirements and specifications. It must be presented in such a manner that the finished product will be in accordance with the requirements specified by the designer. Special tools, or drawing instruments, are used to record this language with the necessary accuracy. These tools are used by military draftsmen and engineers to produce engineering drawings that conform to accepted standards and practices.

1-4. Types of Engineer Construction

a. General construction performed by engineer construction units include such structures as headquarters installations, housing facilities, workshops, hospitals, depots, protective shelters, storage and supply facilities, laundries, bakeries, refrigerated warehouses, training facilities, and miscellaneous related projects.

b. Specialized construction projects include construction of new roads or upgrading of existing ones; building permanent and semi-permanent bridges; construction and repair of railroads; planning and constructing military pipeline facilities; repair and construction of port facilities; and construction of airfields and heliports.

1-5. Principles of Military Construction

a. Construction should be accomplished within the allocated time using a minimum of materials, equipment and manpower. If new design is necessary, it should be simple and flexible and must reflect available materials and level of training of construction personnel. The permanency of any structure erected must not exceed limits established by the theater commander.

b. Generally, a large project is completed in units to allow the completed parts to be used while construction continues. Underground or protected sites should be considered in the construction of essential facilities. Improvisations should be used whenever possible to reduce material requirements. Facility planning should be of

such a nature as to avoid creating lucrative targets; dispersion of installations should be considered at all times.

1-6. Comments

Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the

specific page, paragraph, and line of text in which change is recommended. Reasons should be provided for each comment to insure complete understanding and evaluation. Comments should be prepared using DA Form 2028 (Recommended Changes to Publications) and forwarded direct to the Commandant, US Army Engineer School, Fort Belvoir, Virginia 22060.

CHAPTER 2

DRAFTING EQUIPMENT AND ITS USE

2-1. Introduction

a. This chapter illustrates and describes the equipment which helps the draftsman to perform his job more easily, swiftly, and accurately in the required graphic language of the engineer. It is important to learn the correct use of these drawing instruments from the beginning. Proficiency will come with continued practice, but it is essential to start with the correct form. With practice, the skillful use of drawing instruments will become a habit.

b. For competence in drawing, accuracy and speed are essential in military as well as commercial drafting. It should be realized from the beginning that a good drawing can be made as quickly as a poor one.

2-2. Drafting Table

a. Professional draftsmen and engineers do most of their drawing on tables similar to those shown in figure 2-1. Although the construction details vary, the tables are made either to a fixed standard height or adjustable to any desired working height. A turn of a hand knob or lever permits the top to be regulated to various angles; on some tables to full easel position. Many tables

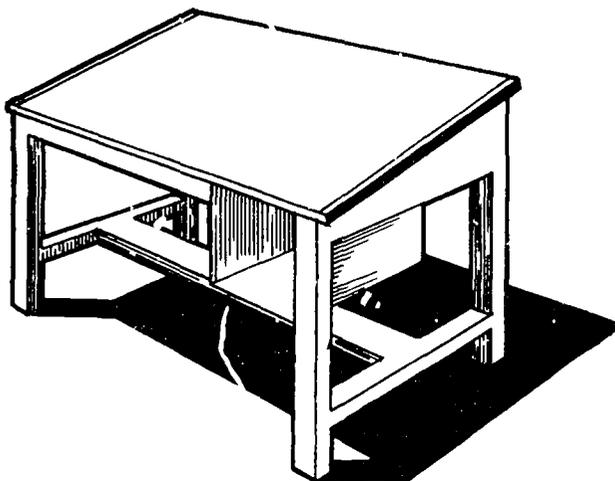


Figure 2-1. Drafting table.

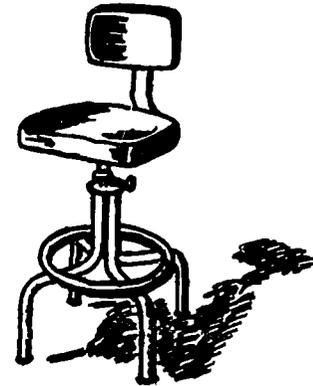


Figure 2-2. Drafting chair.

have a steel cleat on each end to hold and keep a straight edge as well as to prevent warpage.

b. The drawing table should be set so that the light comes from the left, and it should be adjusted to a convenient height, usually 36 to 40 inches, for use while sitting on a standard drafting stool or while standing.

c. The instruments should be placed within easy reach on the table or on a special tray or stand which is located beside the table. The table, the board, and the instruments should be cleaned before starting to draw.

2-3. Table Cover

a. The draftsman usually covers the table top with a special buff or green colored, waterproof, board cover paper. This minimizes glare and provides a smooth, firm working foundation under the drawing sheet. This helps produce sharp, clear—cut pencil lines, and makes erasing easier.

b. There is also a special green plastic board cover that, in addition to providing a smooth, firm working area without glare, is self-sealing, that is, it seals holes made by staples or thumbtacks.

2-4. Drafting Chairs

To facilitate the work of the draftsman, many drafting rooms are equipped with posture chairs in place of the customary drafting stool, as illus-

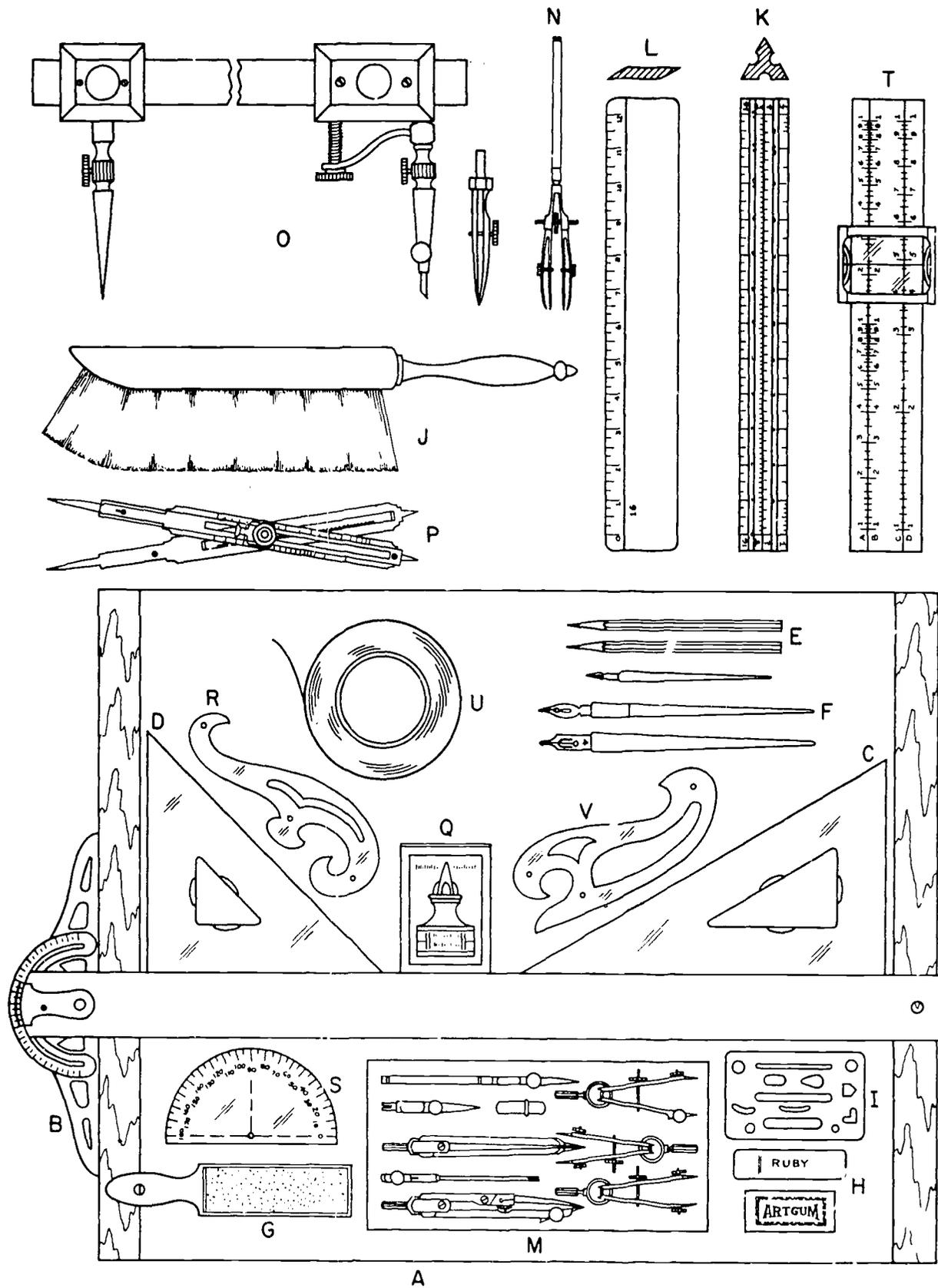


Figure 2-3. Drafting equipment.

trated in figure 2-2. The posture chair has a free floating back rest with a seat that can be raised or lowered to desired positions.

2-5. Drafting Board

The drawing board (A, fig. 2-3) is used by draftsmen primarily for field work. It is commonly found in schools when drafting tables are not available. These boards are made of either white pine or bass wood and come in a variety of sizes.

2-6. T-Square

a. The T-square (B, fig. 2-3) is used for drawing horizontal lines and as a supporting straight-edge for triangles when vertical and slanted lines are to be drawn. The length ranges from 18 to 60 inches. For maximum effectiveness, the T-square should extend the entire length of the drafting board. The most popular T-squares have plastic or celluloid edges which permit lines to be visible underneath the edge of the blade. Care should be taken to avoid marring the celluloid edges. The working edge of the T-square should never be used as a guide for a knife. The T-square must be perfectly square to be accurate, so care must be taken not to drop and damage it.

b. There is also a T-square with a protractor

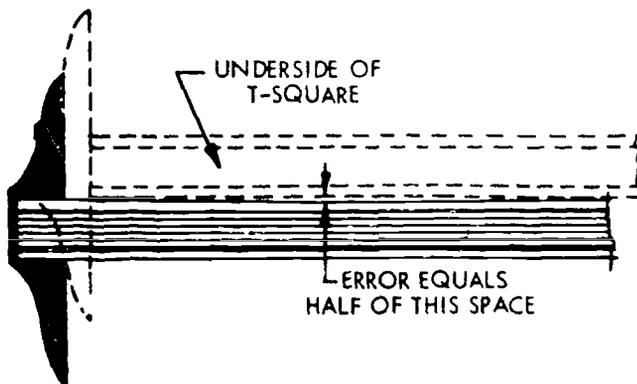


Figure 2-4. Testing the T-square.

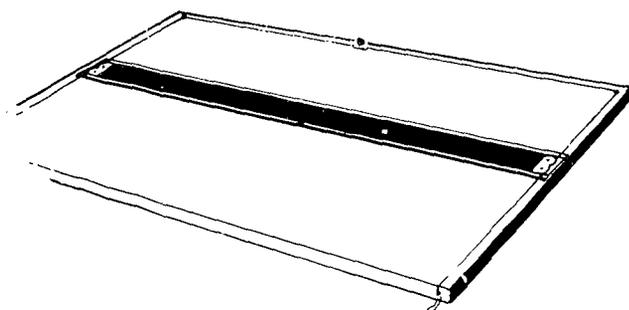


Figure 2-5. Parallel straightedge.

head. An adjustable steel head is fastened to a blade usually made of stainless steel. The head has a vernier corresponding to a protractor fastened to the head so that angles may be set to fractions of a degree.

c. Since accurate work can only be achieved if drafting tools are in proper working condition, a draftsman should periodically check his T-square for straightness. To check, draw a sharp line with the T-square between two widely separated points (fig. 2-4). Then turn the T-square over and draw a line, using the same edge, between the same two points. If the T-square is true, the two lines will coincide. Any deviation from the straight line will indicate an error in the blade equal to one-half the space between the two lines.

d. In drawing lines, take great care to keep them accurately parallel to the guiding edge of the T-square. The pencil should be held lightly, but close against the edge, and the angle should not vary during the progress of the line. Horizontal lines should always be drawn from left to right. In order to help keep a sharp point if a conical point is used on the lead, the pencil is twirled as it is sliding across the page. Always draw lines along the upper edge of the blade. When using your T-square over your drawing as much as possible, but be sure the head is in contact with the left edge of the board before drawing the next line. For the left-handed draftsman the process is reversed.

2-7. Parallel Straightedge

a. The parallel straightedge (fig. 2-5) is preferable to the T-square for large drawings. While the T-square is satisfactory for small work, it becomes inaccurate when working out on the end of the T-square. Since the parallel straightedge is supported at both ends, its advantage over the T-square is that it maintains parallel motion automatically and may be moved up and down with slight pressure at any point along its length.

b. The straightedge can be mounted on either the drafting board or the drafting table. It is controlled by a cord which runs through both ends of the straightedge. The arrangement of the cord and guiding pulleys varies, depending upon the manufacturer.

2-8. Drafting Machine

a. The drafting machine (fig. 2-6) is a standard piece of equipment in most drafting rooms. It is an extremely useful device since it eliminates the

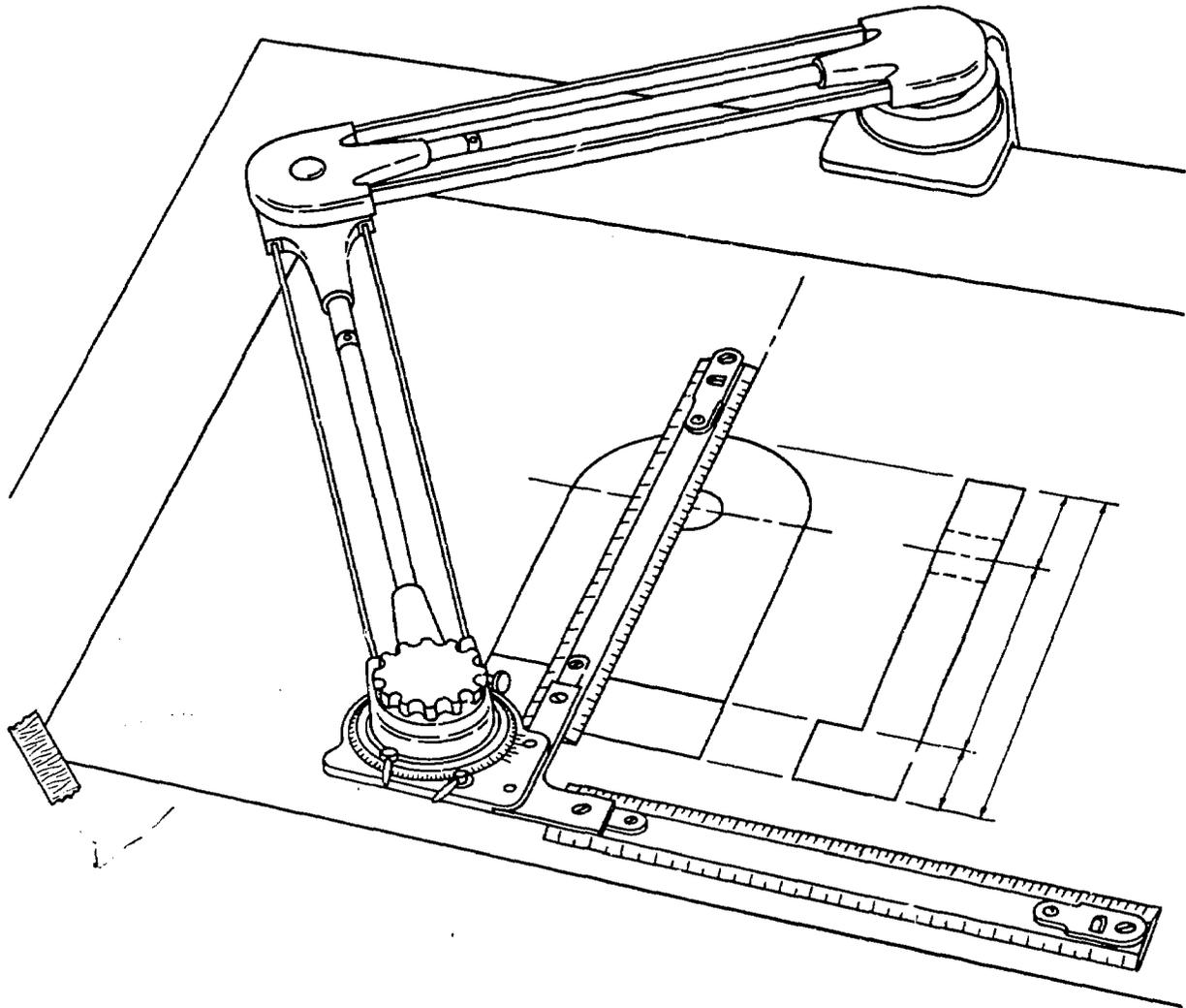


Figure 2-6. Drafting machine.

need for separate scales, triangles, protractor and T-square.

b. Its time saving value lies in the fact that many drawing operations can be combined, such as laying out horizontal and vertical lines, and measuring and laying out angles. The machine allows the draftsman to accomplish these operations with his left hand, leaving his right hand free for drawing. Thus to draw a line of predetermined length at a given angle, the draftsman, using his left hand only, simultaneously sets the correct angle, and swings the arm of the drafting machine until zero of either the horizontal or vertical scale is on the desired point. With his right hand, he simply draws the lines of the required length. Without resetting the controls, parallel or perpendicular lines can be drawn anywhere on the board.

2-9. Triangles

a. Triangles are used for drawing vertical and

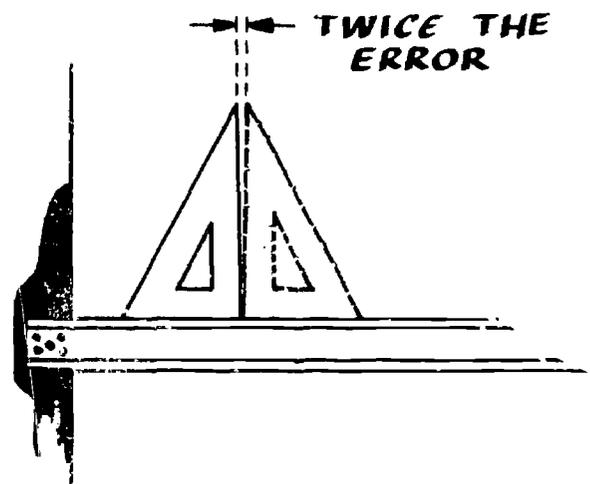


Figure 2-7. Testing triangles.

slanted lines. The two triangles used for this purpose are the 45° (D, fig. 2-3) and the 30° to 60° (C, fig. 2-3) triangles. They are made of transparent celluloid or plastic and come in various

sizes. The most common are the 8- or 10-inch for the 30° to 60° and 6- or 8-inch for the 45° .

b. The straightness of a triangle is tested by placing it against the T-square and drawing a vertical line (fig. 2-7). Then reverse the triangle and draw another line along the same edge. If the triangle is straight, the two lines will coincide; if they don't coincide, the error is half the resulting space.

2-10. Adjustable Triangle

The adjustable triangle (fig. 2-8) is often preferred by draftsmen instead of regular triangles. Since it has a built-in protractor it enables the draftsman to draw any angle from 0° to 90° . The adjustment arm is held firmly in place by a clamp screw, which also serves as a handle for lifting or moving the instrument.

2-11. Protractor

Protractors (S, fig. 2-3) are used to measure and set off angles other than those measurable with the draftsman's triangles. The protractor is usually numbered at 10° intervals. The smallest graduation is $\frac{1}{2}$ of a degree. It is semicircular in shape and is most commonly made of transparent

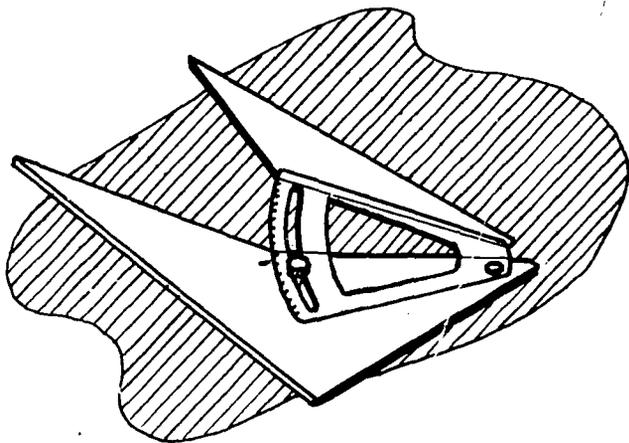


Figure 2-8. Adjustable triangle.

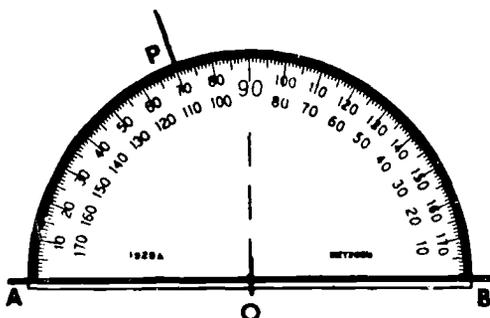


Figure 2-9. Use of protractor.

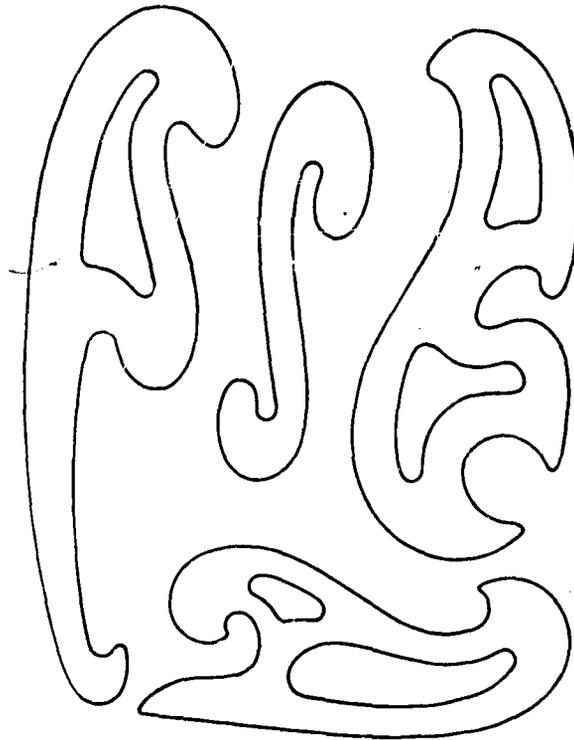


Figure 2-10. Irregular curves.

plastic with a beveled edge. The scale may be read from either end. To draw an angle of 70° or a line inclined 70° to the horizontal (fig. 2-9), draw a line AB . Mark at point O where the inclined line or vertex of the angle is desired. Place the protractor with the 0° and 180° on line AB and the hole directly under 90° place over point O . Place a point P at 70° and connect points O and P .

2-12. Irregular Curves

a. *Description.* Irregular curves (fig. 2-10) are used as mechanical guides for drawing curves other than circles or circular arcs. They are made of transparent plastic and their edges represent successive portions of ellipses, parabolas, spirals, and other standard geometric curves.

b. *Use.*

(1) A uniform and accurate curved line can be produced when two or more points are plotted along each segment of the entire curved line. Figure 2-11 shows how a smooth line is drawn through a series of plotted points.

in (A) match points 1, 2, 3, and 4. Draw line from 1 to 3 only (not to 4).

in (B) match points 3 to beyond 4. Draw line from 3 to 4 only (not to 5).

in (C) match points 4, 5, and 6. Draw line from 4 to 6 (just short of 3).

in (D) match points short of 6 to beyond 7. Draw line from 6 to 7.

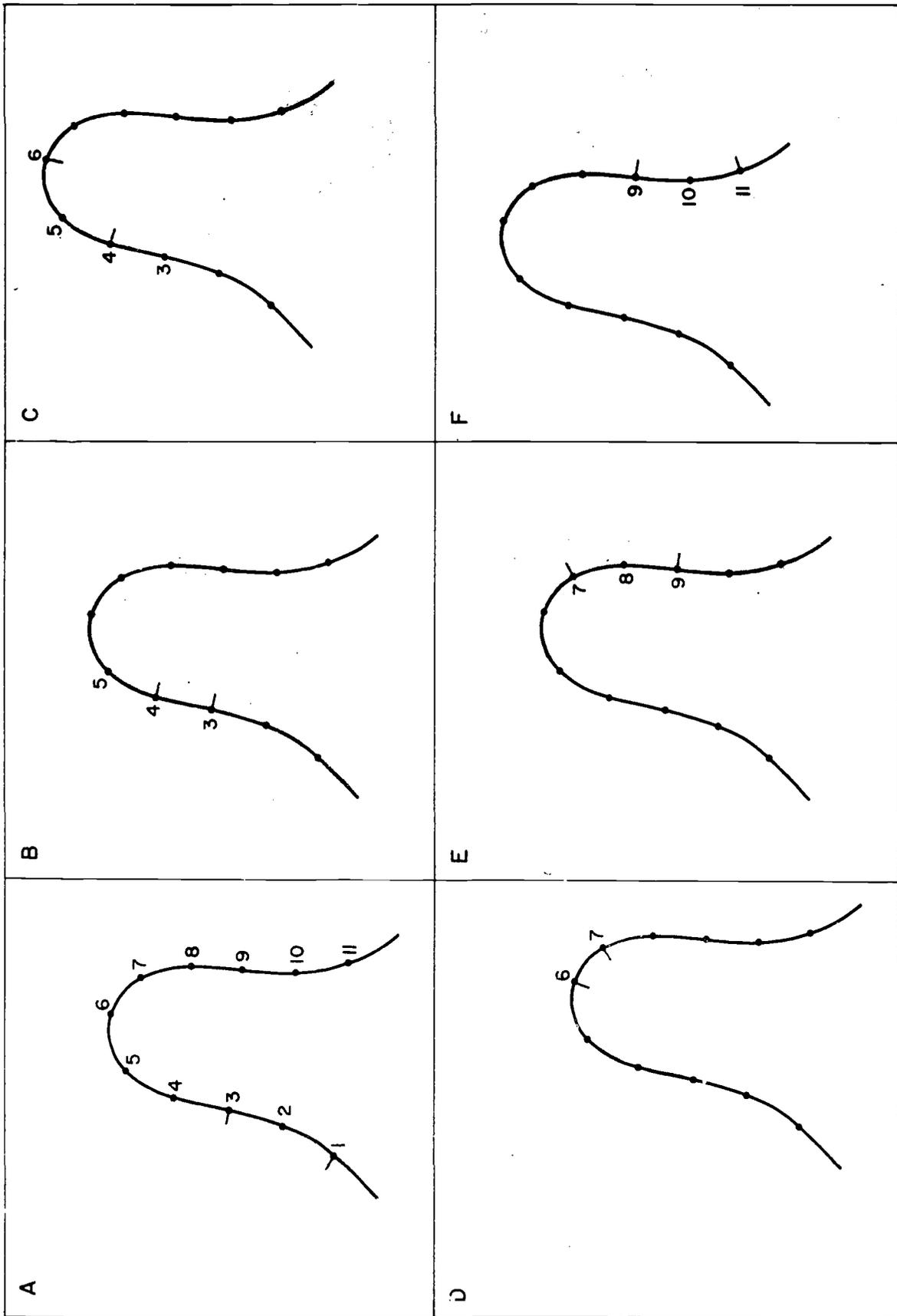


Figure 2-11. Use of irregular curve.

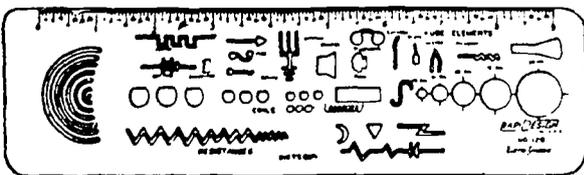
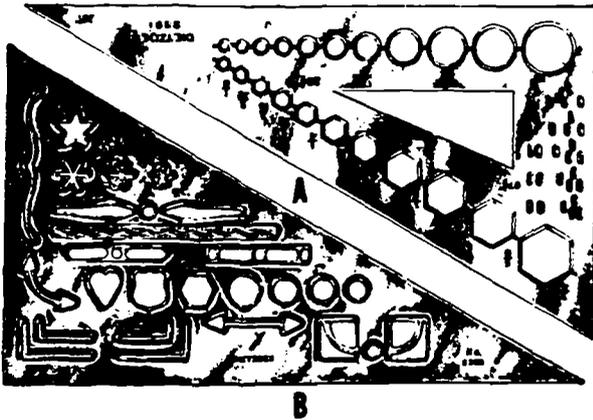
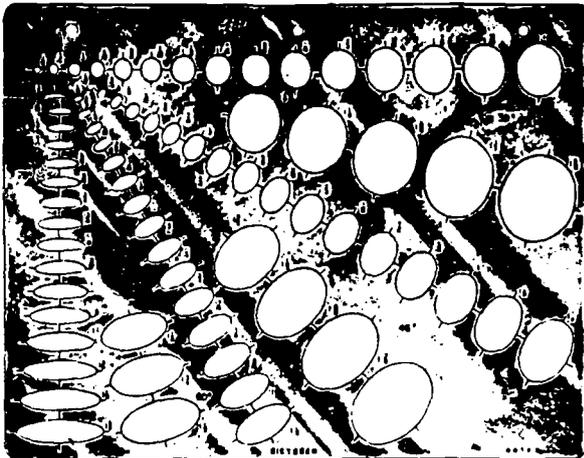


Figure 2-12. Templates.

in (E) match points short of 7 to beyond 9. Draw line from 7 to 9.

in (F) match points short of 9 to beyond 11. Draw line from 9 to 11.

(2) Notice how the irregular curve is turned over and reversed to fine portions which fit the points on the line with increasing or decreasing changes in curvature.

(3) Like the triangles, the irregular curve should always be kept flat to avoid warpage.

2-13. Adjustable Curves and Splines

The adjustable curve consists of a core of lead,

enclosed by a coil spring attached to a flexible strip. The spline consists of a flexible strip to which weights, called ducks, are attached. The adjustable curve and spline can be bent to form any desired curve limited only by the elasticity of the material.

2-14. Railroad Curves

Railroad curves are fixed regular curves, perfect arcs of a circle. They usually come in a set of plastic curves, either edge being usable, making arcs with radii of $1\frac{1}{2}$ inches to 200 inches. Special sets come with arcs from radii of 200 inches to 1000 inches. Used in pairs, one slightly larger than the other depending on the width of the road or railroad, they make perfect curved parallel lines. Some railroad curves come with a short tangent which permit the plotting of highways and railroads from the point of tangency with a straight line. All sets are marked with a center-line (radius).

2-15. Templates

a. A draftsman can save a great deal of time by using templates (fig. 2-12) on jobs where the same shape or symbol is to appear a number of times. Most of the templates commercially available are made of transparent plastic and offer a wide variety of shapes, including ellipses, hyperbolas, circles, hexagons, and arcs. There are special templates for symbols and shapes used in architectural, civil, electrical, mechanical, and industrial process drawings.

b. There are templates for various Mil-Std (Military Standard) symbols; for example: electrical and electronic symbols, dimensioning and tolerancing symbols.

2-16. Scales

a. Introduction.

(1) Technically, a *line* is determined by any two points and may continue to infinity. The draftsman deals only with *line segments*. He must lay off line segments to a given length or measure the length of given line segments or both. The instrument used for either of these purposes is a *measuring scale*. Just as line segments are commonly referred to as lines, so a measuring scale is often called a *scale*. The term *scale* also means the size of a drawing or model relative to the size of the original.

(2) Measuring scales are made of boxwood or plastic and are a little longer than 12 inches. Pocket scales are approximately 6 inches long.

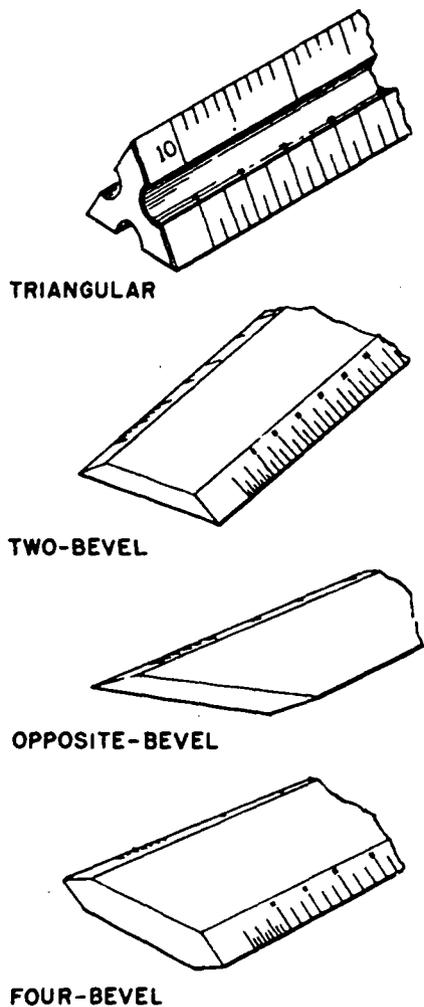


Figure 2-13. Scale shapes.

(3) Standard scales are made in four different cross-sectional shapes (fig. 2-13): triangular, flat with two bevels, flat with opposite bevels, and flat with four bevels. Each shape has its advantages and disadvantages. The triangular scale offers six faces for different size scales, so many scale combinations are readily available on one instrument. Flat scales are usually preferred by professional draftsmen since the scale face being used is always readable without having to search. The two-bevel scale always has both scale faces visible. The opposite-bevel scale can be picked up more easily from the drafting board and reveals the proper scale without a prolonged search. The four-bevel scale is normally used on the 6-inch pocket scale.

b. Scale Graduations.

(1) The inch is the basic unit of measure in most drafting. There are a number of ways of subdividing inches. The most familiar way is to divide it into quarters, eighths, sixteenths, and sometimes thirty-seconds (fig. 2-14).

(2) Another method of division is decimal, in which inches are divided into tenths and fiftieths.

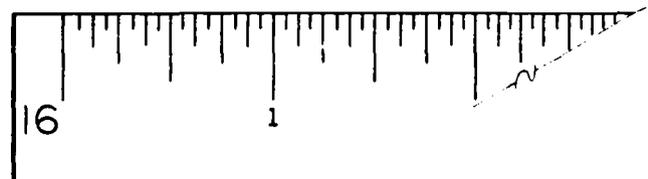


Figure 2-14. Inch scale.

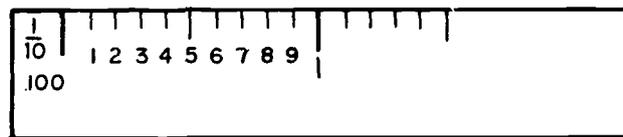


Figure 2-15. Decimal scale.

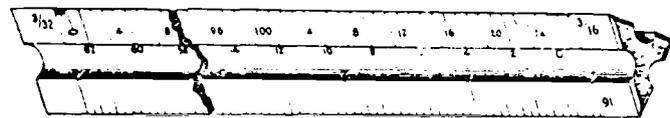


Figure 2-16. Open-divided scales ($3/16''$ and $3/32''$).

On this scale, each $1/10$ equals 0.10 or $1/10$ of an inch (fig. 2-15).

c. Open- and Full-Divided Scales. Scales are divided in one of two ways: they are open-divided or full-divided.

(1) Open-divided scales are those on which the main units are numbered along the entire length but finer units are placed only outside the zero marks. Figure 2-16 contains an example of an open-divided scale. Note that the $3/16$ scale has fine units only outside the zero. On such a scale, each of the large divisions represents one foot. The fine divisions are inches, with each small line representing one inch. A $3/32$ scale, half as large as the $3/16$ scale, runs from the opposite end. For this scale, as with all others, the large section equals one foot. There are only six fine divisions, therefore, each of the lines equal 2 inches. On some open-divided scales, there are divisions smaller than 1 inch. Figure 2-17 above shows two examples of such divisions. On the scale to the left, for example, the entire unit shown equals 1 foot. Each of the long lines represents 1 inch. Each of the medium lines is $1/2$ inch. Each of the short lines is $1/4$ inch. On the scale to the right, the entire unit shown equals 1 foot. The longest line represents 1 inch. The next shorter line represents $1/2$ inch; next, $1/4$ inch. The shortest line represents $1/8$ inch. The fully-divided section of an open-divided scale is called the *divided foot*.

(2) A fully divided scale has divisions along its entire length. Therefore, it does not need a divided foot outside its zero point. Examples of fully divided scales are the full scale shown on the engineers' and metric scales.

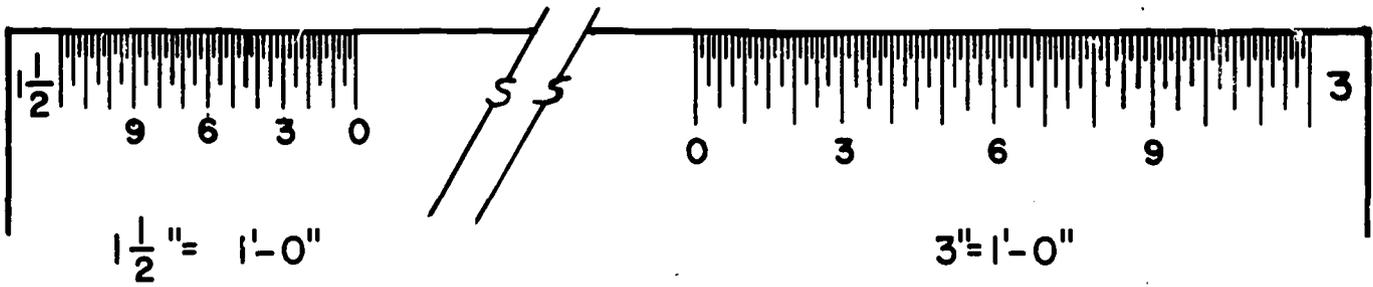


Figure 2-17. Open-divided scales ($1\frac{1}{2}''$ and $3''$).

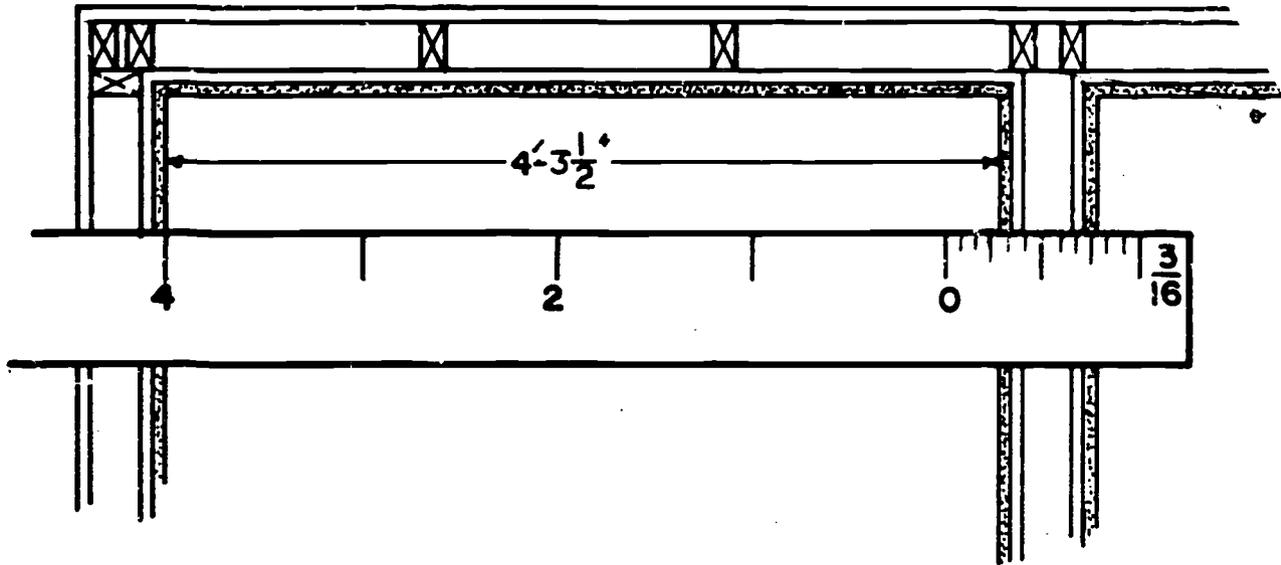


Figure 2-18. Architect's scale.

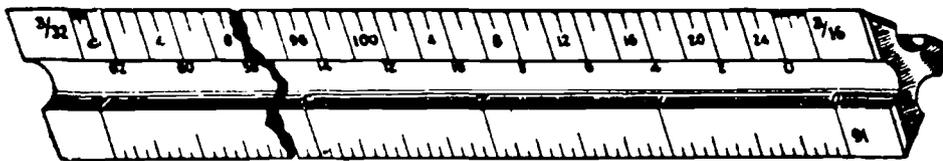
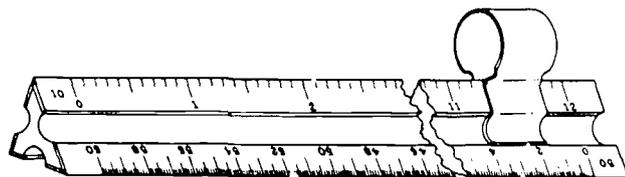


Figure 2-19. Engineer's scale.



e. Engineer's Scale.

(1) The civil engineer's scale, or engineer's scale (fig. 2-19) is a triangular scale 12 inches

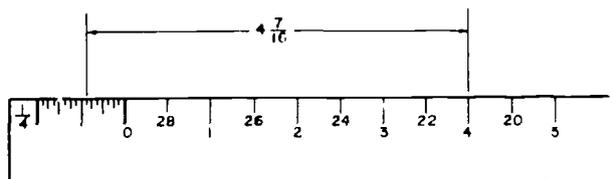


Figure 2-20. Mechanical engineer's scale.

d. Architect's Scale. The architect's scale (fig. 2-18) is used for building construction where length is measured in feet and inches. The large units, representing 1 foot, are subdivided into twelfths, representing inches. The scales are paired, with two on each face as follows: 3 and $\frac{1}{2}$; 1 and $\frac{1}{2}$; $\frac{3}{4}$ and $\frac{3}{8}$; $\frac{1}{4}$ and $\frac{1}{8}$; $\frac{3}{16}$ and $\frac{3}{32}$. Zero marks are at opposite ends of each face.



Figure 2-21. Metric scale.

long with increments on each side of its three faces. The basic unit is the inch, which is divided into 10, 20, 30, 40, 50, and 60 parts on the different scales. These parts represent the number of feet in every inch measured by the scale: in the 10 scale, each of the ten lines is 1 foot, and so on.

(2) This scale is used on drawings where great reduction in size is needed. It deals with long distances measured in feet and decimal parts of a foot. It is often used for maps.

f. Mechanical Engineer's Scale. The mechanical engineer's scale (fig. 2-20) is similar to the architect's scale. Its reduced scales follow the same pattern. It differs in that it is subdivided into sixteenths, thirty-seconds, sixty-fourths, or decimal units (0.01 or 0.02) rather than twelfths.

g. Metric Scale.

(1) A metric scale (fig. 2-21) is a two-bevel scale with one scale on each side of its face. One scale is a fully divided 12-inch scale. The other has metric increments and is 30 centimeters long.

(2) The basic unit of length in the metric system is the meter. There is 39.37 inches in a meter. One meter is divided into 100 centimeters. One centimeter equals 10 millimeters.

- 1 meter = 10 decimeters
- 1 meter = 100 centimeters
- 1 meter = 1000 millimeters

(3) When working with a metric scale, remember that all values are decimal parts of a meter and not of an inch. One inch equals 2.54 centimeters.

h. Use of the Scale.

(1) For a draftsman, accuracy and speed in scaling vary inversely with one another. Exact layouts, made to scale for workmen, must be very accurately represented. This takes time. Drawings with figured dimensions need not be as accurate and may be drawn more quickly.

(2) To lay off a distance, put the scale on the paper aligning the zero with the starting point. Measure out the required distance along the scale and mark it with either a sharp pencil dot or a pin prick. Do not use the scale as a straightedge for drawing the line. To avoid cumulative errors, successive measurements on the same line should be made without moving the scale.

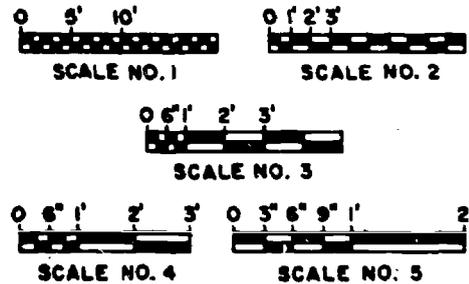
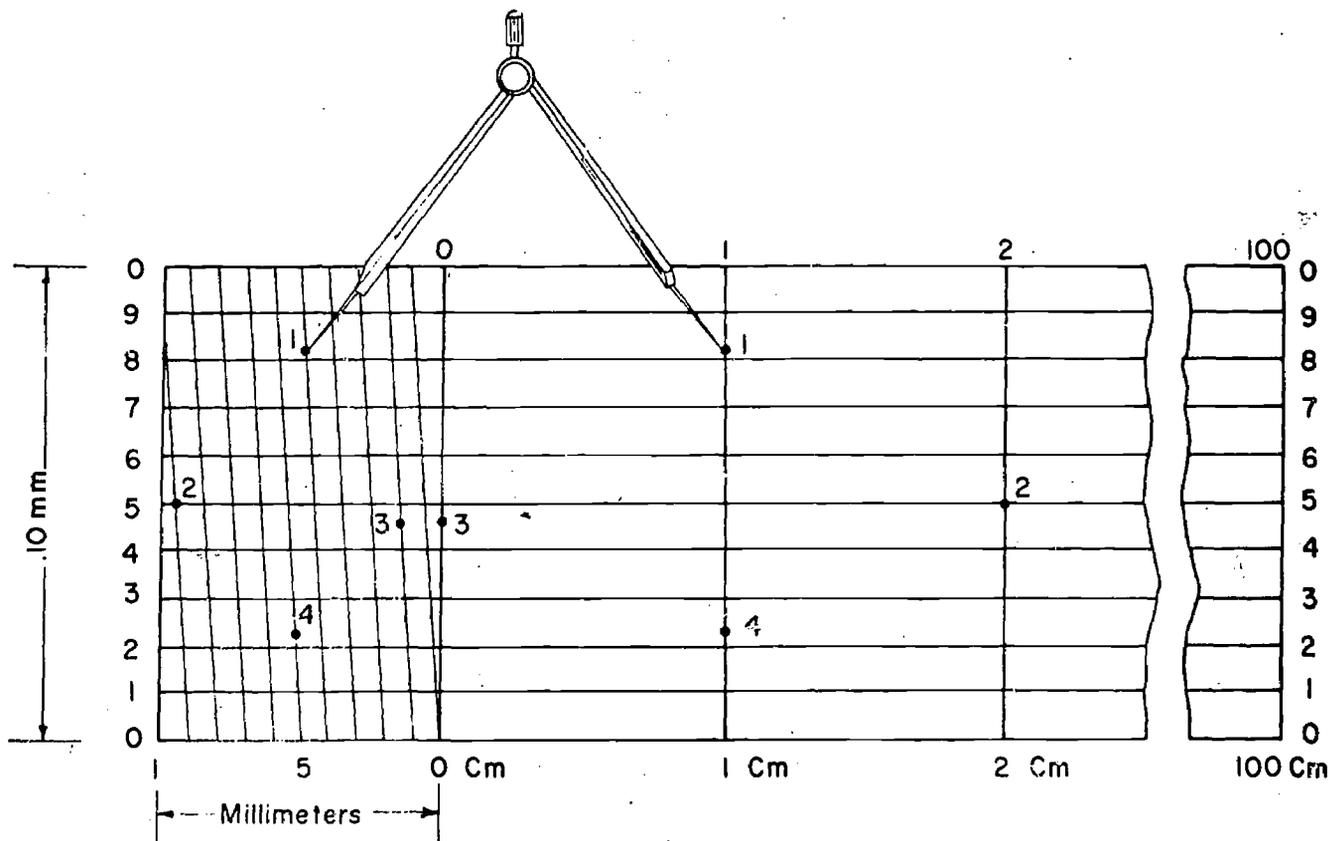


Figure 2-22. Graphic scale.

(3) In stating the scale used on a drawing, the information should be given in compliance with the scale used for the drawing. If a mechanical engineer's scale is used, scale can be expressed as *half size* or *three-tenths size* as well as in the standard equation such as $\frac{1}{2}'' = 1' - 0''$ or $\frac{3}{10}'' = 1''$. The standard form for the architect's scale is $3'' = 1' - 0''$, $\frac{1}{4}'' = 1' - 0''$, and so on. When noting the scale, the first figure always refers to the drawing and the second to the object drawn. For the civil engineer's scale, the format is the same. Examples are: $1'' = 60'$, $1'' = 50'$, and $1'' = 40'$.

(4) In the graphic method of representing scale, an actual measuring scale is shown in the drawing (fig. 2-22). This scale provides a means of determining the approximate dimensions of an object on an enlarged or reduced reproduction. Graphic scales may be used for drawing in which complete dimensions of the object or arrangement are not required, such as assembly, installations, subassembly, and welded assemblies, and which are intended for reproduction at other than actual drawing size. Graphic scales should *never* be used as indications of accurate dimensions. When graphic scales are used to indicate the equation method, a single horizontal bar is divided into appropriate vertical graduations. When graphic scales are used in a drawing, the reference, GRAPHIC, will be entered after SCALE in the space provided on the drawing. When all views and sections are drawn to the same scale, the scale representation and the corresponding fraction followed by SCALE are to be entered near the title block. When more than one scale is used, the graphic scales will be grouped near the title block, and the equation scales will be placed directly below the views to which they pertain.



1. 1.482 Cm 2. 2.950 Cm 3. 0.145 Cm 4. 1.523 Cm

Figure 2-23. Invar scale.

(5) In drawings drawn to scale, but in which certain dimensions are not to scale, the abbreviation NTS is placed directly above or below the dimensions affected, or the dimensions are underlined.

i. Invar Scale.

(1) The invar scale (fig. 2-23) is made from a special steel alloy having a low coefficient of expansion and, therefore, the change in length due to temperature differences is insignificant. This scale is used when very precise measurements are required.

(2) One side of the scale is calibrated in the metric system and the other side in the English system. On the left side of the bar, one unit—an inch on the English side and a centimeter on the metric side—is graduated in tenths by parallel diagonal lines extending from bottom to top. It is further divided into hundredths by parallel lines extending throughout the length of the bar. The thousandths are estimated along the diagonal between the parallel hundredths lines. The measurements must be made parallel to the horizontal lines at all times. For example, if one end of the bar beam compass is on the fourth line from the

bottom, the other end also is placed on the fourth line from the bottom.

(3) The invar scale should never be taken from its protective box. To use the reverse side merely close the box, turn it over, and reopen it. Use care when adjusting the points on the beam compass to a decimal measurement to avoid scratching the surface of the scale.

2-17. Drawing Instrument Sets

A serviceable set of instruments is very essential for producing good drawings with a minimum amount of effort and in the shortest possible time. There are many different kinds of sets. Some contain numerous special accessories while others include only the basic instruments. The set of drawing instruments illustrated in M, figure 2-3 is a standard issue and the tools are common to most sets of drawing instruments. The set contains the following:

a. Compasses.

(1) *Friction compass.* The friction compass has legs approximately 6 inches long. Its radius setting is adjusted by finger pressure and it de-

depends on friction at the pivot joint to maintain its setting. It can be used to draw radii up to 5 inches and when using the extension bar up to 9 inches.

(2) *Bow compass.* There are two types of bow compasses: one has a center thumbscrew between the legs and the other has a side thumbscrew outside one of the legs. The small bow compass can be used for circle arcs up to 1-inch radius.

(3) *Drop compass.* The drop compass is designed for the drawing of small accurate circles. The center rod contains the needlepoint and remains stationary while the tube carrying the pen or pencil revolves around it.

(4) *Beam compass.* A beam compass (0, fig. 2-3) consists of a long bar with a needlepoint attachment at one end and pencil or pen attachment at the other. All of the attachments are adjustable, to permit the drawing of large circles easily.

(5) *Use of the compass.*

(a) The compass, with pencil and inking attachments, is used for drawing circles of approximately 1-inch radius or larger. Most compass needlepoints have a plain end for use when the compass is converted into dividers, and a "shoulder end" for use as a compass. Adjust the needle point with the shoulder end out and so that the small point extends slightly farther than the pencil lead or pen nibs (fig. 2-24). Sharpen compass lead as shown, forming an ellipse approximately a quarter of an inch long.

(b) To draw a penciled circle, take the following steps: set off the required radius on one of the center lines, place the needle point at the exact intersection of the center lines, adjust the compass to the required radius (1 inch or more), lean the compass forward and draw the circle clock-

wise while rotating the handle between the thumb and forefinger. To obtain sufficient weight of line, it may be necessary to repeat the movement several times. Any error in radius will result in a doubled error in diameter; therefore, it is best to draw a trial circle first on scrap paper and then check the diameter with the scale.

(c) When drawing inked circles and large penciled circles, "break" the legs of the compass so that they will stand approximately perpendicular to the paper. On drawings having arcs and tangent straight lines, draw the arcs first as it is easier to connect a straight line to an arc than the reverse. For very large circles, use the lengthening bar to increase the compass radius. Use both hands but be careful not to jar the compass and thus change the adjustment.

(d) When using the compass to draw construction lines, use a 4H to 6H lead so that the lines will be very light. For required lines, the arcs and circles must be black and match the straight lines. Since heavy pressure cannot be exerted on the compass as it can on a pencil, it is usually necessary to use a compass lead that is about one grade softer than the pencil used for the corresponding line work. For example, if an F pencil is used for visible lines drawn with the pencil, then an HB might be found suitable for the compass work. In summary, use compass leads that will produce arcs and circles that match the regular pencil lines.

(e) It is necessary to exert pressure on the compass to produce heavy "printable" circles, and this tends to enlarge the compass center hole in the paper, especially if there are a number of concentric circles. In such cases, use a horn center or "center tack" in the hole, and place the needlepoint in the hole in the tack.

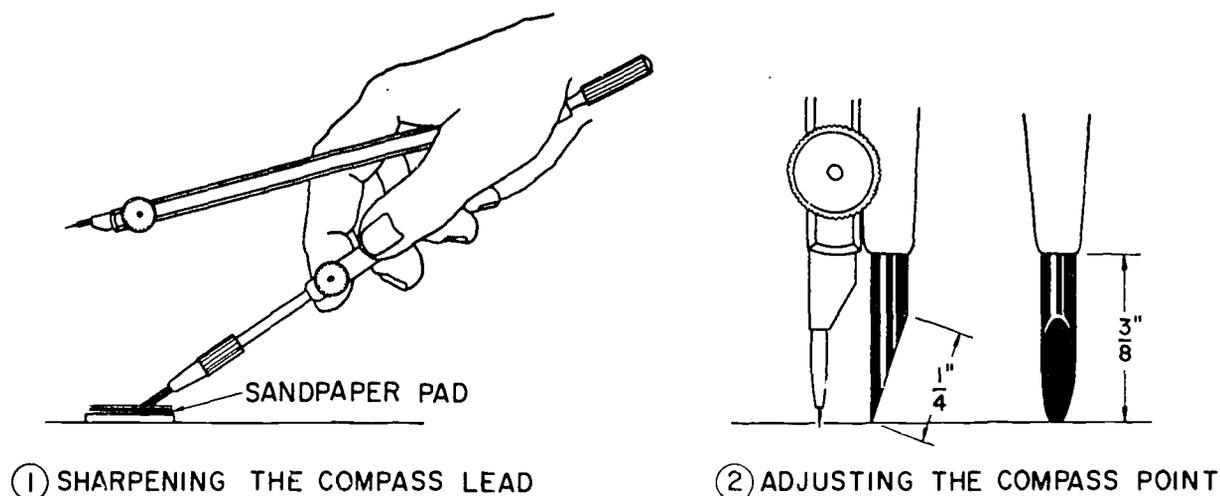


Figure 2-24. Adjusting a compass.

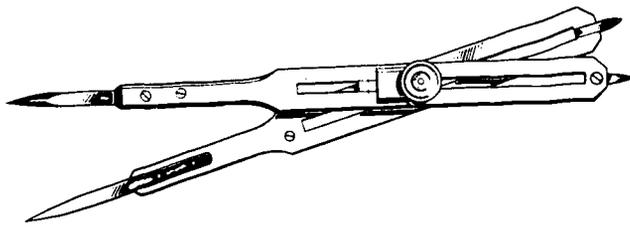


Figure 2-25. Proportional dividers.

b. Dividers.

(1) There are two types of dividers: the *bow dividers* and the *friction dividers*. Dividers are used to space off equal distances, to divide lines into equal parts, and to transfer dimensions.

(2) When a draftsman is required to make copies of drawings to an enlarged or reduced scale, he frequently employs the *proportional dividers*. This instrument permits reproducing the lines of a drawing so the lines in the copy are of a known ratio to the original, and producing a drawing so the content of a solid or area of a plane surface will be in proportion to the original. Proportional dividers (fig. 2-25) consist of two legs on a sliding, adjustable pivot, making it possible, when the legs are open, to have the distance between the points at one end bear a definite proportion to the distance between the points at the opposite end. The legs are marked with correctly divided scales and when the sliding pivot is set to the proportion desired on any particular scale, that proportion is established.

(3) Dividers are used (fig. 2-26) for transferring measurements and for dividing lines into any number of equal parts. The instrument should be opened with one hand by pinching the chamfer with the thumb and second finger. This will throw it into correct position with the thumb and forefinger outside the legs and the second and third fingers inside, with the head resting just above the second joint of the forefinger. It is thus under perfect control, with the thumb and forefinger to close it and the other two to open it. In coming down to small divisions, the second and third fingers must be gradually slipped out from between the legs as they are closed down upon them. Notice that the little finger is not used in manipulating the dividers. Care should be given as to not punch holes in the paper, but just barely mark the surface for future reference.

c. Ruling Pen.

(1) *Use.*

(a) Ruling pen is used for inking straight lines and is always used in connection with a guiding edge, T-square, triangle, or curve. An ink

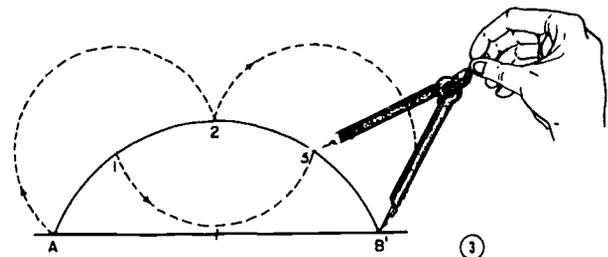
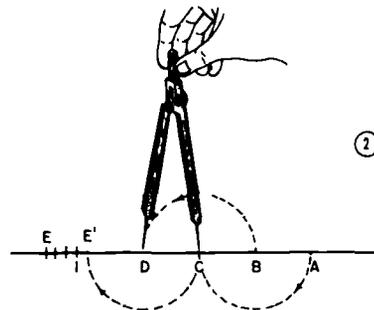
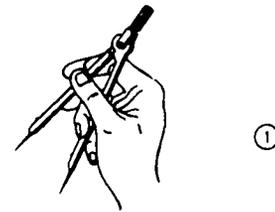


Figure 2-26. Using dividers.

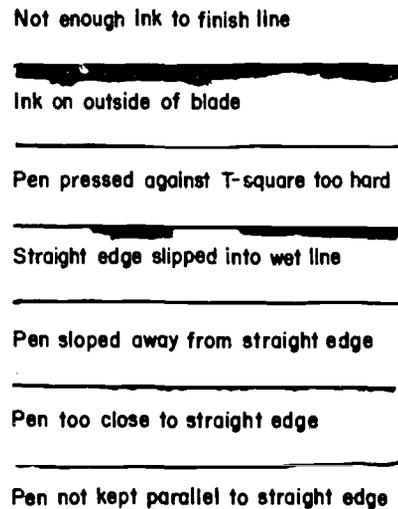


Figure 2-27. Routine mishaps in inking.

reservoir is formed by the space between the two blades. An adjusting screw controls the thickness of the line by regulating the clearance between the pen nibs. Many of the *routine mishaps* (fig. 2-27) encountered by a new draftsman when preparing an ink drawing or tracing can be avoided by paying attention to a few basic principles in inking techniques. Remember that it takes time for ink to dry; and be careful when moving the guiding

edge. It is generally good practice for the beginning draftsman to attach small coins or other suitable devices to the bottom of the straightedge, triangle or curves when inking to lessen the chances of ink running under the straightedge. The ruling pen is held in a vertical plane perpendicular to the plane of the paper and inclined 30° in the direction of the movement. It is held between the thumb and forefinger with the adjusting screw pointing outward and the blade resting against the second finger. The third and fourth fingers slide along the blade of the guiding edge and aid in steadying the pen. Lines are drawn with a steady, regular arm motion. Short lines are drawn with a motion of the fingers holding the pen; the fingers resting on the straightedge remain stationary. Long lines are finished with this finger motion. Do not allow the pen to rest at the end of a completed line; pick it up smartly and move the straightedge from the line.

(b) Fill the ruling pen with the quill attached to inkstand filler or to the stopper of the ink bottle or directly from the squeeze cartridge (fig. 2-28). Do not fill the pen more than $\frac{1}{4}$ inch from the point; too much ink causes blotting. Take care that no ink gets on the outside surface of the blades; if it does, wipe the pen clean and refill it. Never fill pen until it is ready for use because the ink dries quickly when not flowing from the pen. Ink should never be allowed to dry in any instrument. Never lay a ruling pen down with ink in it. Some drawing inks have an acid content that will pit a ruling pen if left to dry in the pen repeatedly. The student should clean the pen frequently by slipping a stiff blotter or a folded cloth between the nibs. Sandpaper should never be used to remove dry ink. Dry ink should be removed by scraping very lightly with a pen knife. Ruling pens constructed so that the nibs will separate for cleaning are available.

(c) Line width is determined by the distance between the pen blades at their points; the greater the separation, the wider the line. Spacing between the blades is regulated by the adjusting screw. The width of a new setting should always be tested by drawing trial lines on a piece of scrap paper of the same quality, or in the margin outside the trim lines of the working sheet. Other factors that affect the width are the amount of ink, speed of pen movement, shape and condition of nibs, quality of paper, and hardness of the working surface. If a pen is held so that its top leans outward, the point leans against the guiding edge and causes ink to run under the edge and blot. If the top of the pen leans too far inward, the outer nib does not touch the paper and causes



Figure 2-28. Filling the inking pen.

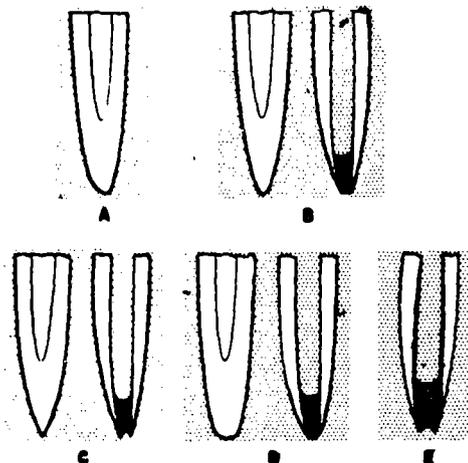


Figure 2-29. Shapes of ruling pen nibs.

an irregular line. The amount of pressure necessary varies with the quality of the paper and the sharpness of the pen. Pressure should be just strong enough to produce a clean, even line. Excessive pressure compresses the blades, narrows the width of the line along its length, or causes a line of varying width. The pressure against the guiding edge need be only enough to control the direction. If ink refuses to flow it may be started by pinching the blades slightly or drawing the pen across the thumbnail. Dried ink or particles from the wiping cloth clog the pen and cause an uneven line if allowed to accumulate. Dried ink can be removed by washing the pen in a weak solution of ammonia. Always put inking instruments away clean.

(d) Fine lines and lines of even width can be produced only by a ruling pen with *sharp, properly shaped nibs*. A draftsman who has trou-

ble producing fine lines or lines of even width, may find that his ruling pen needs sharpening or reshaping either because it is a poorly shaped new pen or because it is worn from constant use. He should know how to detect and remedy these conditions.

(2) *Examining and sharpening pens.*

(a) *Examining pen.* The nibs of a correctly shaped pen are elliptical in form and are founded equally (B, fig. 2-29). When filled and viewed from the side, the ink arches inward slightly at the point. If the nibs are pointed too sharply (C, fig. 2-29), the ink forms a concave arch between the blades and is difficult to start. If the nibs are blunt and rounded (D, fig. 2-29), the ink forms a convex arch that extends beyond the tips and causes blots and thickened lines at the ends. A dull pen (A, fig. 2-29), shows a spot of reflected light that passes from the side of the blade over the end of the point as the pen is turned in the hand. The nibs should be sharpened until these bright points disappear. E, figure 2-29 shows a pen that is too curved.

(b) *Sharpening pen.* Clean the blades thoroughly first in a weak ammonia solution, dry, and screw the nibs together until they just touch. Use a fine-grained Arkansas oilstone and hold the pen against it in line-drawing position (1, fig. 2-30). Draw the pen along the stone, as if drawing a line, moving the handle in a pendulum motion from an angle 30° through perpendicular position to an angle of 30° opposite to the direction of movement. Repeat the motion until the nibs are equally rounded in the proper elliptical shape (3, fig. 2-30). Next open the nibs slightly and sharpen each blade on the outside, holding the pen almost horizontal to the stone (2, fig. 2-30); use a slight, rocking motion, following the contour of the blade. Test the pen at intervals to see that the ink flows easily without blotting and that the blades

do not cut the tracing paper. Burs or wire edges formed on the inside of the blade can be removed by drawing a strip of leather or detail paper through the closed nibs, or open the pen wide and lay the entire inner surface of the blade flat on the stone and move it with a very light touch.

2-18. **Drafting Pens**

a. *Fountain Types.* There are two kinds of fountain pens used for drafting pens; Rapidograph and Graphos. Both fountain pens come with ink reservoir and various replaceable nibs with different sizes and shapes. The advantages in these pens are as follows: One is *speed*. There is practically no need to refill after a line or two as with a ruling pen. It is possible to change from one thickness of line to another rapidly. The second is *continuity*. Since the thickness of size of line is fixed, it is possible to have, without difficulty, the same thickness of line on the entire drawing, or drawings by all draftsmen in the department.

b. *Road Pen.* The road pen (N, fig. 2-3) is a swivel instrument similar to the ruling pen, except that it has two sets of nibs instead of one. Each nib is adjustable for line weight and the two sets can be adjusted with respect to each other. This instrument enables a draftsman to maintain an exact road width by tracing the entire road casing in one motion. This pen is to be used free-hand.

c. *Railroad Pen.* This pen (fig. 2-3) is similar to the road pen except that it has no swivel arrangement. Its purpose is to draw two lines that are parallel in a single motion with the assistance of a straightedge or curve.

d. *Contour Pen.* The contour pen (or curve pen) is an instrument similar to the ruling pen with

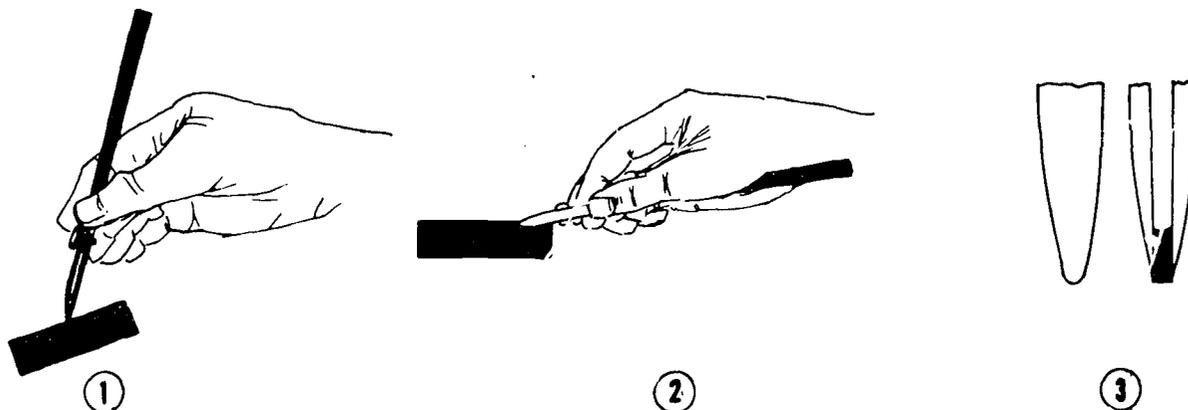


Figure 2-30. Sharpening the inking pen.

curved nibs and a swiveling barrel. It is used for drawing irregularly curved lines such as contour lines. The swivel barrel allows the draftsman to change direction of movement with a slight lateral pressure. The contour pen is used freehand and never in conjunction with a straightedge or curve. This pen is held almost perpendicular to the paper, with only a slight inclination in the direction of the stroke.

2-19. Freehand Pens

These pens (F, fig. 2-3) are held in the same manner as the pencil, tightly enough for control but allowing a loose, free movement. Strokes are drawn, not sketched, in the same manner as a ruling pen. Avoid pressure on the pen; pressure spreads the nibs and produces an uneven line. Hold the pen in the same manner consistently because tilting it in different directions causes different stroke weights. Regular practice is the only way to achieve uniform lettering of acceptable quality.

a. Penpoints. Crowquill pens produce the finest lineweight. Gillott or equivalent pens produce a heavier line weight and are for normal lettering. Payzant pens have a flat body containing a reservoir and curved nibs resembling a beak. These pens come in 11 sizes ranging from No. 000, the coarsest, to No. 8, the finest. Speedball pens are used with a regular pen holder. These pens come in four styles and resemble ordinary pens with a round, square, oval, or oblong shoe at the end.

b. Filling and Cleaning. Do not ink the pen too heavily or apply ink to the point. If ink flows too freely, blots occur more frequently and the first line strokes made after each filling will be heavier than the rest. While in use, pens should be wiped often with a soft cloth. They should be cleaned thoroughly before being put away.

2-20. Ink and Ink Holders

Drawing ink is finely ground carbon in suspension with natural or synthetic gum added to make the mixture waterproof. Nonwaterproof ink flows more freely but smudges easily. Bottleholders prevent the bottle from upsetting and ruining the drawing table or floor. Drawing ink also comes in small plastic squeeze dropper cartridges which are very convenient.

2-21. Drawing Pencils

a. Various Types.

(1) Drawing pencils are made of graphite encased in wood (fig. 2-32), shaped hexagonally, marked according to hardness, and are usually without erasers. Care should be taken not to cut off the hardness mark by sharpening the wrong end.

(2) Drawing pencils are available with leads of different grades of hardness. The hardness is designated on the pencil by numbers and letters. These symbols range from 7B, which is very soft, through 6B, 5B, 4B, 3B, 2B, B, HB, F, H, 2H, 3H, 4H, 5H, 6H, 7H, 8H, and 9H which is the hardest. A 6H or 5H pencil may be used for a penciled layout on detail paper of good texture and a 4H,

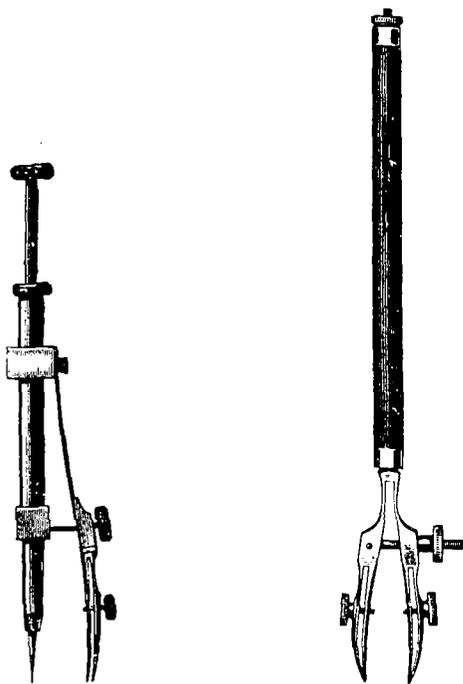


Figure 2-31. Drop compass and railroad pen.



Figure 2-32. Standard and mechanical pencils.

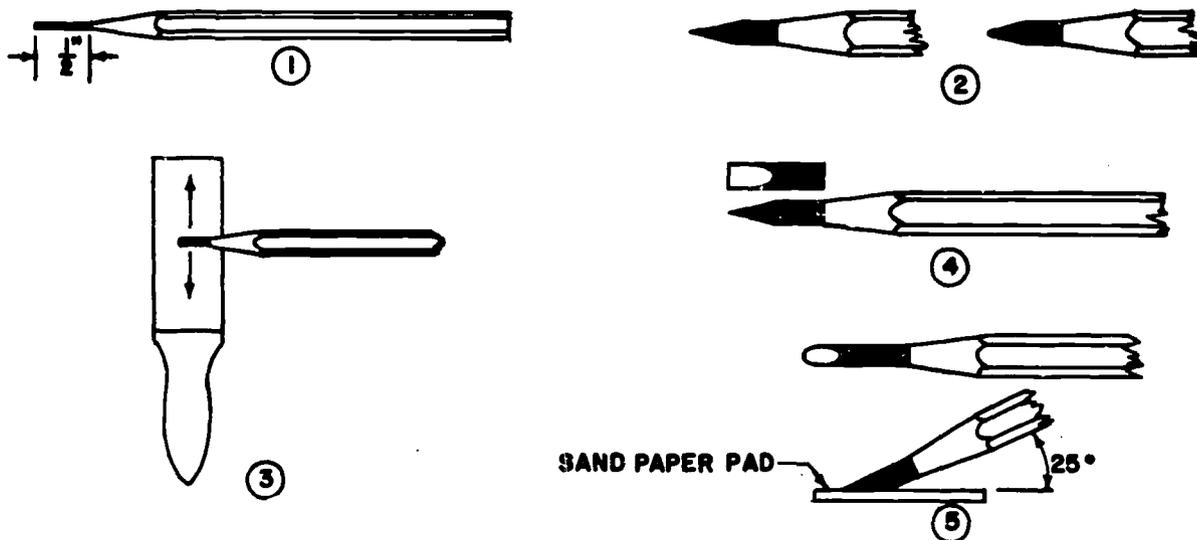


Figure 2-33. Pencil points.

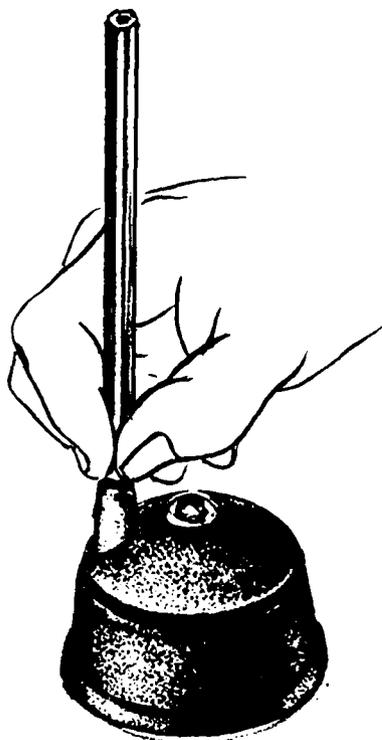


Figure 2-34. Lead sharpener.

3H, or 2H pencil may be used to darken these lines. The 3H to H pencils are used for finished pencil drawings or tracings on vellum. The F pencil is generally used for technical sketching while the H or HB is used for lettering. In every case, the pencil must be hard enough not to blur or smudge but not so hard as to cut grooves in the paper under reasonable pressure.

(3) There are also special plastic leads designed to be used on plastic paper or drafting film. These leads come in various degrees of hardness

similar to the graphite leads, (H, B or HB, and so on) or use a special numbering system (K1-5, 2S-6S, E1-E5 or V1-V5, etc.) depending on the manufacturer.

(4) Many draftsmen prefer to use a mechanical pencil (fig. 2-32) because its length is constant and it can easily be refilled with new lead.

b. Sharpening the Pencil.

(1) In sharpening your pencil, use a knife or a razor blade to cut the wood away from the pencil lead, as shown in figure 2-33. Cut the wood back until about $\frac{3}{8}$ of an inch of the lead is visible. Sharpen the tip of the lead on a sandpaper pad (G, fig. 2-3) by twirling the pencil as the lead is rubbed with long even strokes against the sandpaper pad or file; or place in a special lead sharpener (fig. 2-34). Do not allow graphite to fall on paper, drafting board, or equipment.

(2) The conical pencil point shown in 2, figure 2-33 is most commonly used. However, some draftsmen prefer using the wedge point (4, fig. 2-33) for drawing straight lines as the wedge point will not wear away as fast as the conical point. Have the sandpaper pad within easy reach, and keep the pencils sharp. The professional draftsman sharpens his pencil every few minutes. After sharpening the lead, wipe the excess graphite dust from the point before using the pencil. Form the habit of sharpening the lead often and keeping the point clean and free of graphite dust.

(3) Not only must pencil lines be clean and sharp, but for pencil drawings and tracing to be blueprinted, it is necessary that all the lines be uniform, firm, and opaque. This means a careful choice of pencils and the proper use of them. Too much emphasis cannot be given to the importance of clean, careful, accurate penciling.

2-22. Pencil Pointers

After the wood of the ordinary pencil is cut away with a pocket knife or mechanical sharpener, or the lead extended from a mechanical pencil, the lead must be sharpened. This can be done by a sandpaper pencil-pointer pad (G, fig. 2-3) or by a variable taper lead pointer (fig. 2-34). Some electric erasers come with an adapter which sharpens lead pencil points.

2-23. Erasing and Cleaning Supplies

a. A red rubber eraser (H, fig. 2-3) should be used for general erasing of both pencil and ink lines. This eraser not only removes pencil lines effectively but also removes ink lines without seriously damaging the surface of the paper or cloth.

b. An artgum eraser, (H, fig. 2-3) is useful for cleaning paper and cloth of finger marks and smears.

c. A steel arrowhead or knife eraser should be used only as a last resort for removing small segments of inked lines because it is almost certain to damage the drawing sheet.

d. The plastic eraser is useful in erasing special drafting lead used on plastic vellum, and is also useful in removing pencil lines without erasing ink lines.

e. The electric erasing machine with erasers of various degrees of hardness—white, grey, and pink—saves time and is essential if much drafting is being done.

f. There are also various kinds of eradicators to remove ink, bluelines, or sepia lines on paper, cloth, prints, or reproducibles.

g. Pounce is a fine white powder that can be sprinkled over the paper when ink is used to prevent smudges, and cut oily or greasy smudges.

h. The dry-clean pad is a rubbery granular substance in a loosely woven cloth sack that can be sprinkled over paper when pencil is used to prevent graphite smudges.

i. The erasing shield (I, fig. 2-3) is a small plate of thin spring steel that has slots of various shapes stamped out, allowing unwanted lines to be removed while leaving other lines untouched. The edges of the shield also clean the eraser, thus avoiding smudges.

j. The dustbrush (J, fig. 2-3) is a soft-bristled brush used to keep the drawing sheet free of eraser debris. The brush should be kept clean and dry and be used only for its intended purpose,

otherwise it may become dirty and smear the working area of the paper or cloth.

2-24. Materials

a. *Drawing Paper.* Many drawings are made on tracing paper or cloth rather than on paper. However, beginning students of drawing usually start their work on drawing paper and then progress to tracing paper and cloth after some skill in drawing is mastered. Drawing paper is produced in roll and sheet form and comes in white, cream, and light green color. The light green paper has the advantage of not showing dirt as readily as the others and reduces glare to a minimum. Several grades of drawing paper are available; however, it is advisable to use a good quality paper because it withstands erasing better. One surface of the paper has a smooth finish and the other surface a rough finish. The smooth finish is more adaptable for ink work whereas the rough finish is better suited for pencil drawings.

b. *Tracing Paper.* Formerly, most drawings were first prepared on some kind of opaque paper and then traced on tracing paper from which a print was developed. Today, draftsmen make their drawings directly on tracing paper in order to accelerate the drawing process. Tracing paper is a thin, transparent paper, which is sometimes chemically treated. The treated papers are called vellums while the untreated types are referred to as natural tracing papers. Natural tracing papers are manufactured in many different grades in either pure white or blue tinted colors. These papers do not, as a rule, possess the high degree of transparency as the vellums. The vellums are made of 100 percent pure white rag stock and are particularly noted for their high transparency. They withstand repeated erasing without leaving ghost marks, have good pencil and ink taking qualities, do not discolor with age, and stand a considerable amount of, handling without damage.

c. Tracing Cloth.

(1) *Description.* Tracing cloth is a transparent fabric and is used when the original tracing has to be preserved for a long period of time. It is available in either white- or blue-tinted colors. One side is usually dull and the other glazed. Tracing cloth will take both pencil and ink. In making drawings on cloth, the dull side should always be used. For inking purposes, a tracing cloth powder or pumice is sprinkled over the cloth and then dusted off with a felt pad or brush. The pumice prepares the cloth to take ink more readily.

(2) *Preparation.* Tracing cloth should be cut

several inches larger than the required finish size. For large drawings, allow the tracing cloth to lie flat for a short time before tacking it down. Occasional traces of oil that appear on tracing cloth prevent a smooth flow of ink; dusting the sheet with pounce or powdered chalk after it has been tacked down and wiping it with clean, dry cloth will remove any traces of oil.

(3) *Erasing.* Erasing inked lines must be done with care if re-inking is contemplated; a pencil eraser can be used in conjunction with an erasing shield to avoid wrinkling the paper. A triangle slipped underneath the tracing cloth at the point of erasure also minimizes wrinkling. The erased spot should be finished smooth with a thumbnail or triangle edge after erasing. A cloth dipped in carbon tetrachloride or benzine can be used to remove graphite smudges and pencil lines from tracing cloth. Never use a knife eraser on a line that must be re-inked because it will invariably damage the surface enough to permit ink to seep through. Use a draftsman's dustbrush to remove eraser debris.

(4) *Moisture.* Certain types of tracing cloth are sensitive to moisture and atmospheric changes. Do not allow moist hands and arms to come in contact with tracing cloth. For large tracings, it is advisable to cut a shield from detail paper to protect finished work. When the making of a tracing is to extend over several days, it is recommended that one view at a time be fully completed rather than working over the entire area. The cloth is quite responsive to changes in the moisture content of the air and will expand or shrink a great deal from one day to the next.

d. Plastic. Plastic paper, such as Mylar, Helios, Polyester, and so on, is transparent, more durable, and can be easily erased without leaving a "ghost" or damaging the working surface.

e. Cross Section Paper. Cross section paper is printed in many different grid sizes; but it is usually printed in green or red squares with 100 squares (10×10) or 400 squares (20×20) to the square inch and is available in sheets or rolls. Cross section paper is used to plot statistical data, graphs, and road elevations taken transversely to the centerline section of the road. It can also be used for sketching using the various squares as a guide.

f. Profile Paper. Profile paper is generally used in road work. The lower half of the paper is normally printed in orange squares, of 4 divisions horizontally by 20 divisions vertically to the square inch. The upper half of the sheet is blank and is used for drawing a plan view as of a road

seen from the air. The portion printed with orange squares is used to plot the elevation of the road along its centerline. The most common sizes are 23 by 36 inches; special sizes and profile paper in rolls are obtainable on special order in quantity. For further details refer to TM 5-581B.

g. Poster Board. Poster board is used by the military draftsman mainly for charts and graphs. Made with sturdy 3-ply construction, the smooth, white surface of these boards accepts ink easily. Available with printed border and titles or plain, the boards may be rolled without damage to board or surface.

2-25. Paper Fasteners

a. A drawing sheet can be fastened to the drawing board with drafting, masking, or cellophane tape. Though these tapes do not make holes like thumbtacks or staplers, they may roll up under the T-square or damage or leave sticky gum on the paper or drafting board. Thumbtacks preferably with thin flat heads, or wire staples inserted with a stapling machine can be used but they damage the working surface of the drawing board unless it is protected with a plastic drafting board cover that is self-sealing.

b. Since the T-square blade is more rigid near the head than toward the outer end, the paper should be placed close to the left edge of the board with its lower edge several inches from the bottom of the board. With the T-square against the left edge of the board, square the top of the paper; hold it in this position, slipping the T-square down from the edge, and fasten each upper corner. Then move the T-square down over the paper to smooth out possible wrinkles, and fasten the other two corners. When the sheet is larger, fasten drawing material in between corners as necessary.

2-26. Special Equipment

a. Mechanical Lettering Sets.

(1) One type of mechanical lettering set consists of five component parts: a number of guides or templates in which the lines of the letters are indented, a three-legged scribe, a number of inking pens of varying sizes and a pen holder with a special penciling attachment for the scribe. One leg of the scribe holds the pen or pencil, and the other two legs terminate in tracer points. One tracer point or tail pin moves in a long, straight groove on the template. When this latter point is moved around the contour of a letter, the entire scribe hinges on the tail pin in the groove and

the pen or pencil traces the letter on the drawing paper. Refer to paragraphs 4-13 through 4-15 and figure 4-11 for a complete description and use of this set.

(2) Another type of lettering set contains a vertical penholder for various penpoints and a number of templates. Each template contains a number of differently shaped perforations from which letters in one size and style can be stenciled.

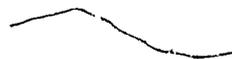
(3) The Varigraph is a more elaborate device for making a wide variety of either single-stroke letters or "built-up" letters. The Letterguide scribe is a much simpler instrument, which also makes a large variety of styles and sizes of letters when used with various templates available. They both operate with a guide pin moving in the grooved letters of the template, while the pen, which is mounted on an adjustable arm, makes the letters in outline. The letters can be filled in black, zip-a-toned, shaded, left blank, or reversed, that is, white letters with a black background.

b. Scribing Instruments. The standard military method of making color separations for map reproduction is the use of scribing instruments on

coated plastic sheets. The principal scribing instruments are called gravers, which hold scribing needles or blades. There are several types of gravers and accessories. For detailed information of their use, refer to TM 5-240.

c. Slide Rule. A slide rule (T, fig. 2-3) is a portable calculating device based on the principle of logarithmic addition and subtraction. Computations are an important part of engineering drawing and a draftsman who is proficient in the use of a slide rule finds it an essential aid in rapid calculations.

d. Other Miscellaneous Items. Certain other items may or may not be available to the draftsman through local purchase or supply, but may be used by the draftsman if available. They include, but are not limited to: pantographs, polar planimeter, scale guards, lettering triangle, parallel rules, hatching pens, Zip-a-tone, Prestype, horn centers, tri-tractor map measures, paper cutters, tack lifters, staple removers, oilstones, draftsman's pencil sharpeners, horizontal map files, vertical plan hold files, stack roll files, mailing tubes, headliner, and so forth.



CHAPTER 3

LINE WEIGHTS, CONVENTIONS AND FORMATS

3-1. Line Conventions

Line conventions are symbols that furnish a means of representing or describing some basic aspect of a real object. The meaning of the symbols is determined by definition, and is expressed by a combination of line weight and characteristic appearance, as presented in MIL-STD-100A, Engineering Drawing Practice and NAVFAC DM-6, Design Manual, Drawings and Specifications.

3-2. "Alphabet of Lines"

Four widths of lines (fig. 3-1) for finished drawings are recommended: *thin* for center, extension, dimension, leader, long-break, adjacent-part, alternate-position, section and repeat lines; *medium* for hidden outlines, stitch lines, phantom and reference lines; *thick* for visible outlines, short-break and datum lines; *extra thick* for cutting plane, viewing plane and cutting plane lines for complex or offset views. The weights of these lines for the average drawings in ink should be 1/100 inch for thin lines; 1/60 inch for medium lines; 1/40 inch for thick lines; and 1/25 inch for extra thick lines. Pencil lines will be a little thinner.

a. Types of Lines.

(1) *Ink lines.* Ink lines shall be opaque and of uniform width for each type of line. Three widths of lines will be used—thin, medium, and thick, as shown in figure 3-1, with their widths in proportions of 1:2:4. The actual width of each type of line will be governed by the size and style of the drawing; relative widths of the lines will approximate those shown in figure 3-1.

(2) *Pencil lines.* Pencil lines will be opaque and of uniform width throughout their length. The line widths specified above do not apply to pencil lines; however, the thick lines used for outlines and other visible lines will be sufficiently prominent to differentiate them immediately from lines used for other purposes. Hidden, sectioning, center, phantom, extension, dimension, and leader lines will be thinner than outlines. In selecting the widths of pencil lines, consideration will be given to the medium of reproduction involved to insure

proper reproduction and reduction of the thinner lines.

b. *Line Characteristics.* The line characteristics described in (1) through (12) below will be used for all drawings other than diagrams, such as schematic. Figures 3-1 and 3-2 illustrate the proper presentation and use of line conventions.

(1) *Centerlines.* Centerlines are composed of long and short dashes, alternately and evenly spaced with a long dash at each end, and at intersections the short dashes intersect. Very short centerlines (fig. 3-2) may be broken if there is no confusion with other lines. Centerlines are also used to indicate the travel of a center.

(2) *Dimension lines.* Dimension lines will terminate in arrowheads at each end. They will be unbroken on construction drawings and will be broken on production drawings only where space is required for the dimension. The proper method of showing dimensions and tolerance is presented in chapter 10.

(3) *Leader lines.* Leader lines are used to indicate a part or portion to which a number, note, or other reference applies and will terminate in an arrowhead or a dot. Arrowheads should always terminate at a line; dots should be within the outline of an object. Leaders should terminate at any suitable portion of the note, reference, or dimension. Penetration of leaders is permissible when necessary for clarity.

(4) *Break lines.* Short breaks will be indicated by solid, freehand lines. For long breaks (fig. 3-1), full, ruled lines with freehand zigzags will be used. Shafts, rods, and tubes that have a portion of their lengths broken out will have the ends of the break drawn as indicated in figure 3-2.

(5) *Phantom lines.* Phantom lines will be used to indicate the alternate position of delineated parts of the item, repeated detail, or the relative position of an absent part. They will be composed of alternating one long and two short dashes evenly spaced with a long dash at each end.

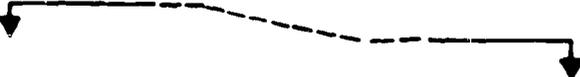
CENTER LINE		THIN
DIMENSION		THIN
LEADER		THIN
BREAK (LONG)		THIN
PHANTOM		THIN
SECTIONING AND EXTENSION LINE		THIN
HIDDEN		MEDIUM
STITCH LINE		MEDIUM
OUTLINE OR VISIBLE LINE		THICK
BREAK (SHORT)		THICK
DATUM LINE		THICK
CUTTING PLANE		EXTRA THICK
VIEWING PLANE		EXTRA THICK
CUTTING PLANE FOR COMPLEX OR OFFSET VIEWS		EXTRA THICK

Figure 3-1. Line characteristics and conventions.

(6) *Sectioning lines.* Sectioning lines will be used to indicate the exposed surfaces of an object in a sectional view. They are generally full thin lines but may vary with the kind of material shown.

(7) *Extension lines.* Extension lines will be used to indicate the extent of a dimension and will not touch the outline.

(8) *Hidden lines.* Hidden lines will consist of

short dashes evenly spaced and will be used to show the hidden features of a part. They will always begin with a dash in contact with the line from which they start, except when such a dash would form the continuation of a full line. Dashes will touch at corners and arcs will start with dashes at the tangent points.

(9) *Stitch lines.* Stitch lines (fig. 3-1) will be used to indicate the stitching or sewing lines on

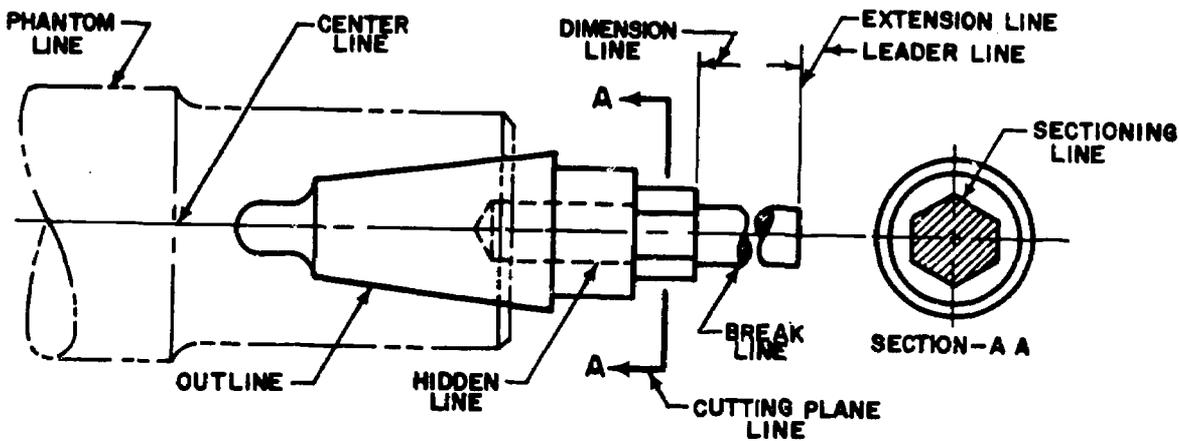


Figure 3-2. Line conventions.

an article. They will consist of a series of very short dashes, approximately half the length of the dash of hidden lines, evenly spaced. Long lines of stitching may be indicated by a series of stitch lines connected by phantom lines.

(10) *Outlines or visible lines.* The outline, or visible line, will be used for all lines in the drawing representing visible lines on the object.

(11) *Datum lines.* Datum lines (fig. 3-1) will be used to indicate the position of a datum plane and will consist of one long dash and two short dashes evenly spaced. Application of datum planes is covered in chapter 10.

(12) *Cutting-plane and viewing-plane lines.* Cutting-plane lines will be used to indicate a plane in which a section is taken. Viewing-plane lines (fig. 3-1) will be used to indicate the plane from which a surface is viewed.

c. Reading Line Conventions

(1) *Uniformity.* A draftsman must always be aware that he is drawing line conventions for others to read. Their understanding of the meaning of line symbols is based on the definitions in *b* above and figures 3-1 and 3-2. Line conventions will conform to the specifications so that only one interpretation is possible. Specific notes must identify the structural or mechanical symbolism which requires heavier than standard line weights, for example, steel beam centerlines.

(2) *Reproduction.* Copies of original drawings prepared by draftsmen are produced for distribution to the various mechanics and supervisors responsible for the manufacture of the part or assembly represented. Various reproduction processes are used, but the best known are blueprints and ammonia process prints. Regardless of the process used, fine pencil drawing is the basis of a good reproduction. Reproductions are made

either directly from a finished pencil drawing or from an ink tracing made from a pencil drawing.

d. Precedence of Lines.

(1) In any drawing where there is a coincidence of lines, the following precedence of lines should be followed:

- (a) Object line.
- (b) Hidden line.
- (c) Centerline or cutting-plane line.
- (d) Break line.
- (e) Dimension and extension lines.
- (f) Crosshatch lines.

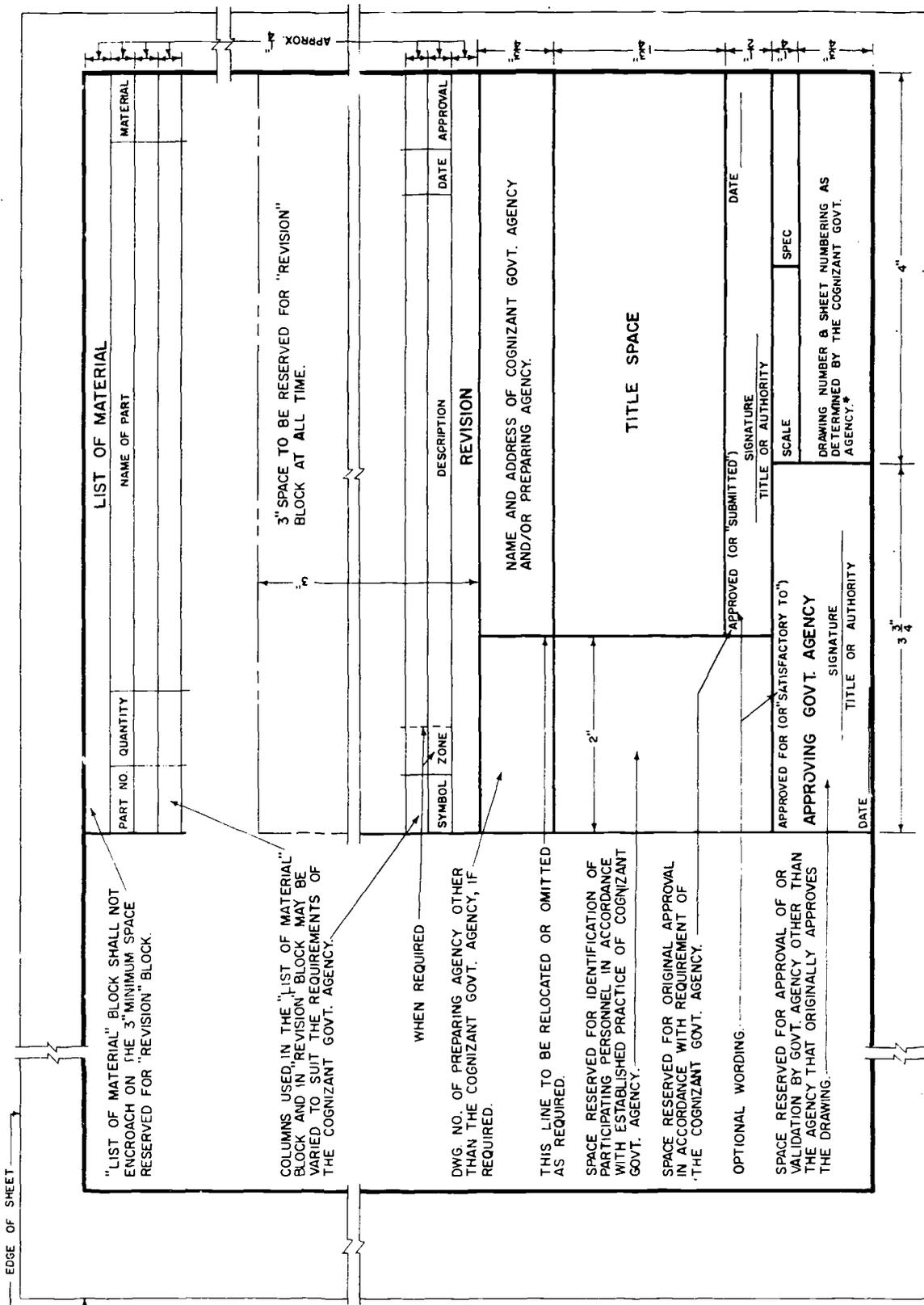
(2) In accordance with the above list, whenever a centerline coincides with a hidden line, the hidden line should be drawn and the centerline left out.

3-3. Drawing Formats

A drawing must not only provide information about the size and shape of the object being represented but must provide information that enables the drawing to be identified, processed, and filed methodically (fig. 3-3). The systematic arrangement of sheet space to provide a consistent location for this information is known as the format of a drawing. Sizes and formats for military drawings are arranged in accordance with military standards.

3-4. Sheet Sizes

Flat size refers to drawings that usually have a printed format and, because of their relatively small size, can be stored flat. Roll size refers to drawings that, because of their length, are filed in rolls and usually do not have a printed format. To provide protection, a 4-inch margin may be added to the right end of minimum lengths specified for roll sizes. When practicable, the maximum length



"LIST OF MATERIAL" BLOCK SHALL NOT ENCRUCH ON THE 3" MINIMUM SPACE RESERVED FOR "REVISION" BLOCK.

COLUMNS USED IN THE "LIST OF MATERIAL" BLOCK AND IN "REVISION" BLOCK MAY BE VARIED TO SUIT THE REQUIREMENTS OF THE COGNIZANT GOVT. AGENCY.

WHEN REQUIRED

DWG. NO. OF PREPARING AGENCY OTHER THAN THE COGNIZANT GOVT. AGENCY, IF REQUIRED.

THIS LINE TO BE RELOCATED OR OMITTED AS REQUIRED.

SPACE RESERVED FOR IDENTIFICATION OF PARTICIPATING PERSONNEL IN ACCORDANCE WITH ESTABLISHED PRACTICE OF COGNIZANT GOVT. AGENCY.

SPACE RESERVED FOR ORIGINAL APPROVAL IN ACCORDANCE WITH REQUIREMENT OF THE COGNIZANT GOVT. AGENCY.

OPTIONAL WORDING.

SPACE RESERVED FOR APPROVAL OF OR VALIDATION BY GOVT. AGENCY OTHER THAN THE AGENCY THAT ORIGINALLY APPROVES THE DRAWING.

* COGNIZANT GOVERNMENT AGENCY IS THE AGENCY HAVING COGNIZANT OVER THE PREPARATION OF THE DRAWING, WHETHER PREPARED BY IT OR BY ANOTHER PREPARING AGENCY UNDER ITS DIRECTION.

Figure 3-3. Format for drawings.

of roll sizes should not exceed 144 inches. Finished sheet size refers to dimensions between trim lines. Sheet width is measured parallel to the working edge of the drawing board; length is

measured perpendicularly to the working edge of the drawing board. Further information on drawing size can be found in table 3-1 and MIL-STD-100A.

Table 3-1. Finished Format Sizes (Inches)

Flat sizes				Roll sizes				
Size	X (Width)	Y (Length)	Z (Margin)	Size	X (Width)	Y Min (Length)	Y Max (Length)	Z (Margin)
(A) Horiz	8½	11	¼ and ⅜ *	G	11	42	144	⅜
(A) Vert	11	8½	¼ and ⅜ *	H	28	48	144	½
B	11	17	⅜	J	34	48	144	½
C	17	22	½	K	40	48	144	½
D	22	34	½					
E	34	44	½					
F	28	40	½					

* Horizontal margin ⅜ inch; vertical margin ¼ inch.

3-5. Sheet Layout

Sheets of drawing or tracing paper are cut slightly larger than their required finished sizes and are fastened to the drawing board. Using a hard (6H) pencil and a T-square, draw a horizontal trim line near the lower edge of the paper, then draw a vertical trim line near the left edge of the paper with a T-square, pencil and triangle. Dimensions establishing the finished length of the sheet (distance between vertical trim lines) and the location of the vertical borderlines are marked off on the horizontal trim line. The full-size scale is used when laying off a series of measurements along a line. Dimensions, establishing the finished width of the sheet (distance between horizontal trim lines) and the location of the horizontal borderlines, are marked off on the vertical trim line. Dimensions may be scaled along the borderlines. Borderlines are given the required weight (fig. 3-3) when the drawing has been completed. After the completed drawing has been removed from the board, it is cut to its finished size along the trim lines.

3-6. Basic Formats

Military drawings are classified as construction or production drawings, depending on the method of manufacture of the object or assembly represented on the drawing or set of drawings. The format of each type is arranged differently, although sheet and margin sizes are common to both.

3-7. Construction Drawing Formats

Construction drawings are drawings developed or

used to illustrate the design of structures or other constructions, and include services, utilities, approaches, and any other required features. Maps (except those with construction drawings), reports, sketches, presentation drawings, or renderings are not considered to be construction drawings within the meaning of this standard. The basic construction drawing format consists of the margin, the title block with its various subdivisions, the revision block, and the block containing the list of material. Figure 3-3 shows the layout and dimensions of the typical construction drawing format. Table 1 gives margin requirements between trim and border lines. The following modifications should be applied to the data presented in figure 3-3.

a. *Drawing Number.* The drawing number is assigned by the cognizant Government agency.

b. *Approval by Government Agency.* The use of "Approved for" or "Satisfactory to" is optional in the block requiring the signature of a government agency. Space should be reserved in this block, to the left of the signature line, for approval of validation by government activities other than the agency that originally approves the plan.

c. *Approval by Individual Authority.* The use of "Approved" or "Submitted" is optional.

d. *Revision Block.* When there is no list of material, the revision block may be placed in the upper right-hand corner and extended downward; headings and column widths can be changed to suit requirements.

e. *List of Material.* Headings and column widths in the list of material may be changed to

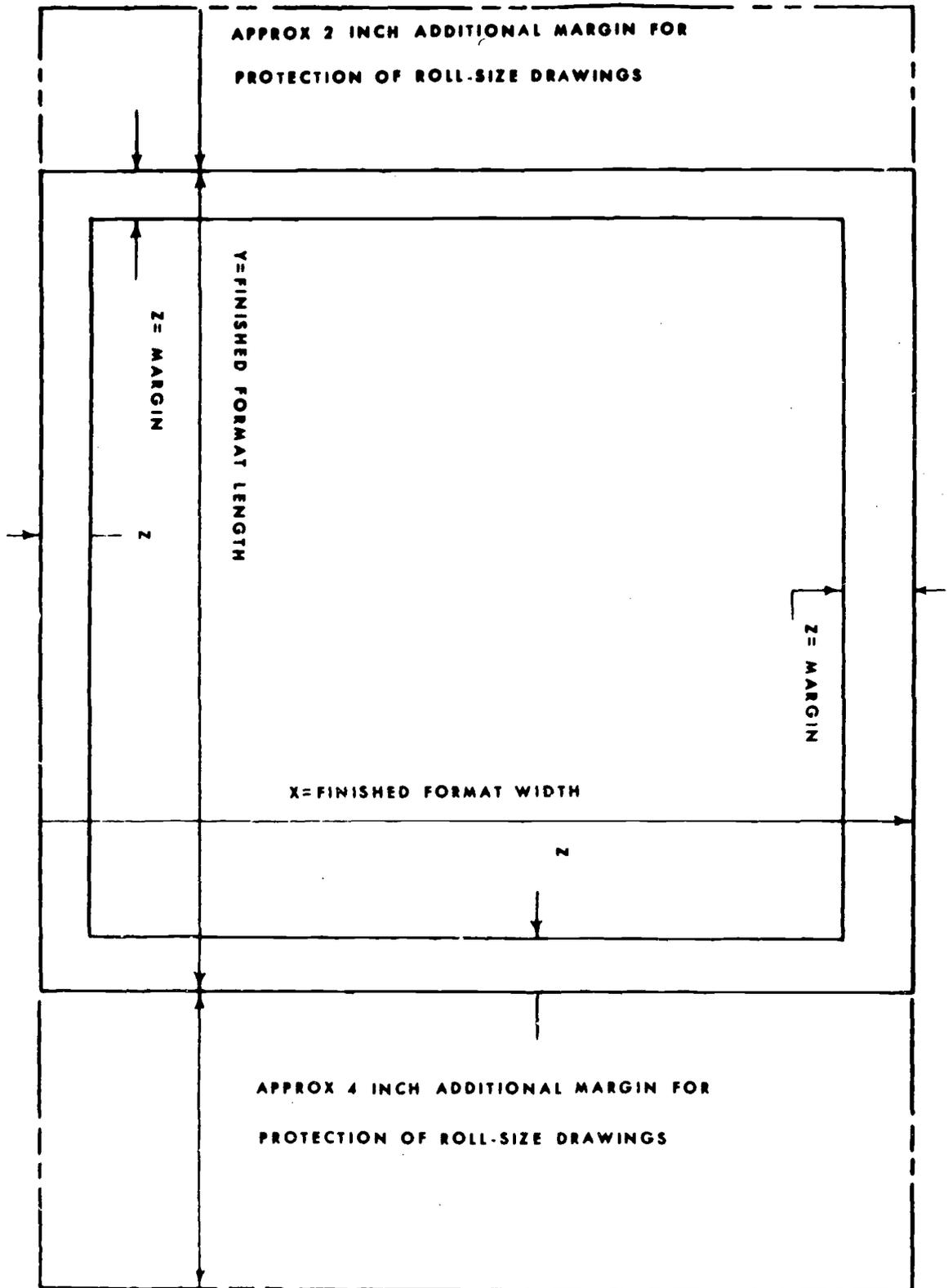


Figure 3-4. Finished format sizes (inches).

suit the requirements of the agency preparing the drawing. Additional columns may be used as required.

f. *Patent Notice, Security Classification.* If pat-

ent has been requested, a patent notice block should be included. If the drawing is classified, a security classification block must be included (MIL-STD-100A, and NAVFAC DM-6).

3-8. Production Drawing Formats

Production drawings represent those types of equipment or articles that are produced in quantity, or that are of such design as to permit such production. The basic format consists of the margin (fig. 3-4), title block, and revision block.

a. Title Block. The title block is located in the lower right-hand corner of the drawing. It contains the number that identified the drawing; the drawing number (located in a block in the lower right-hand corner of the title block); and certain information common to all drawings, including the name and address of the government agency preparing the drawing, the title of the drawing scale, drafting record, authentication, and date.

b. Line Weights and Lettering. All lettering and numbering that ordinarily would be printed on drawing forms to indicate items, such as zoning, column headings, and space identification, may be of any appropriate size. Line weights and all other lettering are the same as specified for construction drawing formats.

c. Additional Specifications. For further specifications concerning size, location, and use of the blocks described above, as well as data on supplementary blocks, security classification, and patent notices, refer to MIL-STD-100A.

3-9. Order of Inking

Lines are inked in a definite order to save time

that would otherwise be wasted in waiting for inked lines to dry, and to produce lines of the same width from the same adjusting screw setting. The natural progression for the right-handed person for drawing horizontal lines is from top to bottom; vertical lines normally are drawn in sequence from the left to the right-hand side of the sheet.

a. Centerlines. Ink all centerlines first; begin with centerlines for full circles.

b. Points of Tangency. Be sure all tangent points are marked in pencil directly on tracing.

c. Thick Lines. Ink all arcs and circles, irregular curves; then all horizontal lines from the top down, vertical lines beginning at the left, and then inclined lines.

d. Medium Lines. Ink all hidden and stitch lines in the order described in *c* above.

e. Thin Lines. Ink all dimensions, extension, leader, phantom, and sectioning lines next, and inclined lines last. When drawing sectioning lines, do not attempt to trace them; place a blank sheet of paper between the pencil drawing and the tracing cloth and draw sectioning lines by eye.

f. Freehand Lettering. Ink all arrowheads, dimension figures, specific notes, and general notes including the list of materials.

g. Border and Title Block. Ink borderlines, and letter the title block.

CHAPTER 4

LETTERING

Section I. LETTERING REQUIREMENTS

4-1. Legible Information

The shape and description of a part, machine, or structure that is presented graphically by the various views in a drawing will be supplemented by additional information that is freehand or mechanically lettered. Numerical dimensions, notes on material and finish, and a descriptive title should all be lettered in a style that is legible, uniform, and capable of rapid execution. As far as the appearance of a drawing is concerned, the lettering is the most important part. The usefulness of a drawing can be destroyed by lettering done haphazardly or carelessly, because illegible figures are apt to cause mistakes in the work. Illegible information may be interpreted by the contractor to produce a cheaper and inferior product or structure than required by the contract, or cause unnecessary expense due to a claim made against the US Government by the contractor.

4-2. Style

Lettering style will be single-stroke upper-case, commercial Gothic, except when typewritten characters are used. Vertical lettering or inclined lettering may be used, but only one type should appear for a single drawing or set of drawings. Lower-case letters may be used on construction drawings, except for titles. Typewritten characters may be uppercase or lowercase. The expression single-stroke means that the width of lines composing the letters is the same as the width of a stroke of the pen or pencil used for lettering; it does not mean that each letter is executed with a single, continuous movement of the pen or pencil. Uppercase refers to capital letters.

4-3. Proportions

The ratio of letter width to letter height varies with individual letters. This chapter presents standard proportions that take into consideration the characteristics of individual letters. Letters using these proportions are called normal letters.

When letter width is decreased in relation to letter height to conserve space, the letters are said to be compressed letters. When letter width is increased in relation to letter height, the letters are known as extended letters.

4-4. Stability

If the areas of the upper and lower portions of certain letters and numerals are made equal, an optical illusion is created which causes them to seem top-heavy. To correct this and give the impression of stability, the letters *B, E, F, H, K, S, X,* and *Z,* and the numbers *2, 3, 5,* and *8* must be drawn smaller at the top than at the bottom.

4-5. Uniformity

Lettering in a drawing will present a uniform appearance. Height, inclination, alinement, line weight, and spacing are the principal considerations. Uniform height, alinement, and inclination are achieved through the use of guidelines; uniformity in line weight depends on skillful use of the pencil or lettering pen. Uniform spacing of letters in words and of words in sentences is performed by eye; good judgment results from practice.

4-6. Guidelines

Guidelines are horizontal, vertical, and/or inclines. They are always used in executing freehand lettering. Horizontal guidelines determine horizontal alinement, letter height, and the spacing between lines of lettering. Two horizontal guidelines are used for uppercase letters; the upper line is called the cap line, and the lower line is called the baseline. The distance between cap lines and baselines establishes the height of uppercase letters. Guide lines for lowercase letters are constructed in proportion to uppercase sizes. Four horizontal guidelines are used, cap lines and baselines being the same. The two additional lines are called the waistlines and droplines. Vertical and inclined guidelines serve to keep the vertical-

ity of inclination of freehand characters uniform. Guidelines are drawn with either standard or lettering triangles and are spaced at random.

a. *Size and Spacing.* The size of lettering and the line spacing which should be used on a drawing are controlled by the size of the drawing form in relation to the detail incorporated, and by the amount of reduction, if any, which will be used. The modern procedure of reducing drawings to small size or reproducing them on microfilm and then enlarging them, limits the minimum size of characters and the line spacing which may be used. It is recommended that the minimum size of lettering after reduction be not less than 3/64 inch. In the absence of factors making larger characters desirable, the recommendations for size of characters for drawing sizes A, B, and C table 3-1 are listed in table 4-1. For D-size drawings or larger (table 3-1) the sizes of characters shall be governed by the considerations set forth above. When commercial lettering guides are used, sizes corresponding to those given above are acceptable.

Table 4-1. Character Sizes.

	Size (inches)	Lettering guide size
Drawing and part number -----	1/4	.250
Title -----	3/16	.175
Subtitle -----	5/32	.140
Letters and figures for body of drawing	1/8	.125
Fractions and tolerances -----	3/32	.100
Designation of section and detail views:		
"Section" "Detail" -----	5/32	.140
"A-A" "B" -----	1/4	.250

Note. Lettering and numbering used for special notices, such as patent notices, may be of any size satisfactory for the purpose intended.

b. Lettering Triangle.

(1) *Description.* Lettering triangles are made in many sizes and styles. The 45° triangle shown in figure 4-1 is typical. It has an elongated slot for drawing standard slant guidelines and is columns of countersunk holes numbered 3, 4, 5, 6, 7, and 8 for drawing horizontal guidelines. The triangle is always used with its hypotenuse sliding against the working edge of the T-square (or another straightedge if lettering lines are not horizontal). The round hole cut through the center of the triangle has beveled edges and is intended for inserting the fingernails as an aid in picking up the triangle.

(2) *Horizontal guidelines.* The six columns of numbered countersunk holes are designed for inserting the cone point of the 6H pencil and horizontal guidelines by sliding the triangle with the pencil inserted along the working edge of the T-square. The numbers mean 32nds of an inch be-

tween cap line and baseline, (the size of the capital letters required). For example: (8) = 8/32 or 1/4 inch (6) = 6/32 or 3/16 inch, (5) = 5/32 inch and so on; also the numbers correspond to MIL-STD-1A, governing lettering sizes. Note that the holes are grouped in clusters of 3 for drawing a cap line, a waistline and a baseline. No holes are drilled for drawing droplines. The letters requiring a dropline are drawn to size by eye. For normal lettering the standard spacing between lines is two-thirds the height of the capital letters. Line spacing is half capital height for compressed lettering and one and a half capital height for extended lettering. The holes in the lettering triangle are drilled for normal lettering and to give standard spacing between lines if two or more clusters are used in sequence without relocating the T-square. Figure 4-1 illustrates by arrows the manner of drawing guide lines for 8/32- or 1/4-inch lettering. In special cases where the size of lettering varies from line to line, such as in title blocks, the single hole at the top of a column is placed over the baseline of the preceding lettering to determine the spacing between lines.

(3) *Inclined guidelines.* The standard slope for inclined lettering is at an angle of 22½° to the right of vertical or at an angle of 67½° with the horizontal. The elongated slot (fig. 4-1) in the lettering triangle is cut at an angle of 67½° to the hypotenuse for use as a guide in drawing inclined guidelines for slant lettering. The sides of the slot are parallel so that either side may be used for drawing slant guidelines. The triangle rests with its hypotenuse free to slide along the working edge of the T-square to the desired location for the guidelines. As many inclined guidelines may be drawn as experience dictates, but at least one for each letter for a beginner. There are several other methods of obtaining the correct angle for inclined lettering if no lettering triangle is available. Two simple methods are:

(a) Bisect the angle between a vertical line and a 45° line.

(b) Construct a small triangle of base equal to 1 inch and an altitude of 2-7/16 inches. The hypotenuse of this triangle will make an angle of 67.7° with the horizontal which is close enough for guidelines. In each case, having established a line at 67½° it is necessary to draw all slant guidelines parallel to it by using two triangles sliding against each other.

c. Lettering Instrument.

(1) The Ames lettering instrument (fig. 4-2) works on the same principle as the lettering triangle. The main difference is that it has angles of

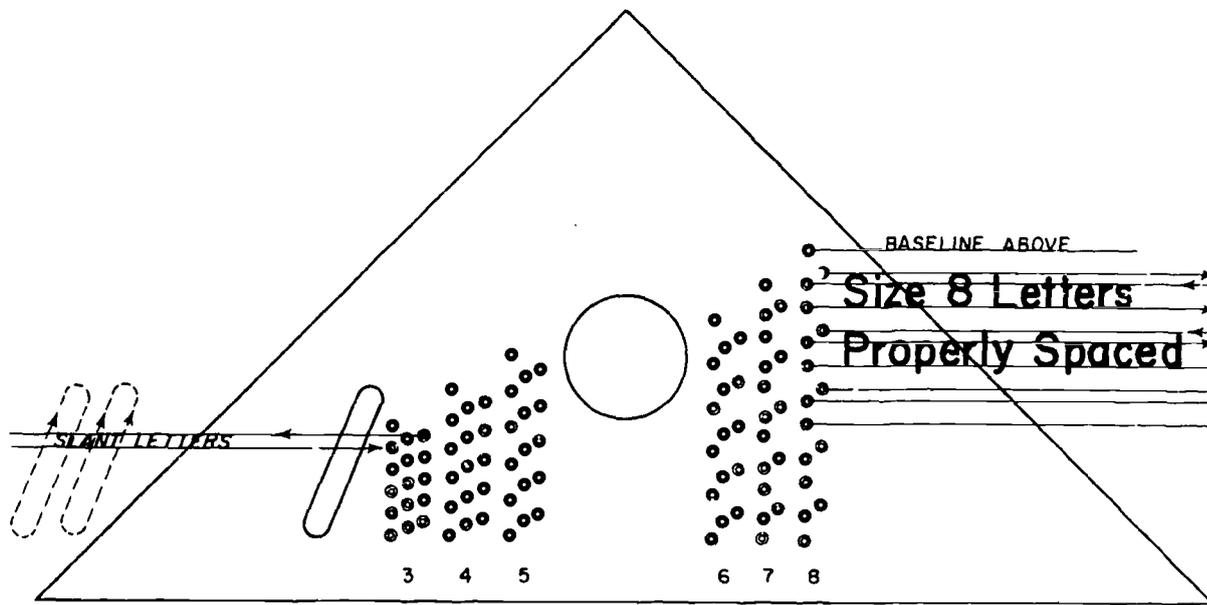


Figure 4-1. Use of the lettering triangle.

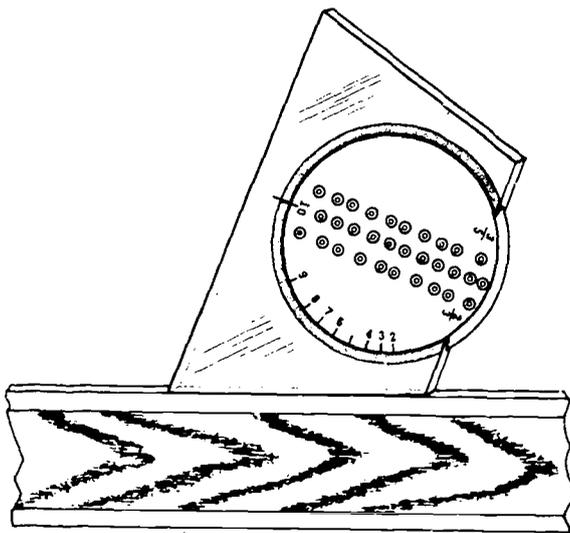


Figure 4-2. Ames lettering instrument.

68° and 75° for construction of inclined guide-lines. The numbers 2 through 10 are numerators of the denominator 32. If the circular disk is turned so that numerator 9 is matched with the line on the frame, the total height of the resultant capital letter would be $9/32$ inch.

(2) If the disk becomes too loose in the frame, remove it and press the edges of the frame about $1/4$ inch together. If the disk is too tight, apply a light powder on the edge of the disk. To clean, use soap and water.

Section II. FREEHAND LETTERING

4-7. Pencil Technique

All letters and figures are drawn with the basic strokes illustrated in figure 4-3. To execute satisfactory letters, a draftsman must learn and practice the direction and sequence of strokes used to form each letter.

a. Position. Rest the forearm on the drawing board below the edge of the paper. Hold the pencil between the thumb, forefinger, and second finger so that each rests against a flat side. The third and fourth fingers and the ball of the palm rest on the drawing sheet.

b. Basic Strokes. Vertical strokes are drawn from the top down with an even finger movement. Inclined strokes are drawn in the same way and are slanted in the desired direction. Horizontal strokes are drawn from left to right with a complete hand movement, pivoting at the wrist. Curved strokes proceed from above downward, moving in the desired direction, and are produced with a combined finger and wrist motion. Lettering strokes are drawn, not sketched; the uniform, single-stroke appearance required of lettering can be achieved only by practicing the fundamental strokes in the manner described.

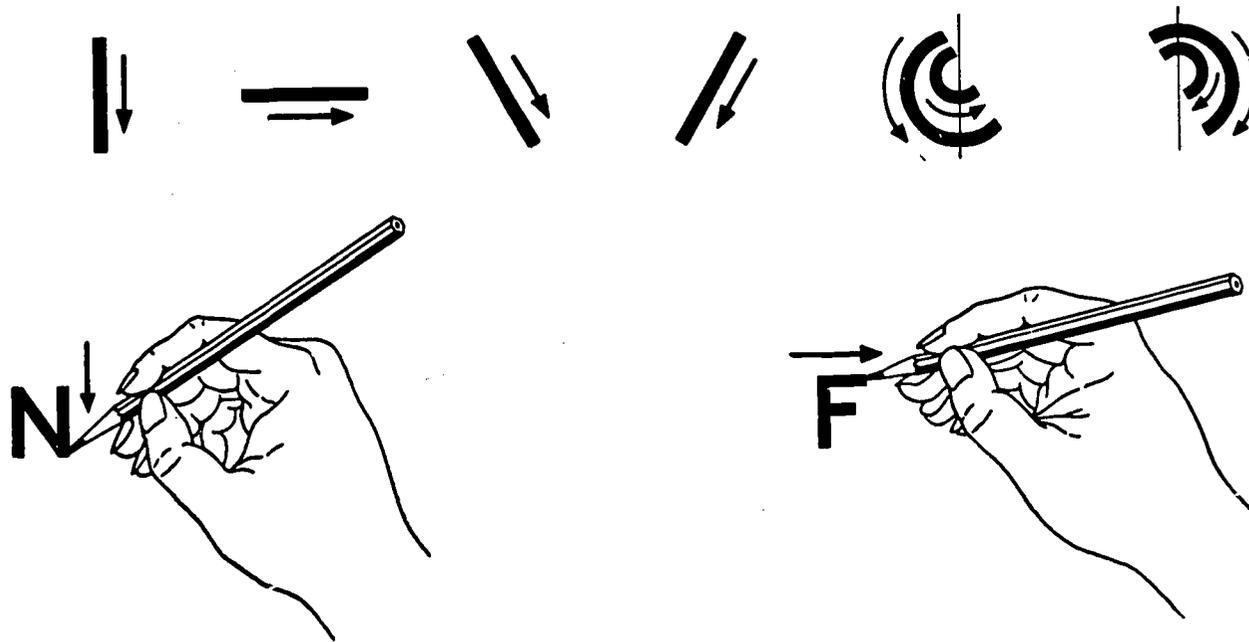


Figure 4-3. Basic lettering strokes.

4-8. Lettering Pen Technique

The lettering pen is held in the same manner as the pencil, tightly enough for control but allowing a loose, free movement. Strokes are drawn, not sketched, in the same manner as pencil strokes. Avoid pressure on the pen; pressure spreads the nibs and produces an uneven line. Hold the pen in the same manner consistently because tilting it in different directions causes different stroke weights. Regular practice is the only way to achieve uniform lettering of acceptable quality.

a. Pen Points. Crowquill pens produce the finest line weight. Gillott or equivalent pens produce a heavier line weight and are used for normal lettering. In general, penpoints that are too flexible produce a wavering line and those that are too stiff cause the draftsman to use too much pressure, thus spreading the nibs.

b. Filling and Cleaning. Do not fill pens by dipping them into the bottle. Use the quill in the stopper of the ink bottle and insert ink in the slot on the underside of the pen. Do not ink the pen too heavily or apply ink to the point. If ink flows too freely, blots occur more frequently and the first line strokes made after each filling will be heavier than the rest. While in use, pens should be wiped regularly with a soft cloth. They should be thoroughly cleaned before being put away.

4-9. Vertical Letters

Figure 4-4 illustrates the required shape of vertical letters and numerals. Figures 4-5, 4-6, 4-7, and

4-8 illustrate construction of characters against a square background with each side divided into six equal units except the letters *I* and *W*. The background serves as a reference framework for comparing the height of the various characters in proportion to their width as well as locating the individual lines that compose these characters. A smaller drawing below each character in figures 4-5 and 4-6 shows the direction and sequence of the strokes used in the formation of the character.

a. Straight-Line Capitals, (Figure 4-5).

(1) *I, A, L, T.* The letter *I* is the basic vertical stroke. Stroke 3 of the *A* is located a third of the distance up from the baseline; inclined strokes 1 and 2 intersect just above the cap line. The horizontal stroke of the *T* is drawn first; the vertical stroke, or stem, is drawn from the center. With both *L* and *T*, the horizontal stroke may be lengthened or shortened to balance the letters in a word. If, for example, *L* precedes *A*, its horizontal stroke is reduced slightly; if *T* precedes *A*, its horizontal stroke is extended slightly.

(2) *H, F, E.* In *H, F*, and *E*, the central horizontal bar is placed slightly above the center for stability. In both *E* and *F*, the cap line stroke is 4 units long. The baseline of *E* is $\frac{1}{2}$ unit longer than its cap line.

(3) *V, W, M, N.* The 2 inclined strokes of the *V* intersect just below the baseline. The *W* is $1\frac{1}{3}$ times the width of a normal letter; note that it is wider than the *M*. Strokes 1 and 2, and 3 and 4 of the *W* intersect below the baseline. Strokes 3 and 4 of the *M* and 2 and 3 of the *N* intersect on the

ABCDEFGHIJKLMNOPQRSTUVWXYZ

1 2 3 4 5 6 7 8 9 0 $\frac{1}{2}$ $\frac{3}{4}$ $\frac{5}{8}$ $\frac{7}{16}$

ABCDEFGHIJKLMNOPQRSTUVWXYZ

1 2 3 4 5 6 7 8 9 0 $\frac{1}{2}$ $\frac{3}{4}$ $\frac{5}{8}$ $\frac{7}{16}$

ABCDEFGHIJKLMNOPQRSTUVWXYZ

1 2 3 4 5 6 7 8 9 0 $\frac{1}{2}$ $\frac{3}{4}$ $\frac{5}{8}$ $\frac{7}{16}$

ABCDEFGHIJKLMNOPQRSTUVWXYZ abcdefghijklmnopqrstuvwxyz

.498-.002 .498^{+.000}_{-.002} .498
.496 $\frac{1}{2}$ $\frac{3}{4}$ $\frac{5}{8}$ $\frac{7}{16}$

Figure 4-4. Vertical Gothic lettering.

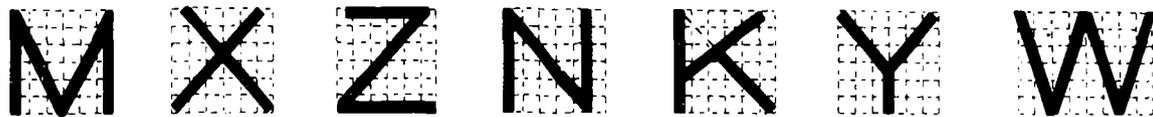
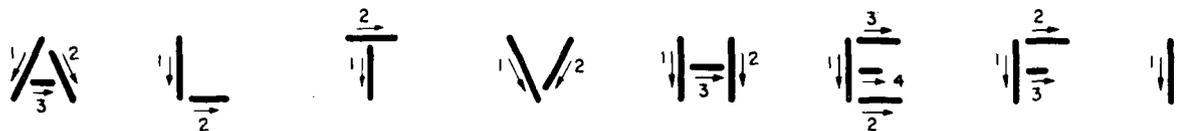


Figure 4-5. Vertical straight-line capitals.

baseline. Note that the outside strokes of the *M* and *N* are drawn first.

(4) *Z*, *X*, *Y*, *K*. Stroke 2 of the *Z* is longer than stroke 1. The inclined strokes of the *X* are closer together at their starting than at their finishing points. The 3 strokes of the *Y* intersect

slightly below the center of the square. Stroke 2 of the *K* intersects stroke 1 at a point $\frac{1}{3}$ of the distance up from the baseline. Stroke 3, if extended, would intersect stroke 1 at the top.

b. *Curved and Straight-Line Combination*, (Figure 4-6).

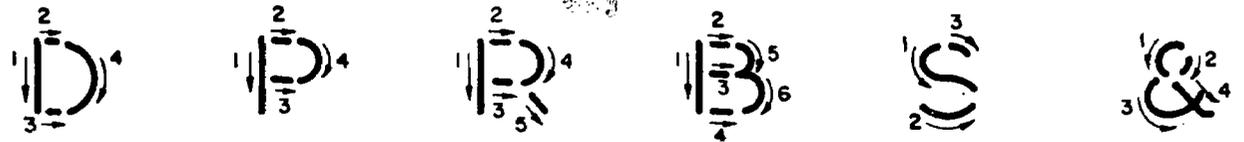
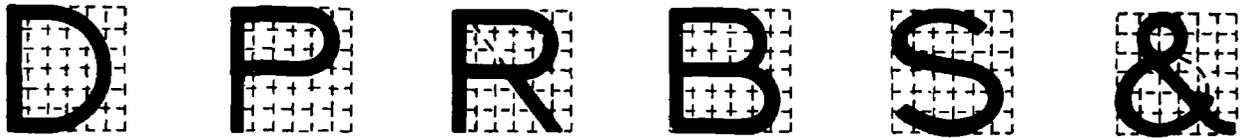
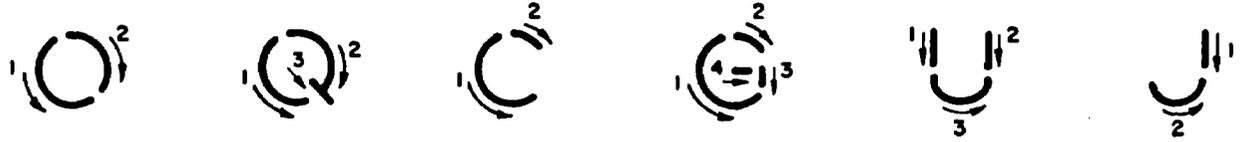
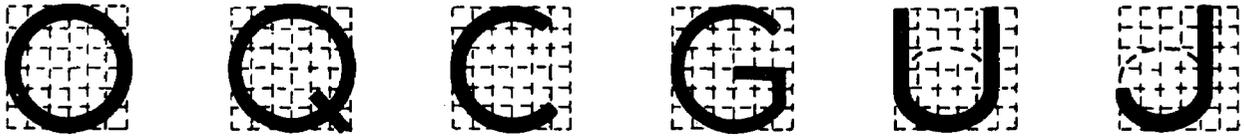


Figure 4-6. Vertical capitals, curved and straight-line combinations.

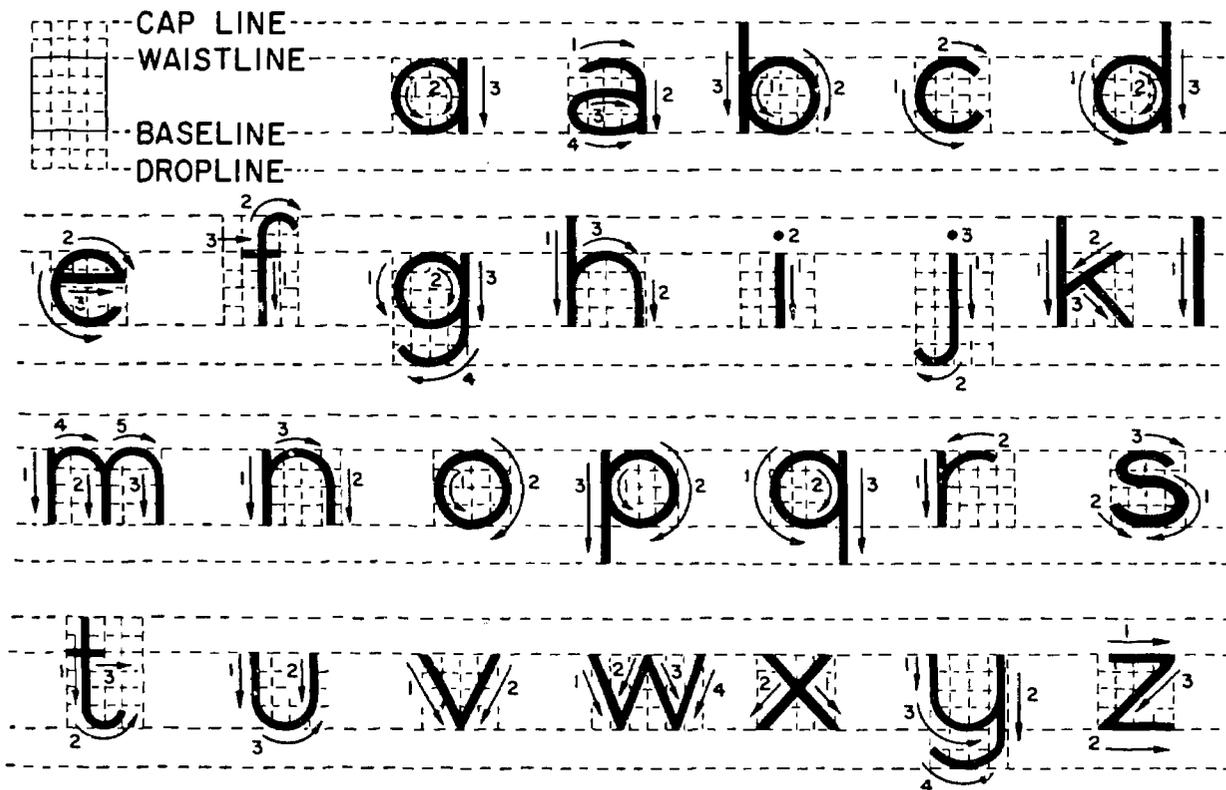


Figure 4-7. Vertical lowercase letters.

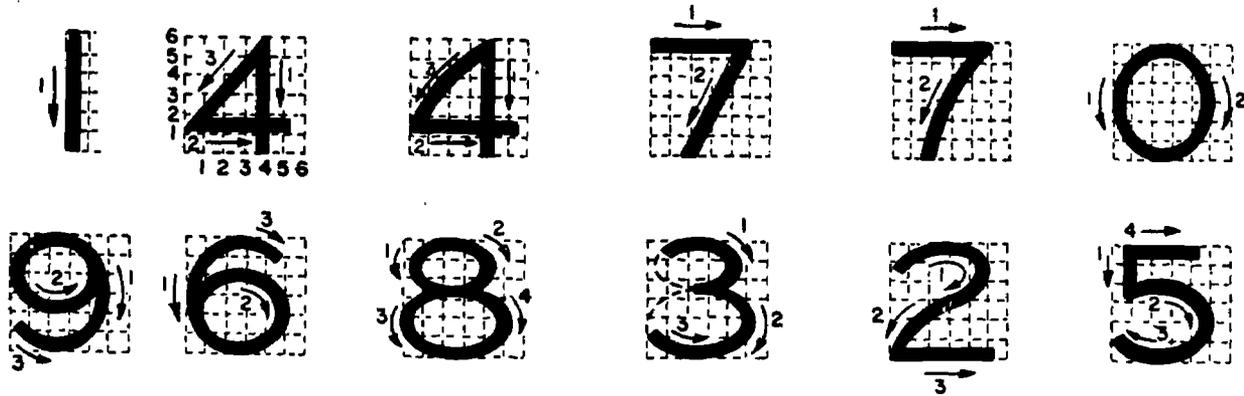


Figure 4-8. Vertical numerals.

(1) *O, Q, C, G*. The *O* and *Q* are complete circles; *C* and *G* are not the full width of the square because they are not full circles. The tail of *Q* if extended, would intersect the center of the circle. Stroke 4 of *G* begins at the center of the circle.

(2) *U, I, D*. Stroke 3 of *U* is elliptical and connects two parallel vertical lines a third of the distance above the baseline. Stroke 2 of *J* is similar but not as broad. Stroke 4 of *D* is circular, joining two horizontal segments.

(3) *P, R, B*. The horizontal midstrokes of *P* and *R* lie just below the midpoint, and the horizontal midstroke of *B* lies just above the midpoint. Horizontal stroke 4 in *B* is slightly longer than strokes 2 and 3, which are the same length.

(4) *S* and *&*. The upper and lower portions of *S* are ellipses, the upper slightly smaller than the lower. The ampersand is basically similar despite a greater difference in the sizes of the ellipses.

c. Lowercase Letters.

(1) *Guidelines*. The waistline is two-thirds the distance from the baseline to the cap line (fig. 4-7). The waistline establishes the body height of lowercase letters. Extensions of lowercase letters above the waistline are called ascenders. The dropline is drawn below the baseline (fig. 4-7) at a distance equal to that between the waistline and cap line. Extensions of lowercase letters below the baselines are called descenders. The dropline is used to establish the length of descenders and can be eliminated once a draftsman is able to judge this distance by eye. All ascenders, except that of *t*, extend to the cap line. All descenders extend to the dropline. As with capital letters, vertical guidelines are drawn at random.

(2) *Characteristics*. The crosses of *f* and *t* are on the waistline and extend the same distance on either side of stroke 1. The bodies of *a*, *b*, *g*, *p*,

and *q* are circular and the vertical strokes of these letters do not increase their width at the points of tangency. The vertical strokes of *p* and *q* terminate in curves that are tangent to the drop-line.

d. *Numerals and Fractions*. The need for drawing numerals (fig. 4-8) carefully cannot be overstressed, particularly in the preparation of construction drawings in which a poorly drawn numeral can cause costly errors and delay.

(1) *Guidelines*. Numerals are drawn to the same guidelines as capital letters. Vertical guidelines are spaced at random. Numerals should not be made so small or be crowded so closely as to impair their legibility.

(2) *Characteristics*. The vertical stroke of the 4 is placed 2 units from the right side. The horizontal bar is $\frac{1}{4}$ the height of the number above the baseline. Note that the closed curves of 0, 6, and 9 are elliptical not circular. The 6 is an inverted 9. The 8 is composed of 2 ellipses tangent slightly above the center point. The top ellipse also is narrower. The 3 is the same as the 8 with the left portions of the loops cut off. The curved lines of 2 follow the elliptical contours of 8. The top portion of the 5 is slightly narrower than the bottom. The bottom ellipse is $\frac{2}{3}$ the height of the figure from the baseline.

(3) *Fractions*. The division sign of a common fraction (figs. 4-4 and 4-9) will be parallel to the direction in which the dimension reads. The complete height of a fraction is twice that of a whole number. The division bar is centered midway between the baseline and cap line. The top guideline of the numerator and the bottom guideline of the denominator are spaced a full number height from the division bar. The numbers composing a fraction are $\frac{3}{4}$ the height of a full number. The clear space on either side of the division

connecting horizontal strokes of *L* and *T*. Actual clearance between *E* and *L* can be slightly less than that between *M* and *E*. The spacing between words should be equivalent to the basic width of the letters *M* and *O*.

b. Uppercase and Lowercase Combinations. Spacing between letters in words using either lowercase or uppercase and lowercase combinations follows the same general rules of word composition as set forth above. Spacing between lines of lettering on a drawing requires that the clear space between the dropline and the cap line below it be equal to $\frac{1}{3}$ the distance between the baseline and cap line (or $\frac{1}{3}$ the height of capital letters) as established for that drawing. If droplines are not used, the distance between one baseline and the cap line below it is equal to $\frac{2}{3}$ the height of capital letters as established for that drawing.

c. Spacing Between Words. Spacing between words should be uniform for the entire drawing and is estimated by the space necessary to insert a capital letter *I* between words. Thus by erasing the *I* in WATERIGAP the two words WATER and GAP are properly spaced.

d. Spacing Between Sentences. Spacing between sentences should be uniform for the entire drawing and is a matter of personal choice. For uniformity, the space necessary to insert a capital *M*

between the period at the end of a sentence and the first letter of the next sentence is satisfactory.

e. Spacing Between Lines. Spacing between lines is described in paragraph 4-6b(2).

4-12. Title Blocks

The location and size of letters for title blocks have already been described (para 3-8a and 4-6a). The remaining problem is one of composition. Using the space allotted, lines of lettering must be arranged symmetrically about a vertical centerline. First, a satisfactory trial title is worked out on a separate sheet of paper, using guidelines marked to equal the space in the title block. When a satisfactory line of lettering has been achieved, count the number of letters (each space between words also counts as a letter) and mark the midpoint of the line. Draw horizontal and vertical guidelines in the title block of the drawing sheet and establish a vertical centerline. If transparent tracing paper or tracing cloth is used, the trial title may be slipped underneath, guidelines and midpoint aligned, and the title traced. If the drawing sheet is not transparent, the trial lettering may be placed directly above the drawing sheet guidelines and centered. The space arrangement worked out on the trial sheet is used as a guide in lettering the drawing sheet title.

Section III. MECHANICAL LETTERING

4-13. Use

Mechanical lettering is executed with a special pen held in a scribe and guided by a template. The standard lettering set is used for mechanical lettering in military drawings. Because guidelines are not required, uniform, legible characters can be produced more rapidly than by freehand methods. Mechanical lettering is used principally for title blocks and marginal data for special maps, charts, graphs, and photographs for reproduction. It should be noted that freehand lettering is the required lettering in drafting; mechanical lettering is confined to the special uses just described. The availability of mechanical lettering devices should not deter draftsmen from the daily practice required to execute freehand lettering.

4-14. Standard Lettering Set

The standard lettering set consists of a set of templates, a scribe, and a set of pens (fig. 4-11).

a. Templates. Templates are made of laminated plastic with characters engraved in the face so

that their component lines are guide grooves for the scribe. The height of the characters, in thousandths of an inch, is given by a number on the upper right-hand side of the template. The range of character heights offered by a standard set of templates is from 80 (0.008 inch or $\frac{5}{64}$ inch) to 500 (0.5 inch or $\frac{1}{2}$ inch). The scale at the bottom of each template has the zero in the center and is arranged for proper spacing in relation to character heights. The distance between each scale division represents the area required by a normal letter.

b. Pens. A standard set of pens for producing various line weights consists of 10 sizes ranging from 00, the finest, to 8N. Each pen is composed of two parts: the ink reservoir and the cleaning pin. The reservoir is a series of connected tubes of decreasing diameters, the lowest establishing line thickness. The cleaning pin acts as a valve, protruding beyond the edge of the bottom tube when the pen is not touching the drawing surface. In this position, no ink flows. When the pen is rested on a drawing surface the cleaning pin is pushed

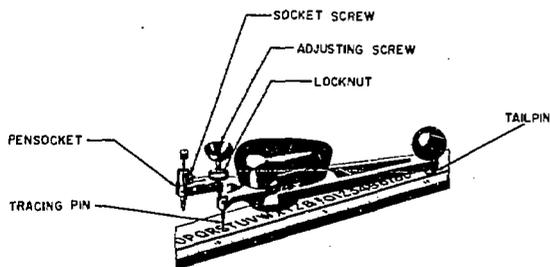
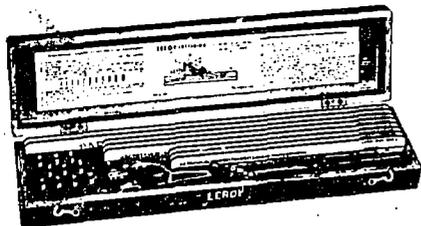


Figure 4-11. Standard lettering set.

up, allowing a flow of ink. Action of the pin in the tube minimizes ink clogging.

c. *Scribers.* The scriber holds the pen in alignment and controls its motion as the tracing pin is guided through the character grooves of the template. Two types of scribers are available, adjustable and fixed. An adjustable scriber produces vertical and inclined letters ($22\frac{1}{2}^\circ$) from a single template; a fixed scriber produces only vertical letters. Except for the locknut, which permits the setting of an adjustable scriber to be changed, both scribers consist of a tracing pen, pen socket, socket screw, adjusting screw, locknut, and a tailpin.

4-15. Lettering Set Operation

a. *Line Weight.* Recommended combinations of template and pen for best proportion between line thickness and letter size are presented below. If a heavier line weight is required, do not use a pen more than two grades above the recommended size.

Template size	Pen size
060	000
080	000
100	00
120	0
140	1
175	2
200	3
240	3
290	4
350	4
425	5
500	6

b. *Letter Size and Spacing.* The rules for free-hand letter sizing and spacing also apply to mechanical lettering. For blocks having more than one line of lettering, horizontal baselines may be drawn at intervals for the size of letters used. Lines of lettering are arranged symmetrically about a vertical centerline. In centering a line of lettering, count the number of letters in the line, add $\frac{1}{2}$ for spaces between words, and subtract $\frac{1}{2}$ for each letter I. Select the template bearing letters of the desired size and place the zero of its scale on the vertical centerline. Mark the number of divisions equal to half the number of words in the line first to the left and then to the right of the zero. This indicates the starting and finishing points.

c. *Procedure.* Loosen the socket screw of the scriber. Choose the pen recommended for the template selected. Insert the pen in the pen socket, so that the shoulder seats against the scriber arm, and tighten the socket screw. Loosen the adjusting screw locknut, and fill the pen reservoir with drawing ink. With the template edge against a T-square, set the scriber tailpin, in the straight groove of the template and the scriber tracing pin, in the groove of a character. Using a piece of scrap paper for trial lines, regulate the adjusting screw, so that the cleaning pin is pushed far enough back to allow the ink to flow freely. If the pin is pushed back level with the end of the tube (that is, if no clearance is provided and the tube is allowed to rest against the drawing surface), ink will not flow smoothly. The amount of clearance varies with the consistency of the ink and the nature of the drawing surface. When satisfactory trial lines are produced, tighten the adjusting screw locknut. Proceed with the lettering by moving the tracing pin in the character groove, at the same time keeping the tailpin in the straight groove. Spacing between letters is by eye and involves the same considerations of equal letter areas as in freehand lettering.

d. *Technique.* Hold a T-square in position with the ball of the left hand against the blade. The fingers of the left hand hold the template against the working edge and change the position of the template when necessary. The scriber is held between the thumb and first three fingers of the right hand. The little finger of the right hand presses the right side of the template against the T-square edge, preventing slipping from the motion of the tracing pin in the character grooves.

(1) *Ink flow.* The reservoir should be kept from $\frac{1}{4}$ to $\frac{3}{4}$ full; too low an ink level results in

irregular lines. When the pen is filled and not in use, it should be placed so that the tip is not in contact with any surface. Before reusing, the cleaning pin should be twirled in the tube to loosen any clotted ink. Never use pressure on a

scriber if the ink does not flow. Check the adjusting screw setting and the reservoir level.

(2) *Fractions*. The numbers in a fraction are made by using a template one size smaller than that used for whole numbers.

Section IV. OTHER LETTERING DEVICES

4-16. Typing

When there is an extraordinarily large number of long notes, they may be typed on transparent tracing paper with a "yellow backing" (an orange colored carbon used with the carbon facing the back of the tracing paper). Black typing will appear on the front side, and orange typing will appear on the back side in reverse. Type in either uppercase or lowercase. After proofreading, adhere to desired location on transparent tracing paper with transparent mending tape. In order to cut the typewritten sheet in the exact size and shape of the "hole" in the drawing, place typewritten sheet in the desired location, and cut both sheets at the same time with a razor blade and a metal straightedge. Adhere with the tape and press firmly and rub so that tape becomes thoroughly transparent.

4-17. Printed Title Blocks

Some offices provide drawing sheets with the main headings and borders of the title block and margin lines already printed on. The missing information need only to be added.

4-18. Prepared Lettering

Prestype and Zipatone have lettering of various styles and sizes printed in reverse on a waxed paper, that can be transferred simply by rubbing into position. The Headliner manufactured by Varitype produces various styles and sizes of print photographically on 35 mm strips of transparent film or opaque paper with or without adhesive back.

CHAPTER 5

ENGINEERING CHARTS AND GRAPHS

Section I. GRAPHIC PRESENTATION OF ENGINEERING DATA

5-1. Definition

Graphic presentation of engineering data means using charts and graphs, rather than numerical tables or work descriptions, to present statistical engineering information. Properly selected and constructed, each form of charts and graphs offers a sharp, clear, visual statement about a particular aspect of a series of related facts. The visual statement either emphasizes the numerical value of the facts or shows the way in which they are related. A chart or graph that emphasizes numerical value is called *quantitative*; one that emphasizes relationships is called *qualitative*. The trend of an activity over a period of time, such as the number of tanks produced over a 10-year period, is more easily remembered from the shape of a curve describing the trend than from numerical statistics. Successful graphic presentation of engineering data requires as much drafting ability as the graphic representation of engineering objects. Lines must be sharp, opaque, well contrasted, and of uniform weight. Letters and figures are normally executed with the standard lettering set in accordance with the standards presented in chapter 4.

5-2. Classification

Graphs and charts are classified as technical charts, display charts, and training aids, according to the use for which they are intended.

a. Technical Charts. Technical engineering charts usually are based on a series of measurements of laboratory experiments or work activities. Such measurements examine the quantitative relationship between a set of two factors, or variables. Of the two variables, one has either a controlled or regular variation and is called the independent variable. The other is called the dependent variable, because its values are related to

those of the independent variable. The line connecting plotted points is called a curve, although it may be broken, straight, or curved. The curve demonstrates the relationship between the variables and permits reading approximate values between plotted points. This type of chart is discussed fully in section II of this chapter.

b. Display Charts. Display charts are drafted primarily to convey statistical data to nontechnical audiences. The message presents a general picture of a situation, usually comparative. There are many varieties of display charts, including bar charts, pictorial charts, pie charts, and training aids. This type of chart is discussed fully in section III of this chapter.

c. Training Aids. Training aids are graphic illustrations that assist the instructor in teaching and the students in understanding a point not easily understood verbally. They are usually poster-like in simple bold design, and with some wording or simple brief text. Training aids are discussed in section IV of this chapter.

5-3. Graphic Aids in Construction Work

Any construction job involves quantities of men, materials, and equipment. Efficient operation and completion of the job results from planning, organization, and supervision. Graphic presentation of data is important. Statistics of results on past jobs with similar working conditions provide a basis for predicting the amount of time that a proposed job will take. These statistics offer the best possibilities for study when presented graphically, usually in the form of a curve. The prediction of expected achievement usually is presented as a bar chart and is called a time-and-work schedule. Safety posters are another example of graphic aids in construction supervision. As a supplement to this chapter, refer to DA Pam 325-10.

Section II. TECHNICAL CHARTS

5-4. Frame of Reference

When the statement is made that an automobile has moved a mile, it usually is meant that the vehicle has moved a mile relative to the earth's surface. If the position of the automobile is measured relative to the sun, the vehicle may be thousands of miles from where it started. Relative to its passengers, the automobile has not moved at all. The position of a point, like the motion of a body, cannot be expressed except in relation to a known point or framework of lines that must be considered fixed. The way in which the position of a point is described depends on the choice of a frame of reference.

5-5. Rectangular Grid Systems

A fixed framework of straight lines intersecting at right angles to each other, made for locating points, is called a rectangular grid system. The system is based on two primary reference lines that intersect and are perpendicular to each other. When a grid system is staked out on the ground these main reference lines are called *zero lines*. The main reference lines of a grid system on paper are called coordinate axes. The auxiliary reference lines or coordinates that complete the framework run parallel to the zero lines and have a numerical value proportional to their perpendicular distance from the zero lines. Once a set of zero lines has been established, the position of any point on the grid can be defined by constructing its coordinates, that is, by measuring the perpendicular distances from the point to the two zero lines.

a. City Grids. Many cities are laid out on a grid system, with the avenues running north and south and the streets running east and west. The directions are not required to be exact, merely approximate enough for identification. The streets and avenues from which the numbering begins become the main reference lines.

b. Local Grids. Rectangular grid systems are used for construction projects and are known as local grids. To prevent confusing the designated direction of the coordinate lines with compass bearings, a north-pointing arrow is shown in the drawing to define the direction of the north-and-south baseline as grid north. Building points, such as corners of foundations, are located in the job area by their coordinates.

5-6. Coordinates

Coordinates are quantities which designate the

position of a point in relation to a given reference frame. Telling someone that the post office is "two blocks north of Main Street and three blocks east of Broadway" is using coordinates. Coordinates are often used in conjunction with a grid (para 5-5). There are many systems of coordinates used and below are described three of the most often used systems.

a. Base Line System. The reference frame consists of horizontal and vertical base lines (fig. 5-1). Each base line is divided into units of measurement; each of the units is further divided into tenths. Call the direction of the vertical base "North", call the direction of the horizontal base line "East." The intersection of the base lines is called the origin and has coordinate values of zero-zero; that is, 0.0 North and 0.0 East. Point "P" is located 3 units plus 1/10 of a unit more, or 3.1 units, above the horizontal base line. P is also 2.6 units east of the vertical base line. The coordinates of P, therefore, are 3.1 north and 2.6 east.

b. X and Y System. As described in *a* above, the lines create rectangles; therefore, these coordinates are also referred to as rectangular coordinates. There are various systems for designating the elements of a coordinate system, X and Y being one of these systems. Figure 5-2 shows the X and Y coordinate designation system in which x and y are distances from the base lines to the coordinated point. Theoretically, coordinate axes extend on either side of the point of intersection, called either the point of origin or O. The horizontal axis XX' is called the abscissa or X-axis. The

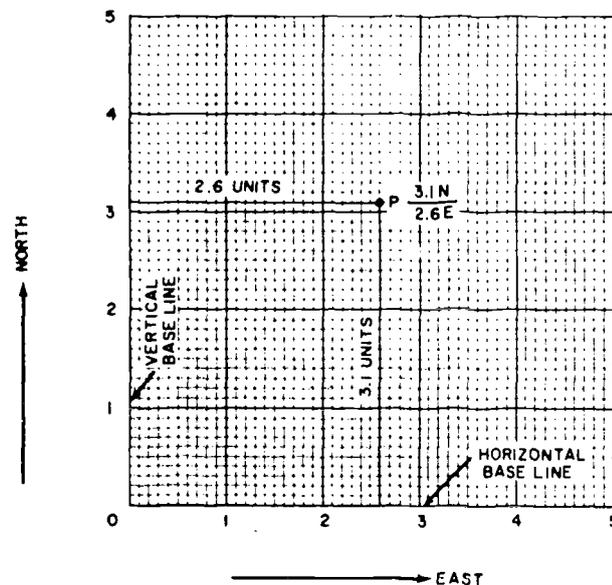


Figure 5-1. Base line systems.

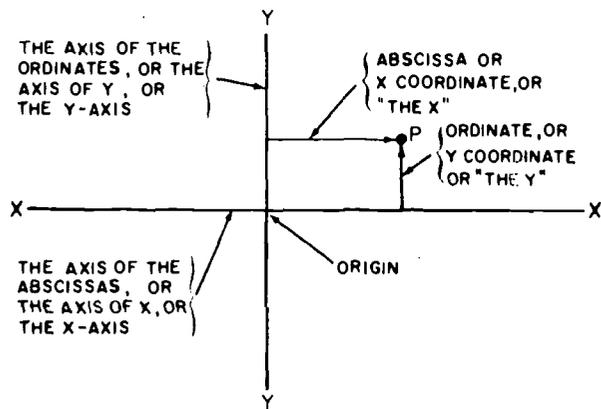


Figure 5-2. X and Y coordinate system.

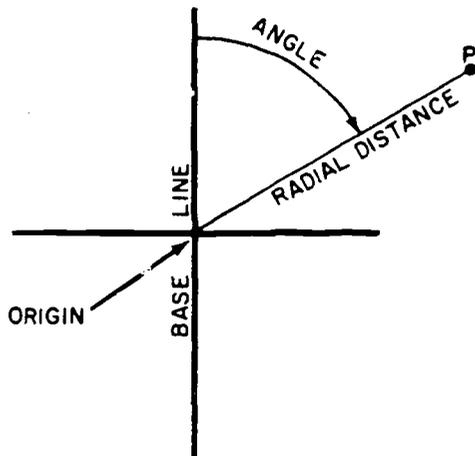


Figure 5-3. Polar system.

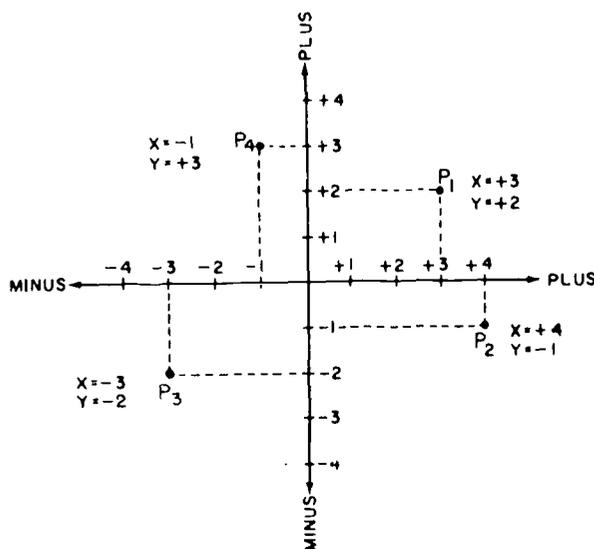


Figure 5-4. Rectangular coordinates.

vertical axis, YY' , is called the ordinate or Y -axis. The coordinate axes divide the sheet into four parts, or quadrants, that are numbered counter-

clockwise. The first quadrant is in the upper right-hand corner. Mathematical graphs use four quadrants; the main axes are considered zero lines and quantities less than zero are plotted below the X -axis and to the left of the Y -axis. The two coordinate axes form a two-coordinate frame of reference because all points within their boundaries are located by reference to the perpendicular distances from the two main axes. It is customary to give the x value first and then the y value when identifying a point by x and y coordinates.

c. Polar System. This system is similar to those described in *a* and *b* above, but not all coordinates are rectangular in nature. In the polar system, point P is located by an angle and distance (fig. 5-3).

5-7. Rectangular Coordinates

Coordinate paper provides a readymade framework for locating numerical data. When plotted data falls between coordinate rulings or when coordinate paper is not used, as on display graphs, the same method of perpendicular measurement is used. In a two-coordinate frame of reference, every point has both an X and a Y coordinate. The X coordinate represents the perpendicular distance to the right (or left) of the Y -axis, and the Y coordinate represents the perpendicular distance above (or below) the X -axis. In figure 5-4 the coordinates of the points are shown as dashed lines. The main axes are represented with the line symbol for a datum line. A datum line is a reference, or zero, line from which measurements are made.

5-8. Curves

When only one curve is depicted on a graph, it should be represented by a solid line; when more than one curve is presented on a graph, they should be differentiated by using varied line characteristics. A solid line should be used for the most important curve. When several curves are presented, each should be identified by a brief label placed close to the curve and aligned horizontally. These labels should be kept within the vertical and horizontal limits of the curve on the graph. When the label must be connected to a curve to avoid confusion, the connecting arrows should be short, straight, inclined to the coordinate rulings, and parallel to each other.

5-9. Scale

The choice of scales should be considered carefully because the picture of the relationship between the two variables is affected most sharply by the

THE GROWTH OF POPULATION OF THE UNITED STATES IN MILLIONS FROM 1830-1960

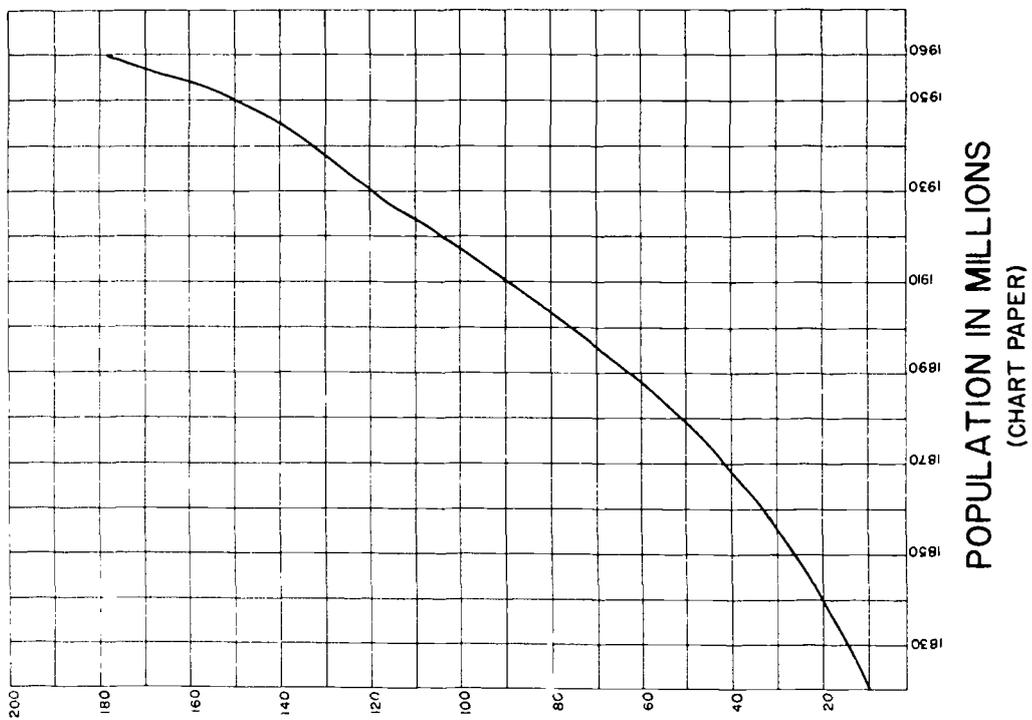
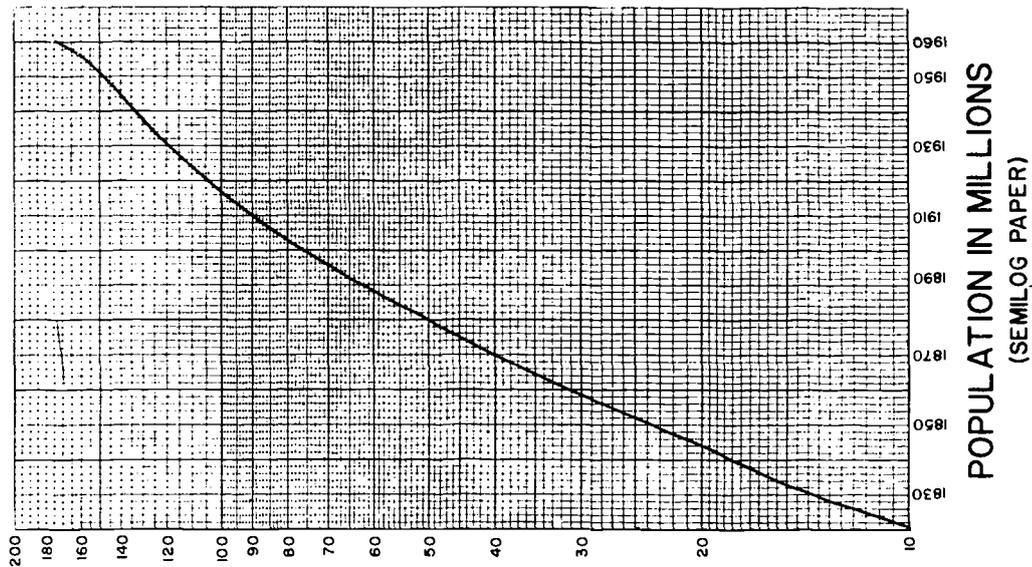


Figure 5-5. Comparison of amount and rate of change.

values assigned to the spaces between coordinate rulings.

a. Range. Separate scales are assigned to the horizontal and vertical axes. In both cases, the range of scales should ensure efficient and effective use of the coordinate area in presenting the message of the chart. The angle of slope (the steepness of the curve) is controlled by expanding or contracting the vertical scale relative to the horizontal scale.

b. Zero Lines. If the chart is quantitative and designed for reading approximate values, the main axes do not have to intersect at the point of origin. Space in the coordinate area may be saved by beginning the marking of a reference line on or just before the first significant measurement.

c. Arithmetic Scales. Values increase arithmetically. Decimal values of 1, 2, and 5 are best for the spaces between coordinate rulings because intermediate values may be interpolated more readily. One square, for example, might equal 0.01, 0.1, 1.0, 10.0, 100.0, and so on. If a value of 0.1 is assigned to a single square, five squares equals 0.5. The independent variable scale values along the abscissa should increase from left to right. The dependent variable scale values along the ordinate should increase from bottom to top.

d. Scale Indication. Scale values should be placed outside the coordinate axes. They are at the bottom for the horizontal (abscissa) scale and at the left side for the vertical (ordinate) scale. The numerical value of coordinates should be indicated at intervals spaced far enough apart to avoid a crowded appearance while still permitting quick identification. On 1/10-inch coordinate paper, every fifth ruling provides a suitable interval.

e. Scale Captions. Each scale caption should describe the variable represented and the unit of measurement. In the case of the independent variable in figure 5-5, the dates of the years are self-explanatory. The dependent variable requires that "Population" be further defined so that the caption reads "Population in Millions." If the symbol *P* had been used in the text to describe population, the caption should read "Population, *P*, in Millions." Captions should be readable from the bottom and right side of the graph.

5-10. Rectilinear Charts

Rectilinear charts are constructed with a two-coordinate frame of reference. Points are located with rectangular coordinates and connected by a curve. Scales are arithmetic, that is, equal spaces on the axes represent equal numerical distances.

Rectilinear charts are used to demonstrate the amount of change during a period. They are also used for interpolating values, demonstrating trends, emphasizing movement rather than actual amounts, and for picturing a series in which there are many successive values to be plotted. Several curves can be shown on the same chart. Rectilinear charts are undesirable when the series depicted has relatively few plotted values, when the movement of the data is extremely irregular and does not indicate a trend, when the emphasis should be on change in amounts rather than a trend, or when the presentation is intended for popular appeal.

5-11. Types of Rectilinear Charts

a. Time Series. A time series chart is the most common form of rectilinear chart. Time in units such as hours, days, months, or years is scaled along the horizontal axis. Amounts, in appropriate units, such as degrees of temperature, thousands of dollars, or millions of population, are scaled along the vertical axis.

b. Profile Graph. A profile graph is made by blackening or crosshatching the area inclosed between the curve and horizontal axis. In such a case, the curve must begin at the vertical axis and end at the right side of the grid area. Profile graphs are used to emphasize the quantities involved in a trend, rather than the amount of variation.

c. Multiple-Curve Graphs. Comparisons between trends of factors representing aspects of a particular problem can be made by plotting several curves within the same frame of reference (fig. 5-6). If the amounts involved in the comparison are so different that two different vertical scales are required, the second scale is placed either along the right-hand edge of the grid or to the left of the first amount scale. Each scale must have a clear caption and each curve must be labeled in this situation.

5-12. Coordinate Ruling of Rectilinear Charts

The proper construction of a grid involves more than simply converting a convenient space with cross rulings. As in the matter of general layout, the nature of the data and purpose of presentation must be considered (fig. 5-1 and 5-4).

a. Vertical Rulings. There should be sufficient number of vertical rulings to aid in reading values on the horizontal scale and to indicate the frequency of plotting. They should be of sufficient weight to guide the eye readily to the horizontal scale. Line weights should be heavier at selected

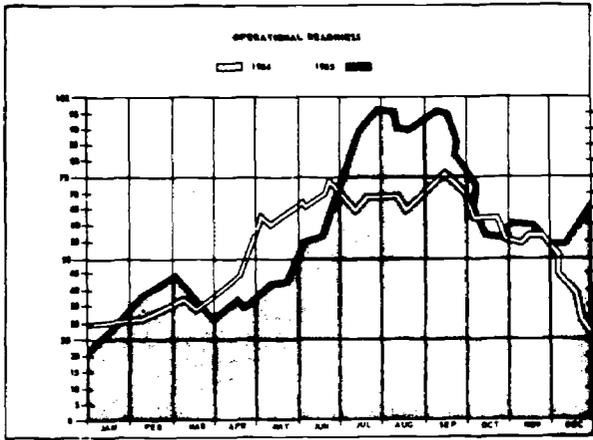


Figure 5-6. Multiple-curve graph.

regular intervals to indicate major divisions along the horizontal scale.

b. *Horizontal Rulings.* Horizontal rulings should be drawn so as to meet the requirements of their two-fold purpose, which is to assist the reading of values on the vertical scale and to provide a series of horizontal bases of comparison. Horizontal rulings should be light enough to contrast sharply with the curves and sufficiently heavy to guide the eye to the vertical scale without conscious effort.

c. *Principal Reference Lines.* Principal reference lines are wider than other coordinate rulings but narrower than the curves. Coordinate rulings are half the weight of reference lines; curves are twice the weight of reference lines.

5-13. Titles and Notes on Rectilinear Charts

The title of a graph must state its message in a clear, concise manner. Given sufficient thought be-

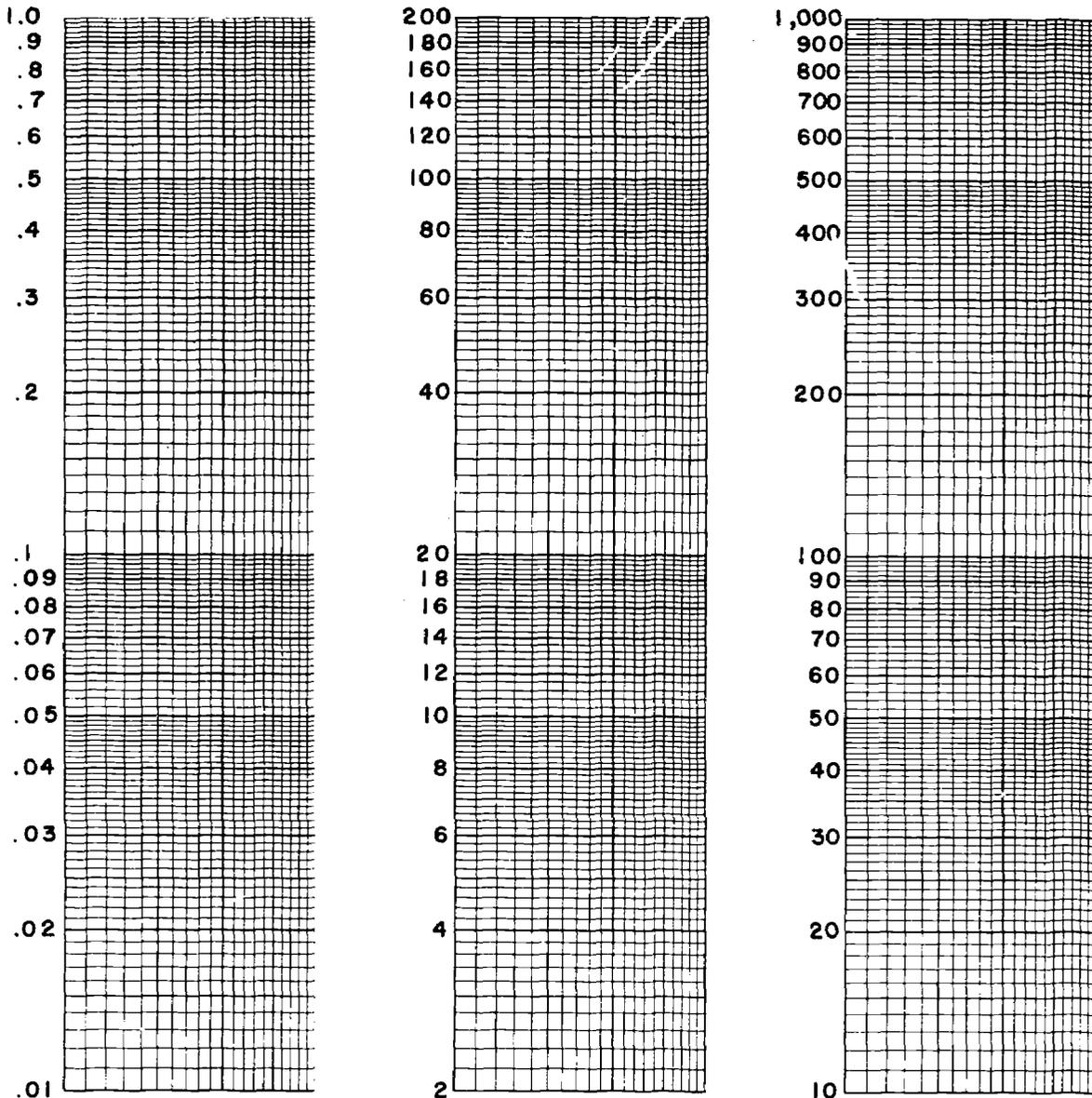


Figure 5-7. Logarithmic scales.

forehand, most titles can present adequate information in a single line. If supplementary information is necessary, a subtitle may be used. Further explanatory information is added, as a note.

a. Location. The title is located outside the grid area at the top of the graph and should be arranged symmetrically around the approximate centerline of the grid area. Subtitles are placed beneath titles and spaced according to the rules for lettering title blocks. Notes are lettered just above the topmost horizontal grid ruling beginning from the left-hand corner with the word NOTE (fig. 5-6).

b. Lettering. Lettering for charts and graphs is executed with the standard lettering set. Choice of template and pen number depends on the size of the chart or graph. The title lettering should be the most prominent.

5-14. Logarithmic Charts

a. Semilogarithmic Charts. Semilogarithmic grids are constructed by dividing the horizontal scale with equally spaced vertical rulings and dividing the vertical scale with logarithmically spaced horizontal rulings. In a time series chart, time would be arranged along; an arithmetic scale and amounts would be arranged along a logarithmic scale. Because semilogarithmic charts are designed to indicate rate of change rather than amount of change, they are also known as rate-of-change charts or ratio charts. Figure 5-7 illustrates the construction and labeling of a logarithmic scale. Figure 5-5 compares the amount of change of population as shown by a curve on coor-

dinate paper with rate of change of population as shown by a curve constructed on semilogarithmic paper.

(1) *Uses.* Semilogarithmic charts should be used to indicate the relative movement of a time series, or to compare the relative movements of several time series, but only when the intended audience is likely to be familiar with this form of chart.

(2) *Reading curves.* If the curve is a straight line inclining upward, it indicates a constant rate of change. A convex curve that flattens out, like that in figure 5-5, indicates an increase at a decreasing rate, despite the increase of population shown on the amount-of-change chart. A concave curve that slopes upward as it approaches the right side of the grid indicates an increase at an increasing rate.

(3) *Precautions.* The plotting in rate-of-change charts requires considerable care because of the peculiar character of the logarithmic spacing. When special grids are prepared without intermediate rulings, it is desirable to use a logarithmic plotting scale, which may be made easily from printed commercial paper. Profile graphs are not constructed on semilogarithmic paper. Points are connected with a solid line when a single curve is drawn.

b. Double Logarithmic Charts. Double logarithmic charts are used more for solving problems than for presenting facts. Both horizontal and vertical scales are spaced logarithmically with the result that all algebraic equations representing multiplication, division, roots and powers are straight lines.

Section III. DISPLAY CHARTS

5-15. Hundred-Percent Bar Charts

The purpose of a 100-percent bar chart is to show graphically the component percentages of a whole, the whole represented as a single bar and the component percentages as component proportional areas. The bar may be drawn either horizontally or vertically; a common ratio of length to width is 6 inches long to 2 inches wide. A scale can be constructed on a separate sheet of paper dividing the length into 10 divisions, each of which is further subdivided into 10 units. Each unit equals 1 percent. The scale is used to divide the bar into the desired percentages, which are expressed graphically as areas by drawing perpendiculars across the width of the bar at the appropriate percentage markings.

a. Shading. The component segments of a 100-percent bar chart are differentiated from each other by solid or line shading (fig. 5-8). Solid (black) shading is used only in a series of segmented 100-percent bar charts. Line shading parallel to the length of the bar is easy to construct; horizontal lines are used for horizontal bars, vertical lines for vertical bars. Line shading perpendicular to the length of the bar is not recommended for segmented bars because it confuses the location of the segment limits. Diagonal line shading or crosshatching is used only in small segments because it causes optical illusions of blending if used over a long segment. Crosshatch shading may be used in place of black for wide columns. Dotted shading (pebbled or strippled) is effective for columns of medium width, particu-

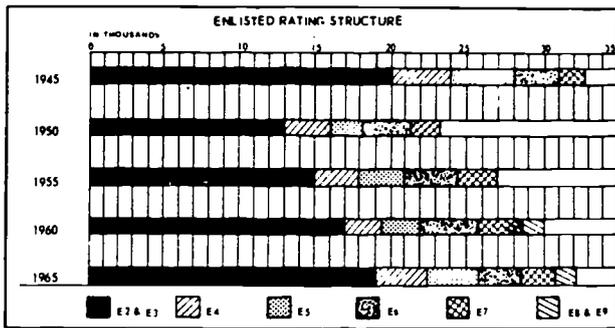


Figure 5-8. Shading in bar charts.

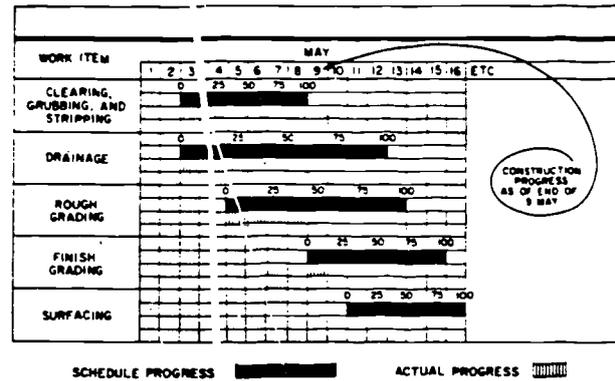


Figure 5-9. Progress chart.

larly where a small segment requires a third or fourth distinguishing shading. Lines are spaced uniformly and not too close together. Intersecting diagonal lines also are used for shading.

b. Labels. In addition to shading, each segment is identified by a percentage figure and a word label. The identifying label is placed outside the bar adjacent to the appropriate section and arranged to read horizontally from left to right whether the bar is drawn horizontally or vertically. Numerical percentage figures are placed inside the bar and arranged about the centerline, running parallel to the length. All lettering should be completed before the areas are crosshatched or shaded. When, for reasons of clarity, it is necessary to give the numerical quantities in addition to percentages, the numbers are presented on the side opposite the identifying segment labels; numerical values are then read from left to right and are aligned horizontally.

c. Comparisons Between 100-Percent Bar Charts. The 100-percent bar chart presents the component parts of a whole, usually for a specific period or for a particular geographical location. If a chart showing comparisons of component items over a period of years or several geographical locations is desired, a series of 100-percent bars is used. Each bar is the same height and width and contains the same component items. Each item is identified by a different kind of shading; the meaning of the shading is explained through a key placed where it will not interfere with the chart. Darkest shadings are placed nearest the baseline. Such charts require a two-coordinate frame of reference. If the bars extend vertically, percentages are scaled along the vertical axis. Time, location, or other limiting conditions are scaled along the horizontal axis, which also serves as the datum line for the bars.

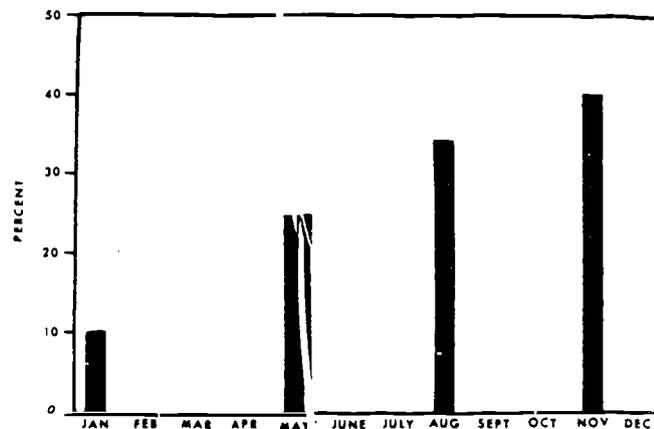


Figure 5-10. Scale selection.

bar chart is to have the length of each bar proportional to the magnitude of the quantity represented (fig. 5-9). Bars may be aligned vertically or horizontally; when aligned vertically, the chart is called a column chart. Rules are given for vertical alignment. The same principles apply for constructing a horizontal chart.

a. Use. The column is effective when used to emphasize comparisons of amount in a single time series, to picture period data as against point data, and to present facts for popular understanding. It should not be used for comparing several time series or for time series over an extended period with many plottings.

b. Layout. A chart consisting of a few columns should be higher than wide; for more than a few columns a wider-than-high chart is preferable.

c. Grids. A completely ruled coordinate surface is not required. The columns themselves make vertical rulings unnecessary. Because multiple-bar charts generally are used for popular presentation and present approximate comparisons, horizontal rulings should be drawn only frequently enough to guide a reader's eye to the vertical scale at major

5-16. Multiple-Bar Charts

A use of the bar form other than as a 100-percent

intervals. Horizontal rulings will not extend through bars and need cover only that portion of the field occupied by the columns.

d. Scale Selection. In column charts, the interest generally is in comparisons of amounts for different dates (fig. 5-10). The amounts are proportionate to the height of the columns; hence the zero line, when it is the principal line of reference, should always be included.

e. Scale Designation. Vertical scale values are placed on the left side, where horizontal rulings are complete. If the tallest columns are at the right, another vertical scale may be placed at the right. Horizontal scale values are centered beneath the columns. Values should not be placed at the top of the individual columns to indicate magnitudes because of the apparent increase they give to the height of the columns.

f. Column Spacing. To space columns equally along the horizontal scale, divide the available horizontal space into twice as many spaces as there are to be columns and center the columns on every other division mark beginning with the first from either end. When there are only a few columns in a chart they should be narrower than the white space between; when there are many columns the reverse should be true.

5-17. Time-and-Work Schedules and Progress Charts

Figure 5-9 shows the application of the principle of the 100-percent bar chart for presenting graphically the time estimated for completing various phases of a road construction project. The figure also affords a comparison of a graphic presentation of estimated time, known as a time-and-work schedule and a graphic presentation of the actual

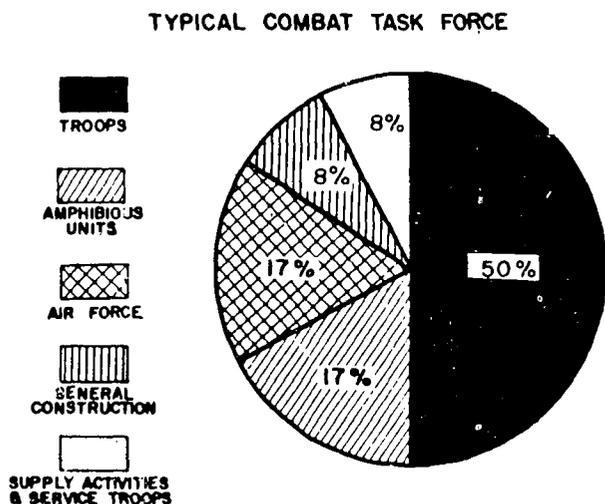


Figure 5-11. Pie chart.

time taken, known as a progress report. The end points of each black bar are determined by the estimated starting and finishing dates of each construction phase. The length of each black shaded bar equals 100 percent of estimated time. Subdividing the black bar into quarters makes comparison of estimated and actual progress easier. Actual progress is represented by transverse cross-hatching. Although not recommended for bar-charts having several component items, transverse crosshatching is acceptable in this case because time is the only item depicted, and because daily limits are demonstrated more easily with transverse shading than with diagonal or stripped shading.

5-18. Hundred-Percent Circles

The circular form (fig. 5-11) can be used in the same manner as the bar form to show the percentage-wise distribution of the component parts of a whole. Charts using the circular form to show distribution are called sector, or pie, charts.

a. Layout. When several component parts are to be shown, as in figure 5-5, the circle is regarded as a clock with the 12 o'clock position as the starting point.

b. Shading. Segments are distinguished from each other with the same shading techniques used in component bar charts. Solid shading is recommended for the largest segment. Color may be used to increase the dramatic effect.

c. Labels. Lettering and numbering should be aligned horizontally inside the circle so that the chart can be read without turning. When it is impossible to place the lettering inside the segments being identified, the labels are placed in a legend or key and identified by shaded symbols. When several circles are used to compare the distribution of the same items in different periods, it is easier to identify the component items with consistent shading patterns than with labels. In such a case, the shading symbols must be explained through a legend or key.

5-19. Pictorial Charts

A pictorial chart (fig. 5-12) is basically a form of multiple-bar chart with the bars aligned horizontally. Magnitudes in the multiple-bar chart are proportional to the lengths of the bars; in a pictorial chart they are proportional to the number of symbols in a line. The subject of a bar chart is presented in its title or the legend that explains the shading symbols; the subject of a pictorial chart is explained through the nature of the pictorial symbols.

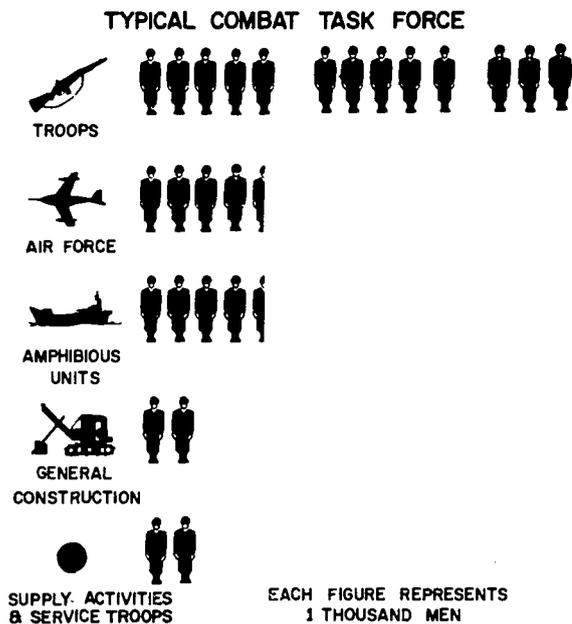


Figure 5-12. Pictorial chart.

a. Scope. Pictorial charts are used to compare approximate quantities. Statistical data are rounded off to fit pictorial units. Symbols should express some basic characteristic of the subject so that a minimum of explanation is required. Increasing quantities are shown by proportional increases in the number of symbols used, not by proportional increases in symbol sizes. Like multiple-bar charts, pictorial charts are used only for comparisons, not for making isolated statements.

b. Layout. Pictorial charts are read from top to bottom and from left to right. The initial problem is to determine the size of the chart. Once this is known, the next step is to divide the space to achieve a balanced effect and clear presentation. A trial chart is blocked out with rectangles of proportions equal to the height and length of the lines of lettering and rows of symbols. Sufficient space must be allowed between rectangles; space between rectangles should not be more than their height or less than half of it. The area occupied by the total of the individual rectangles is represented as a large rectangle and centered in the chart. All rectangles begin from a common, vertical reference line at the left. The reference line is drawn lightly as a guideline and does not appear in the completed chart.

(1) *Rows per chart.* The rule of thumb is to limit the number of rows to between three and six. If the comparison is such that more than six rows are required to present a clear picture of a trend or relationship, the data should be presented as a curve.

(2) *Symbols per row.* Symbols must be large

enough to be clear and with enough white space separating each from its neighbor for both to be distinguishable. Values assigned to the individual symbols influence the number required. For general purposes, the number of wide symbols, buildings and machinery for example, should not exceed 12. The number of narrow symbols, people for example, should not exceed 25. Symbols should be wide enough for the basic unit to be divided in half vertically. To aid in counting long rows of symbols, make units of five by providing a wider space after each fifth symbol.

c. Symbols. Simplified silhouettes are the most effective for pictorial charts. The most important feature of simplified silhouettes is that the simple symbols represent the most general situation and are recognized by the widest audience. A general rule for selecting the most characteristic symbol is to use the one that can be drawn from memory. After the size and shape of the basic symbol has been decided, it must be reproduced uniformly in the necessary quantity. A convenient sized rectangle of detail paper is laid out with a horizontal baseline and vertical width lines extending to the edges of the sheet. Figures are drawn between the vertical lines and from the baseline. Guidelines are drawn lightly on the chart surface. If the chart is to be reproduced and tracing paper is used, the figures are placed underneath the tracing sheet and the guidelines aligned. If the chart is drawn on an opaque surface, the back of the template may be blackened carefully with a soft pencil to create a carbon paper effect. The figures are traced off from above after guidelines are aligned.

d. Titles and Symbols Explanations. Titles are lettered in uppercase letters centered at the top of the chart. They should be as concise as clarity allows and should not include facts not shown in the chart. Symbol explanations are located beneath the rows of symbols and are executed in uppercase letters of a smaller size.

5-20. Organization and Flow Charts

An organization or flow chart is one which shows a related sequence of events, a chain of command, a system of administration, or any other system in which it is necessary to graphically represent a connection between separate but interdependent units. It is not primarily concerned with numbers and quantities but with how the components of an organization relate to one another.

a. Organization Chart. One of the simplest and most common types of organization charts shows

the arrangement of authority and responsibility within an organization (fig. 5-13). Before drawing in finished form, it is advisable to make a rough sketch on a piece of scratch paper to learn what the approximate shape and size of the final drawing will be. The name, rank or grade, and position of the highest authority in the organiza-

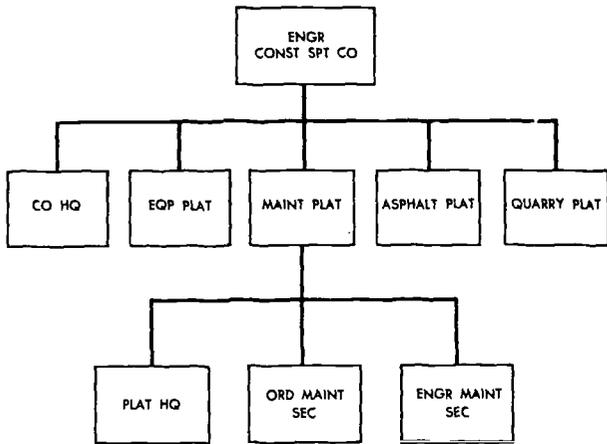


Figure 5-13. Organization chart.

tion chart to be made should be placed centered and near the top of the sheet and inclosed in a box drawn with medium lines. Other members of the organization who are directly responsible to him should be placed below, also in boxes drawn with medium lines. Connect the boxes with thick lines that are perpendicular rather than radiating from a single point. Continue this process downward, placing subsidiary members of the organization below and properly balanced around their superiors. If there is a liaison, organized cooperation, or other regular contact between two units which are equal in authority, connect them horizontally with a dotted or dashed line.

b. Flow Chart. A flow chart (fig. 5-14), like the organization chart, also shows a relation between different parts of steps. It differs in that it shows a process or sequence of events that must take place in a specific order to produce a desired result. The flow may not always be a simple series, with step A followed by step B, then step C, etc. There may be a sequence of events that must take place simultaneously with one step in order to

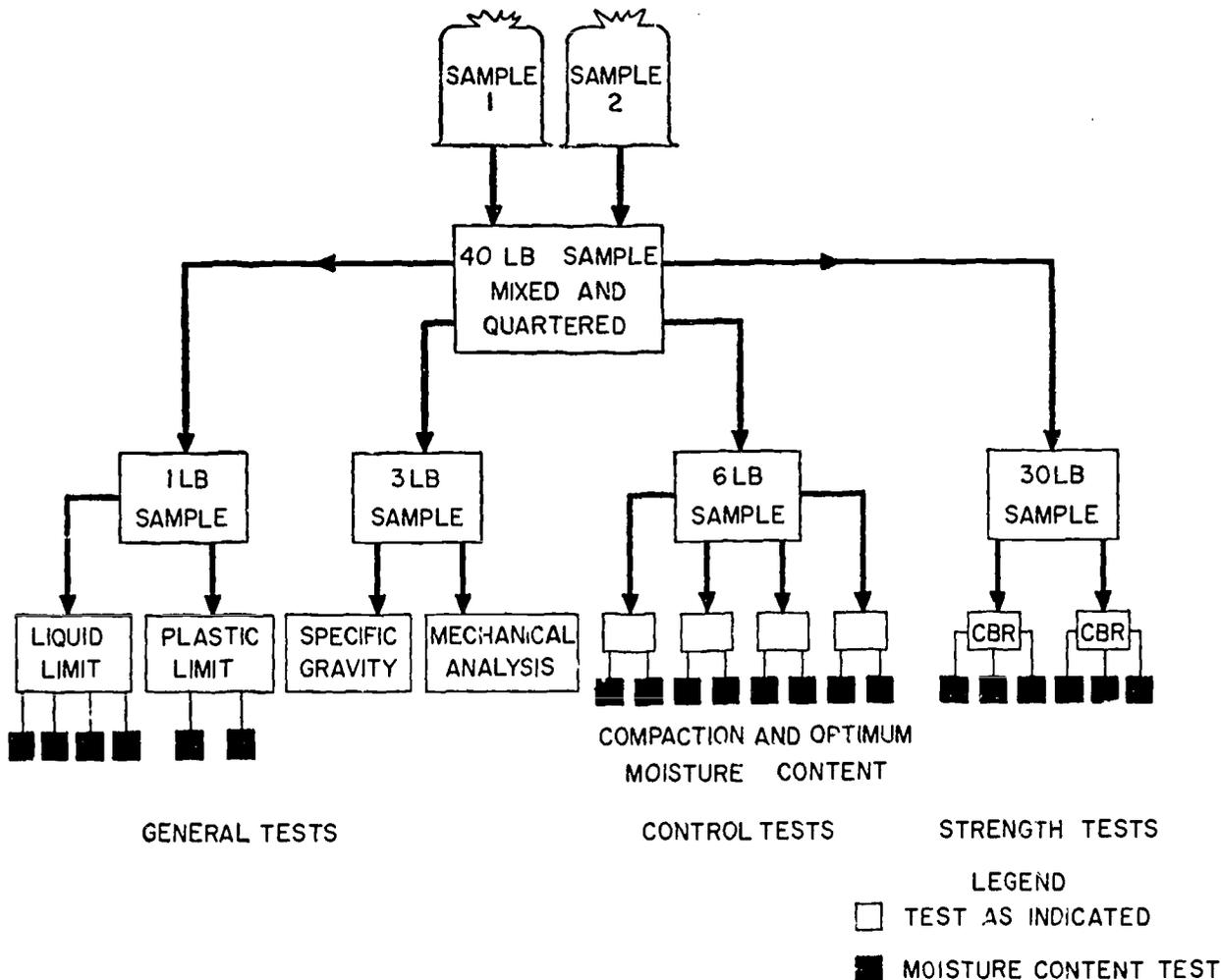


Figure 5-14. Flow chart.

make the next step possible. For example, step X, followed by step Y, followed by step Z may be necessary before steps A and Z can combine to make step B possible. No matter what format is used, keeping the chart as simple as possible is necessary. It must be remembered that the purpose is to make a complex process understandable at a glance. AVOID a chart obscured by needless lines or poorly organized components. For this reason rough drafts should be made, and the flow chart well planned. If the chart is to be used for large-scale display, dimensioning arrows are too small to indicate flow clearly; therefore, large arrows should be used.

5-21. Tools and Materials

a. *Tools.* Working charts not intended for display or reproduction are constructed on coordi-

nate paper with drawing pencils and standard drafting equipment. Charts for display or reproduction are prepared in pencil and traced in ink, or inked in. The ruling pen is used for inking lines drawn with a T-square or triangle. Payzant and Speedball pens are used to give the proper weight to curves and other freehand lines.

b. *Chart Paper.* Smooth, heavy paper provides the best surface for display charts. Bristol board and illustration board normally are available in standard flat sheets 22 by 30 inches and in thicknesses up to 1/8 inch. Both sides of Bristol board are satisfactory drawing surfaces; illustration board provides only one suitable side. Hot-pressed surfaces are glossy and suitable for pen-and-ink work and water colors. Cold-pressed surfaces are duller and suitable for water colors but are not as good for pen-and-ink work as hot-pressed.

Section IV. TRAINING AIDS

5-22. Characteristics

A training aid is a simple explicit poster-like representation of an official standard, and is used to direct its audience to a specific decision, selection, or method of behavior. For example, figure 5-15

provides a quick and ready aid for determining the standard specifications of common nails so that a correct selection can be made. A training aid may consist of a picture plus wording or wording alone. The paragraphs in this section present sufficient information for the draftsman to produce an adequate training aid by using his technical drawing skills.

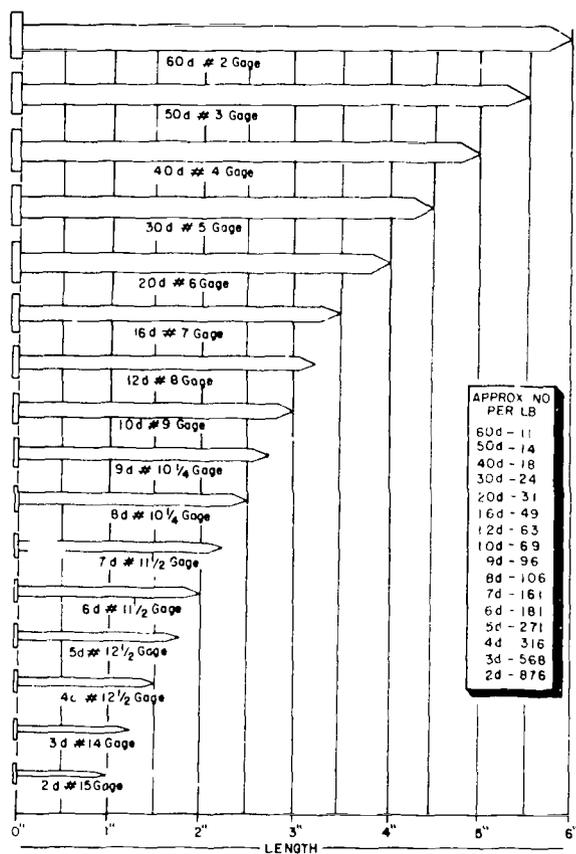


Figure 5-15. Training aid.

5-23. Elements of a Training Aid

Wording, or text, and the picture are the principal elements of a training aid. Together they should compose a poster that is simple and bold in design, brief in text, understood at sight, pleasant and strong in color, balanced in composition, and designed to attract attention.

a. *Picture.* The considerations governing the choice of appropriate pictorial material are similar to those presented for choosing pictorial symbols (para 5-19c). The picture should convey the same information as the text; it should not be so detailed as to distract attention from its message; and it should be general enough to be recognized by the widest possible audience. Clippings of pictures from newspapers and magazines may be used if drawing talent is not available. If the clipping is cut carefully and given a few touches of color after being mounted, it will give the appearance of having been painted on the card. A file of clippings for tracing or mounting will be helpful to draftsmen engaged in preparing training aids. Whenever a clipping contains a human figure, it should be faced toward the text so that the eye of the observer is led toward the text.

b. Text. Text should be brief; it should make a complete statement; and its meaning should be clear. When a training aid makes a series of statements, the number should not exceed four. Negative statements should be avoided; the poster should tell what to do, rather than what not to do. When not expressed as a directive or command, the text should express a conclusive attitude. Wording is effective by virtue of its message and its mechanical arrangement on the poster.

5-24. Layout

The layout of a poster is a rough pencil plan that arranges lines, paragraphs, and pictures so that they have a pleasing relation to one another. The important considerations in the layout of a poster are balance, harmony, unity, and simplicity.

a. Balance. The principle of balance is similar to that described in the layout of a pictorial chart. Lines of lettering and pictures are represented as rectangles and arranged symmetrically about vertical and horizontal centerlines or along intersecting diagonals drawn between opposite corners of the card. The lines of the rectangles parallel the borderlines of the poster. Balance also is affected by tones. If one line of lettering is quite dark, it must be balanced by an equal area of the same tone or a larger area of a lighter tone.

b. Harmony. Harmony implies a relationship between the various layout rectangles. Size, shape, tone, and color must have qualities in common throughout.

c. Unity. The component parts of a training aid must blend to focus audience attention on the most important units. This can be done by arranging the most important parts of the inscription at the most important points on the poster. Unrelated statements should be avoided.

d. Simplicity. Training aids should not be over-ornamented. Letter styles, borders, and backgrounds should be simple enough to permit concentration on the central message. Lettering is drawn to the size required by good balance and emphasis.

e. Lettering. Letters are sketched in with a soft pencil, and with guidelines to establish letter height and inclination. If many posters are to be made with the same size and style of lettering, templates can be made by drawing the alphabet and numbers on a sheet of cardboard and cutting the letters out with a sharp knife and steel straightedge. Beginners should construct block letters of the kind shown in figure 4-4. The outlines are drawn with a ruling pen after the letters

have been sketched, and the open areas are filled in with a brush or ruling pen.

5-25. Use of Color

India inks are available in various colors. Draftsmen should limit themselves at first to two colors in preparing training aids.

a. Color Combinations. Red is the most suitable single color for use in combination with black and white. It provides brightness and effective contrast and its intensity permits the eye to focus readily at normal reading distance. Black lettering against a yellow background provides the best visibility both for those with normal vision and for those who are color blind. For this reason the black-and-yellow combination is used on highway safety signs. Green against red, blue against red, and red against green should be avoided because these combinations seem to make the letters vibrate and difficult to read.

b. Application of Colors. Poster color or ink may be applied with a wide-point pen or a brush. If sufficiently diluted, poster color may be used in place of ink to produce fine lines drawn with a ruling pen. If a stencil is used for uniformity, letters may be cut out of colored paper and pasted on a poster with rubber cement or glue.

5-26. Materials

Illustration and Bristol board are satisfactory for preparing training aids.

a. Brushes. Brushes are made of sable or camel's hair with the former preferable. They are in two styles, round and flat with square ends. The widths of the sizes most generally used range from $\frac{1}{4}$ to 1 inch. Brushes are used for lettering with water colors.

(1) *Use.* A brush is held between the thumb and the first two fingers in a nearly vertical position and should not be gripped too tightly. Strokes are made with a full, swinging movement of the arm and with the extreme tip of the brush. The flat brush should be kept well filled with color and should be lifted abruptly from the paper at the end of the stroke to give the stroke a square tip. Persistent practice is essential for the development of a satisfactory technique.

(2) *Care.* Brushes should always be kept clean and stored either flat or upright on the handle. To clean a brush, use the proper solvent or thinner for the color or colors used, to remove as much of the color as possible. Wet the brush in lukewarm water, apply a mild soap, and work up a lather by rubbing the brush on the palm of the

hand, then rinse it thoroughly. Reshape the brush and put it away.

b. Color. Prepared poster colors are available in jars. Unless a particular color is used extensively, only the following colors need be on hand: white, black, and the basic primary colors, red, yellow, and blue. To obtain the secondary colors combine, red and yellow to get orange, yellow and blue to get green, and blue and red to get purple. White can be added to any of the above colors to get pinks, tints and light pastel colors. Black can be added to the warm colors (yellow, red, and or-

ange) to obtain browns varying from raw umber to burnt sienna. Complimentary colors such as red and green can also be combined in equal amounts to produce a neutral brown. To obtain olive drab (O.D.) start with a quantity of green and add small amounts of red until the desired color is obtained. In some cases, due to the quality of pigment used in the paint, it may be necessary to add a touch of yellow or black or both to achieve the desired color. There are also available special fluorescent colors that glow, especially under ultraviolet light, and can be used for special effects.

CHAPTER 6

GEOMETRICAL CONSTRUCTION

6-1. Introduction

a. The principles of geometric construction were developed using only the pencil, straight-edge, compass and the mathematics of plane geometry. However, the draftsman has at his disposal many other instruments. The T-square, triangles, scales, curves, and so on, are used to make these constructions with speed and

accuracy. Applied geometry is the application of the instruments of the draftsman to make geometric constructions.

b. Knowledge of the principles of geometric constructions and applied geometry is essential to the draftsman. The representation of objects that require this knowledge occur frequently in engineering drawings. Each construction problem in this chapter is described by a sequence of steps.

Section I. GEOMETRICAL NOMENCLATURE

6-2. Point

A *point* represents a location in space or on a drawing, and has no width, height, or depth. A point is represented by the intersection of two lines, by a short crossbar on a line, or by a small cross (fig. 6-1).

6-3. Line

A *line* has length without breadth. A *curved line* is generated by a point moving in a constantly changing direction. A *straight line* is the shortest distance between two points. If the line is indefinite in extent, the length is a matter of convenience, and the end points are not fixed. If the end points of the line are significant, they must be marked by means of small cross bars (fig. 6-1). A *segment* is any part of a divided line. A *vertical line* is the position described by a string hanging in space with a weight attached to its lower end, a plumb line. A *horizontal line* is perpendicular to a vertical line. Two lines are *perpendicular* to each other if they form right angles (90°) at their intersection. Two perpendicular lines may be marked with a box to indicate perpendicularity as shown in figure 6-2. Either straight lines or curved lines are *parallel* if the lines remain equidistance from each other at all points. A common symbol for parallel lines is ||, and for perpendicular lines is \perp (singular) or \perp s (plural).

is measured in degrees of arc or hours of time. In construction drafting the degrees of arc definition is most commonly used. A degree is divided into

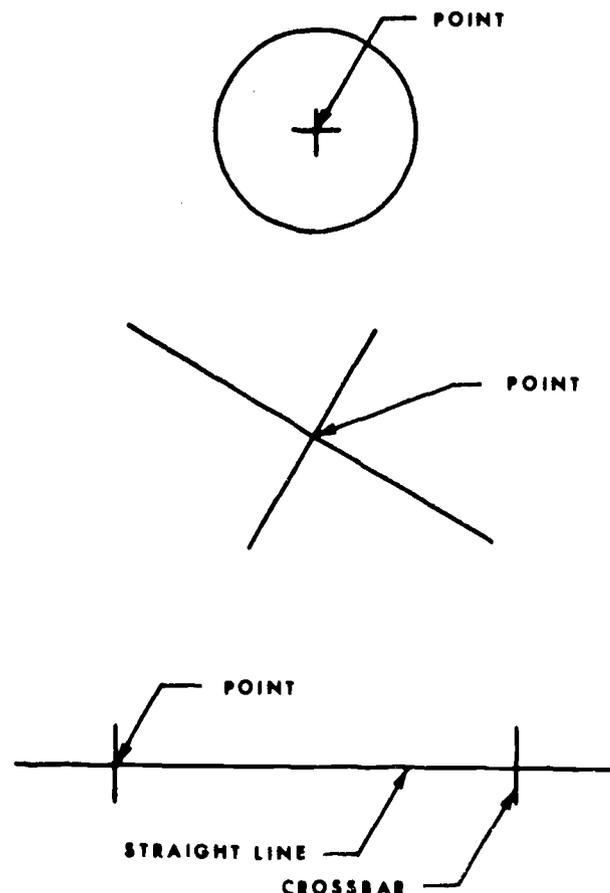


Figure 6-1. Points and straight line.

6-4. Angles

An *angle* is formed by two intersecting lines and

60 minutes (60') and a minute is further divided into 60 seconds (60''). Figure 6-3 shows different types of angles and the terminology used to describe them.

a. A full circle contains 360 degrees (360°).

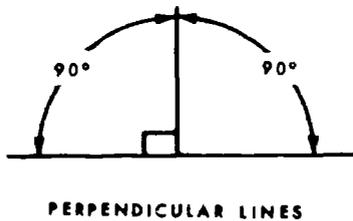
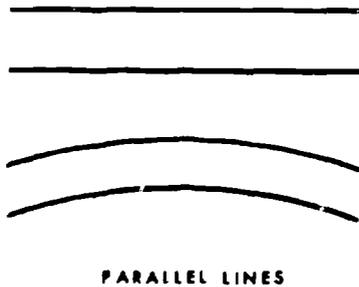
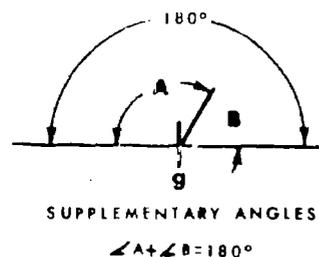
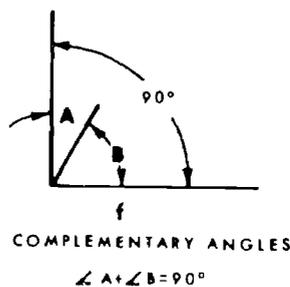
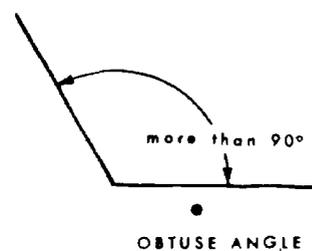
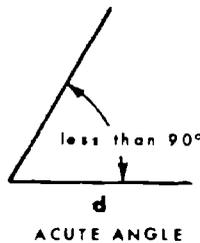
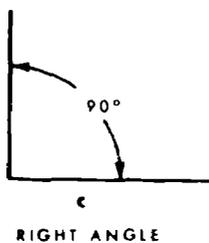
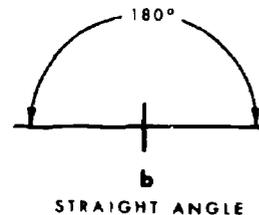
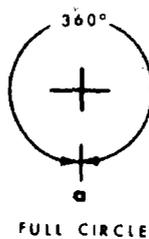


Figure 6-2. Parallel and perpendicular lines.



b. A straight angle is 180° , notice the leaders and crossbar to properly indicate this angle.

c. A right angle is 90° .

d. An acute angle is any angle containing less than 90° .

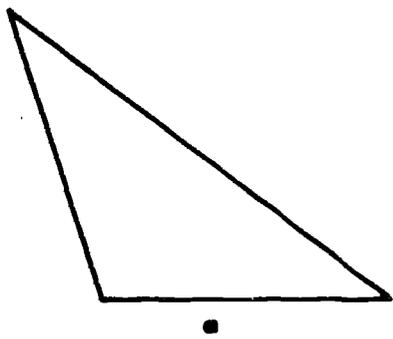
e. An obtuse angle is any angle containing more than 90° .

f. Two angles are complementary if they total exactly 90° .

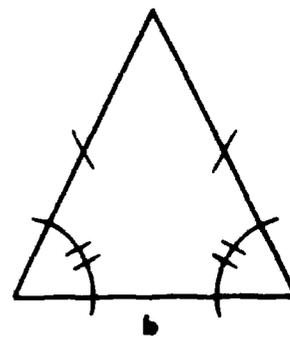
g. Two angles are supplementary if they total exactly 180° .

6-5. Triangles

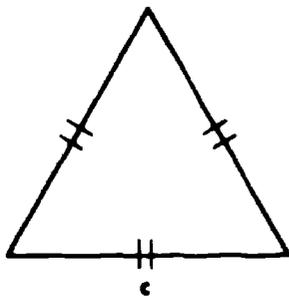
A *plane triangle* is a figure bounded by three straight sides. The sum of the interior angles is always 180° . The following triangles and terminology are keyed to figure 6-4. If no sides or angles are equal, it is a *scalene triangle*. If one of the angles of a scalene triangle is obtuse, it is an *obtuse scalene triangle* (a). If 2 sides and 2 angles are equal, it is an *isosceles triangle* (b). If all sides and angles are equal, it is an *equilateral triangle* (c). If one of the angles is 90° , it is a



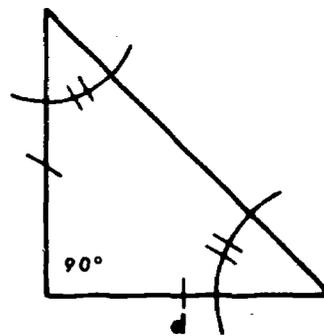
OBTUSE SCALENE TRIANGLE



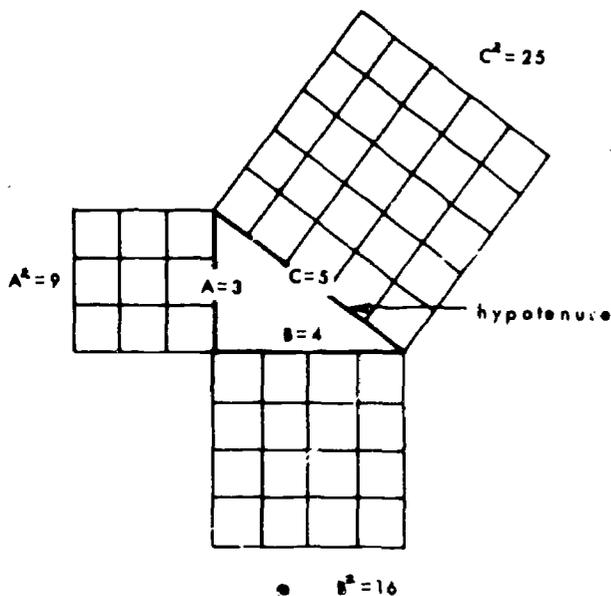
ISOSCELES TRIANGLE



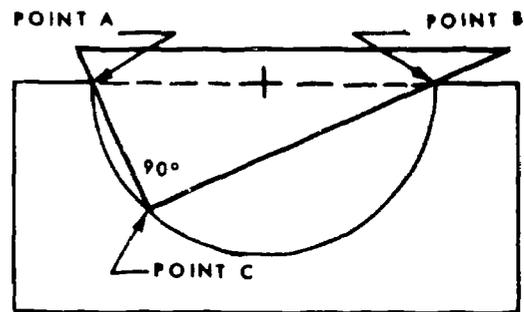
EQUILATERAL TRIANGLE



RIGHT TRIANGLE,
also a right isosceles triangle



RIGHT TRIANGLE, PROOF



f
SCALENE TRIANGLE,
also a right scalene triangle

Figure 6-4. Triangles.

right triangle (d). In a right triangle, the side opposite the 90° angle is called the hypotenuse. The square of the hypotenuse is equal to the sum of the squares of the other two sides $C^2 = A^2 + B^2$ (e). Any triangle inscribed in a semicircle is a right triangle if the hypotenuse coincides with the

diameter (f). Assume any point C on semicircle, line A-B = Hypotenuse = Diameter, and angle $ACB = 90^\circ$.

6-6. Quadrilaterals

A quadrilateral is a plane figure bounded by four

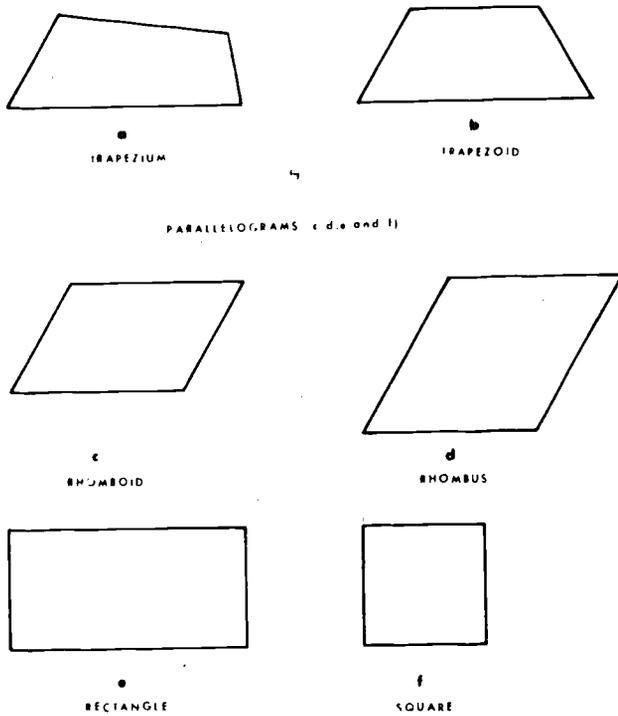


Figure 6-5. Quadrilaterals.

straight lines. Figure 6-5 shows the different types of quadrilaterals and is keyed to the following terminology. If no sides are parallel, it is a *trapezium* (a). If only two sides are parallel, it is a *trapezoid* (b). If the opposite sides are parallel, the quadrilateral is also a *parallelogram* (c, d, e, and f). If opposite sides are parallel and have two obtuse and two acute angles, it is a *rhomboid* (c). If opposites are parallel, all sides equal, with two acute angles and two obtuse, it is a *rhombus* (d). If opposite sides are parallel and equal, with right angles, it is a *rectangle* (e). If all sides are parallel and equal with right angles, it is a *square* (f).

6-7. Polygons

A *polygon* is any plane figure bounded by straight lines. If the polygon has equal angles and equal sides, it can be inscribed in or circumscribed around a circle and is called a *regular polygon*. An equilateral triangle is a regular polygon, while a scalene triangle is not. A square is a regular polygon, while the other quadrilaterals are not. Figure 6-6 shows some of the regular polygons, which are an inscribed triangle, a circumscribed square, an inscribed pentagon, an inscribed hexagon, an inscribed heptagon, and an inscribed octagon. Other polygons that are not shown are Nonagon, which has 9 sides; Decagon, 10 sides; Dodecagon, 12 sides.

6-8. Circle

A *circle* is a closed plane curve all points of which

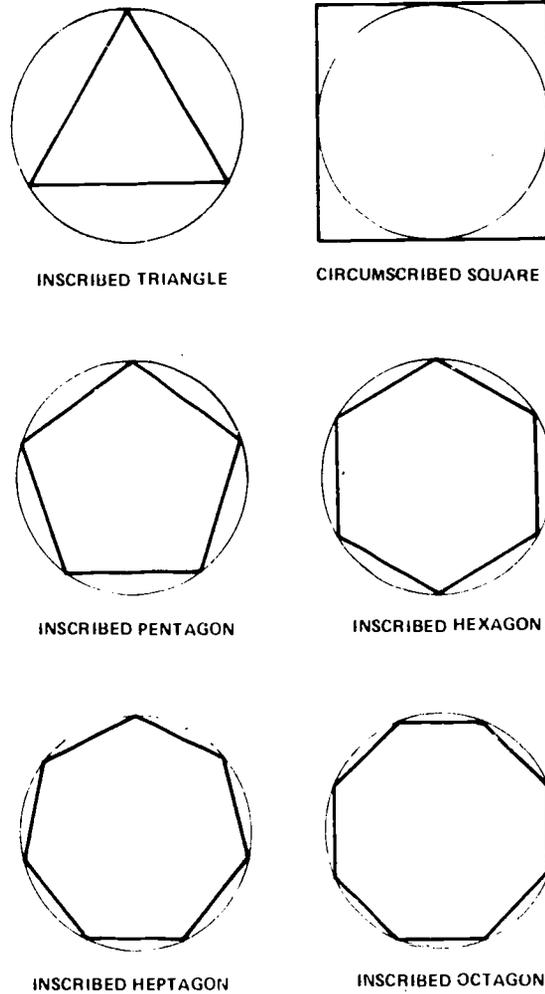


Figure 6-6. Regular polygons.

are the same distance from a point called the *center* (fig. 6-7). The distance around the circle is called the *circumference*. A portion of the circumference is called an *arc*; half the circumference is called a *semicircle*. A straight line from the center to the circumference is called the *radius*. A straight line passing through the center of a circle with the end points at the circumference is referred to as the *diameter*. A line not bounded by the circumference and intersecting a circle at more than one point is called a *secant*. A line intersecting a circle at more than one point with the end points bounded by the circumference is called a *chord*. A line that intersects a circle at only one point is called a *tangent*. Secants, chords and tangents are all perpendicular to one of the radii. Tangents are perpendicular to the radius at the point of intersection. The radii that are perpendicular to the secants and chords bisect them. A plane that is bounded by a 90° arc and two radii is called a *quadrant*. A plane bounded by an arc and two radii is called a *sector*. A plane bounded by a chord (or secant) and an arc is

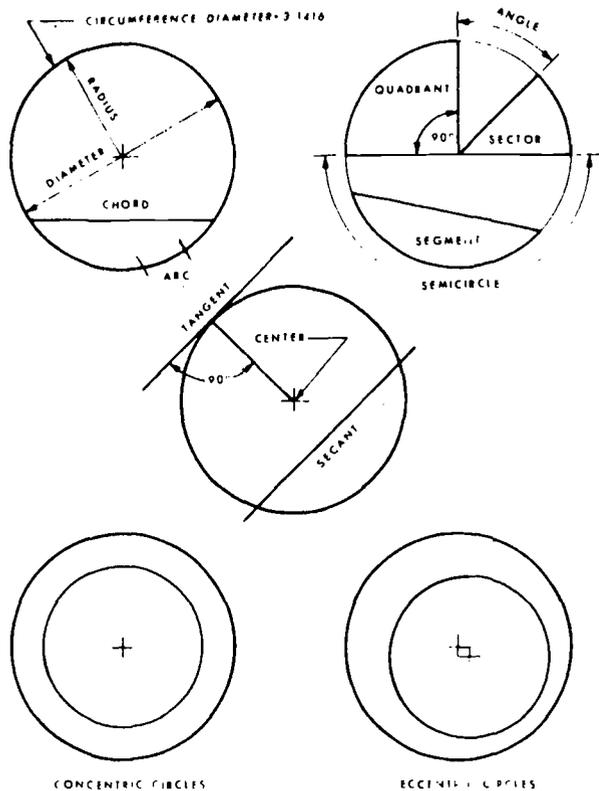


Figure 6-7. Circles.

called a *segment*. Circles having a common center are *concentric circles* and those that do not are *eccentric circles*.

6-9. Four Plane Curves

Four plane curves (conic sections) are obtained

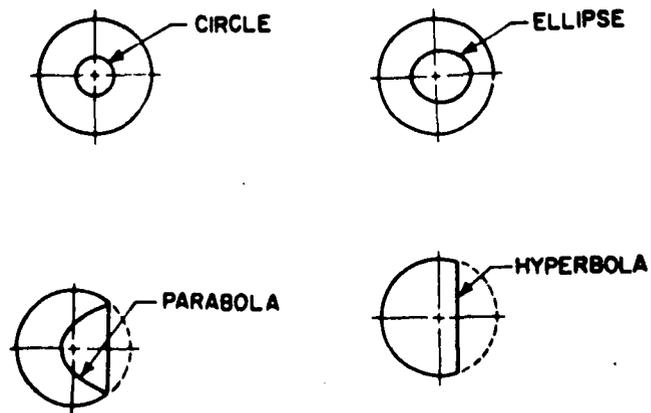


Figure 6-8. Four plane curves.

by cutting a right-circular cone at different angles, producing the following curved figures: circle, ellipse, parabola, and hyperbola. (fig. 6-8).

6-10. Special Curves

Special curves are cycloid, epicycloid, hypocycloid, involutes, spirals and helix. Refer to paragraphs 6-76 through 6-79 for a detailed description and methods of drawing. Other curves, whenever necessary, can be found in any good text book of analytic geometry and calculus. Typical of the curves that may be needed are the catenary, cardioid, sine curve, cosine curve, logarithmic spiral, reciprocal (hyperbolic) spiral, parabolic spiral, logarithmic curve, exponential curve and curves of velocity and acceleration.

Section II. STRAIGHT LINE CONSTRUCTION

6-11. To Draw Straight Lines

a. Horizontal Lines.

(1) *With T-square and drawing board.* The draftsman's horizontal line is constructed by drawing from left to right along the working edge of a T-square (B, fig. 6-9). The pencil should be inclined to the right at an angle of about 60° , with the point close to the junction of the working edge and the paper. The pencil is held lightly and, if sharpened with a conical point, is rotated slowly while the line is being drawn to achieve a uniform line width and preserve the shape of the point. Normally, when a series of horizontal lines is being drawn, the sequence of drawing is from the top down.

(2) *With triangles.* To draw a straight line through two points with triangle (fig. 6-10), place the point of the pencil at point B and bring the triangle against the point of the pencil. Then using this point as a pivot, swing the triangle

until its edge is in alinement with point A, and draw the line.

b. *Vertical Lines.* Vertical lines are produced parallel to the working edge of the drawing board by using triangles in combination with a T-square. One leg of a triangle is placed against the working edge of the blade and the other faces the working edge of the board to prevent the draftsman from casting a shadow over his work (A, fig. 6-9). Lines are drawn from the bottom up. The pencil is inclined toward the top of the working sheet at an angle of approximately 60° , with the point as close as possible to the junction of the triangle and drawing paper. Sequence in drawing a series of vertical lines is from left to right. At no time should the lower edge of the T-square blade be used as a base for triangles.

c. *Inclined Lines.* The direction or angle of inclination of an inclined line on a drawing sheet is measured by reference to the baseline from which

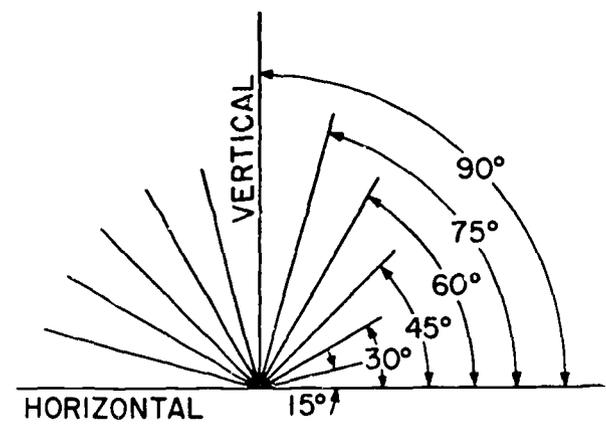
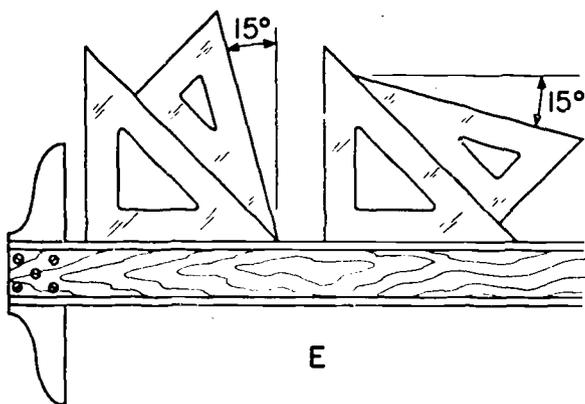
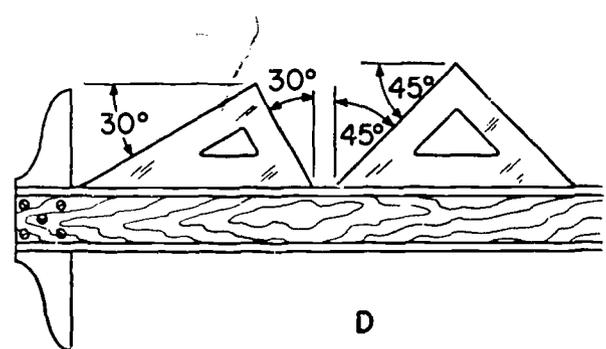
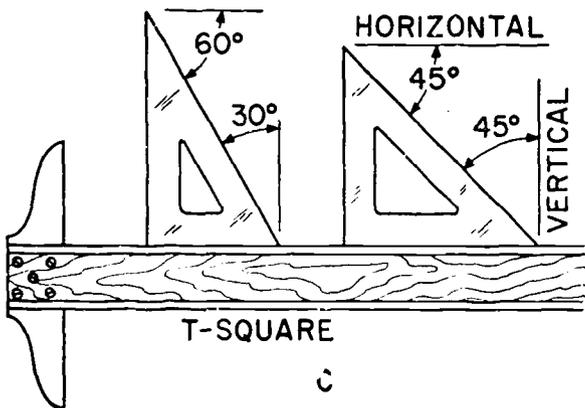
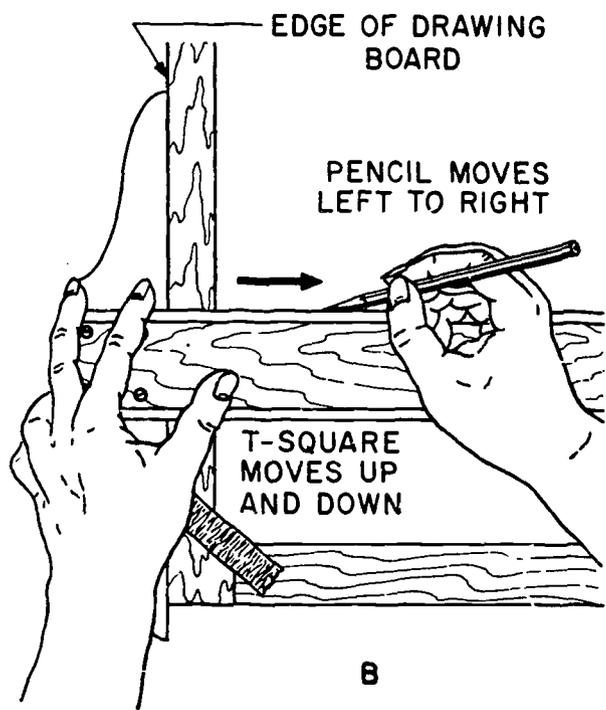
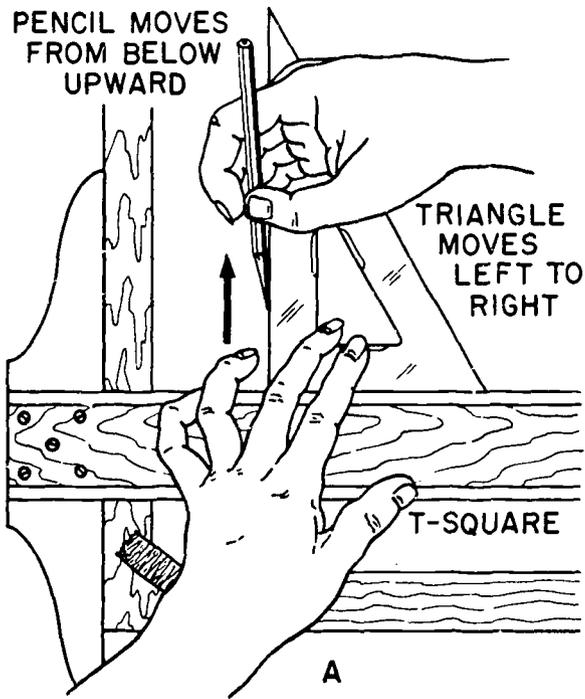


Figure 6-9. Drawing straight lines with T-square and triangles.

it is drawn. Inclined lines at standard angles are constructed with the T-square as a base for triangles used either singly or in combination (fig. 6-9). Used in combination with the T-square as a base, the triangles serve as guides for producing lines at intervals of 15° . Used singly, the 45° triangle will divide a circle into 8 equal parts; the $30^\circ \times 60^\circ$ triangle will divide a circle into 12 equal parts. For drawing lines at angles other than those described above, the protractor is used (para 2-11). Either triangle may be used as a straightedge to connect the two points indicating the vertex and angle of inclination.

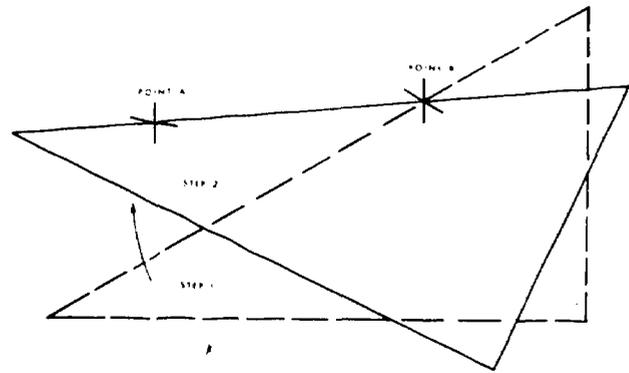


Figure 6-10. Drawing a line with a triangle.

d. *Parallel Lines.* To draw a line parallel (fig. 6-11) to a given line, adjust the hypotenuse of a right triangle in combination with a straightedge (T-square or triangle) to the given line; then, holding the straightedge firmly in position, slip the triangle to the desired position and draw the parallel line along the hypotenuse.

e. *Perpendicular Lines.* To construct a line perpendicular (fig. 6-12) to an existing line, use the right triangle and a straightedge in combination, the hypotenuse of the right triangle resting against the upper edge of the straightedge. Adjust one leg of the right triangle to a given line. Then the right triangle is slid along the supporting straightedge to the desired position. The line is drawn along the leg perpendicular to the leg that was adjusted to the given line.

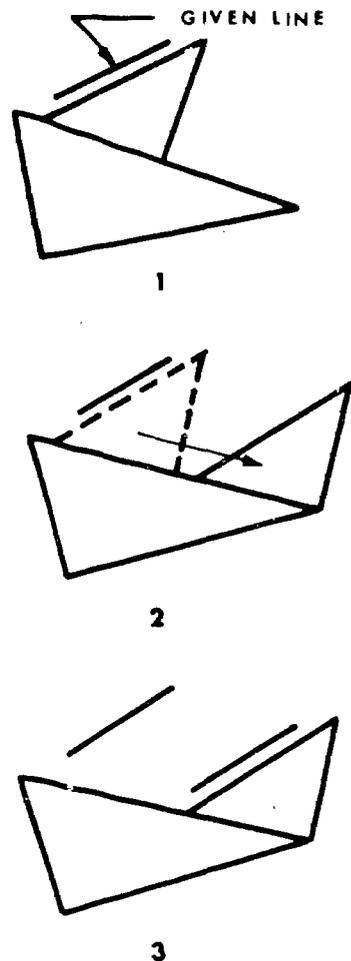


Figure 6-11. Drawing parallel lines.

6-12. Bisecting a Line With a Compass

From the two ends of the line (*A* and *B*), swing arcs of the same radius (1, fig. 6-13), greater than $\frac{1}{2}$ the length of the line, and draw a line through the arc intersections (*C* and *D*). This line bisects the given line and is the *perpendicular bisector*.

6-13. Bisecting a Line With a T-Square and Triangles

To construct on the given line *AB* equal angles at points *A* and *B* (2, fig. 6-13), draw lines *AC* and *BC* using a 30° to 60° or 45° triangle. Then draw a perpendicular line from point *C* to line *AB* using the 90° side of the triangle. The perpendicular line *CD* cuts *AB* at the midpoint *D*. *CD* is the perpendicular bisector of the given line *AB*.

6-14. Trisecting a Line With a Compass and Straightedge

On the given line *AB* (fig. 6-14) and using a radius equal to *AB*, draw two arcs of somewhat

more than quarter circles, using *A* and *B* as centers. These arcs will intersect at *C*. Using the same radius *AB* and with *C* as center intersect the first arcs at *D* and *E*. Then draw lines *DA* and *EB*, which intersect at *O*. Using length *OA* or *OB* (which should be equal) as a radius, *A* and *B* as centers, draw arcs to intersect at *T* which also will cut *AD* and *BE* at *R* and *S*. Draw lines *RT* and *ST*, which will intersect *AB* at the required trisection points *U* and *V*.

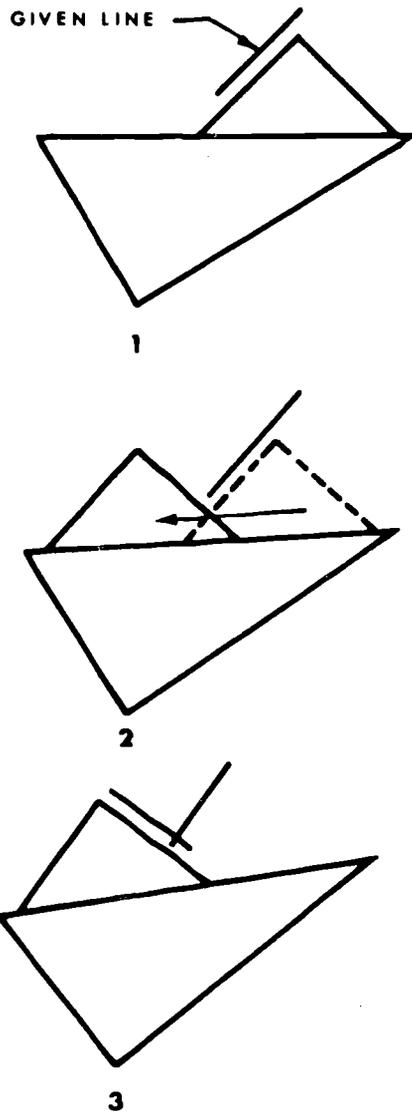


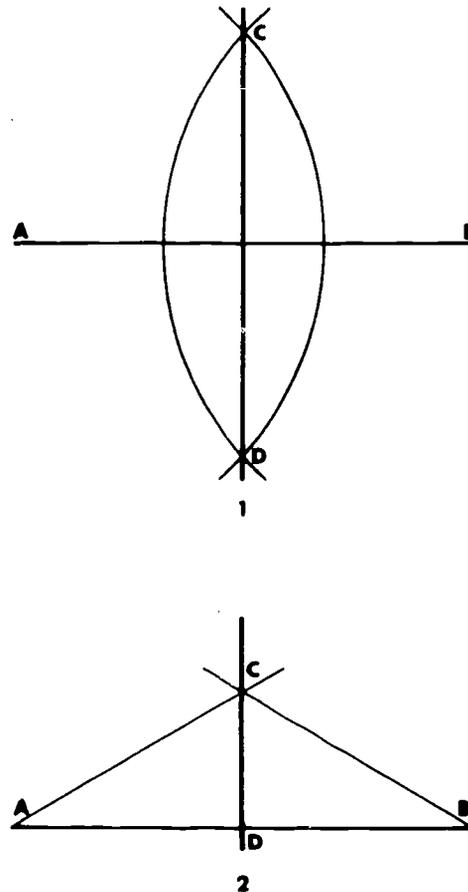
Figure 6-12. Drawing a perpendicular line.

6-15. Trisecting a Line With a T-Square and 30° to 60° Triangle

From the given line AB , draw lines from A and B at an angle of 30° that intersect at C (1, fig. 6-15). Then from C draw lines at an angle 60° that intersect AB at D and E , the required points.

6-16. Dividing a Line Into Equal Parts With a T-Square and Triangles

The principles of bisection and trisection can be combined to achieve successive bisections of a line into 2, 3, 4, 6, 8, 9, 12, or 16 equal parts. As shown in 2, figure 6-15 equal angles from A and B locate C , and the perpendicular from C to AB gives the mid-point. Successive operations will give 4, 8, 16, etc. parts. In figure 6-16, lines at an angle of 30° to AB from A and B locate C , and lines at an angle of 60° to AB from C locate D and E , the



ANGLES AT POINTS A AND B MUST BE EQUAL.

Figure 6-13. Perpendicular bisectors.

third points. Then 30° lines from A and D will bisect AD at F , giving sixth divisions; or trisecting DE gives points G and H producing ninth points; or bisecting EB to locate mid-point J , and again bisecting EJ and BJ locate points K and L , giving twelfth divisions of AB .

6-17. Dividing a Line Into any Number of Equal Parts With a Compass and Straightedge

Given the line AB (fig. 6-17)—

a. Draw line AC from point A at any convenient angle and length.

b. With a compass or dividers, mark off the required number of equal parts along line AC . (Example shows 5 equal parts.)

c. Draw line from point B to last point marked off on AC (5 on example), thus making angle P .

d. The next step is to construct an angle at point 4 equal to angle P . With point 5 as center, with any convenient radius R_1 intersect lines $B5$ and AC at points x and y . Then with point 4 as center, and the same radius R_1 , strike an arc MN .

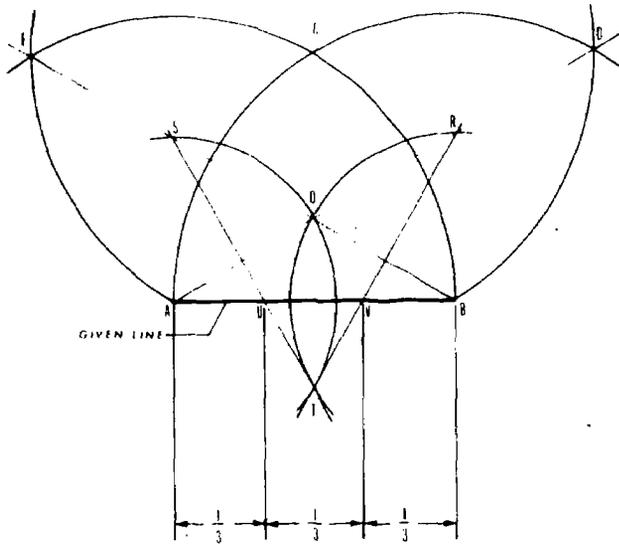


Figure 6-14. Trisecting a line with a compass and straightedge.

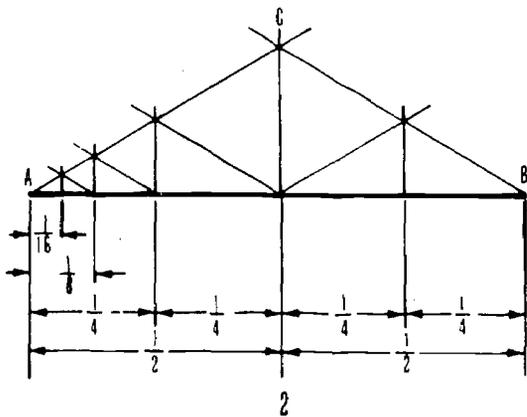
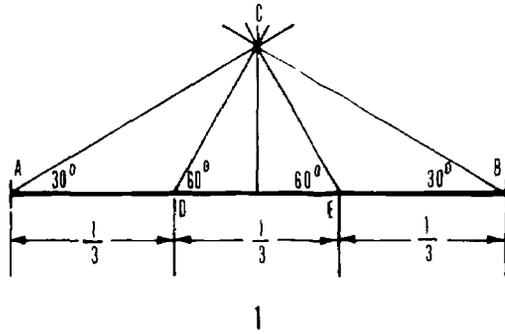


Figure 6-15. Dividing a line into equal parts using a T-square and triangles.

e. With a radius of R_2 equal to the straight line distance of xy , using point y' as center, strike an arc intersecting arc MN at point x' .

f. Step Six. Draw a line from point 4 through point x' intersecting line AB at point $4'$. This forms angle P' equal to angle P , thus making line

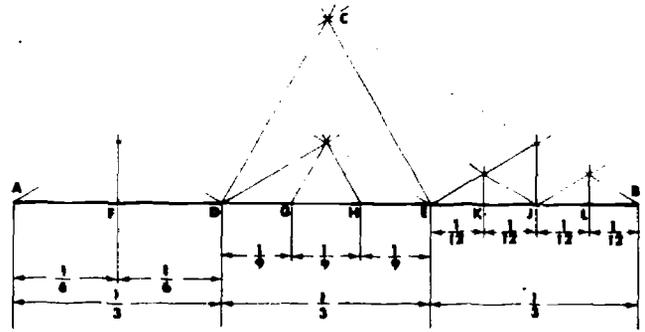


Figure 6-16. Dividing a line into equal parts by bisections and trisections using a T-square and triangles.

4 parallel to line 5. Continue to construct equal angles and parallel lines at 3, 2, and 1 repeating d and e above. Points 1', 2', 3', and 4' divide line AB into 5 equal parts.

6-18. Dividing a Line Into any Number of Equal Parts With a Scale, T-Square and Triangle

Given the line AB (fig. 6-18)—

a. Draw a vertical line from point B of given line AB with T-square and triangle.

b. Set zero of scale at point A .

c. Swing scale up until tenth unit falls on vertical line and make marks at each unit. (Any unit may be used on the vertical line depending on the number of equal parts required.)

d. Draw vertical construction lines through each point with T-square and triangle. These lines divide line AB into the required equal parts (10 in example).

6-19. Drawing a Line Through a Point Parallel to a Given Line Using a Compass and Straightedge

Given the line AB and point P (fig. 6-19)—

a. Take a compass and place pin point at given point P as center, strike an arc CD with any convenient radius R that intersects the given line AB at a point E .

b. Without adjusting the compass, using the same radius R , but this time with point E as center strike an arc FG intersecting given line AB at point H .

c. Adjust the compass to the straight line distance PH , the new radius, R' . With center at E , strike an arc IJ with the new radius R' intersecting arc CD at point Q .

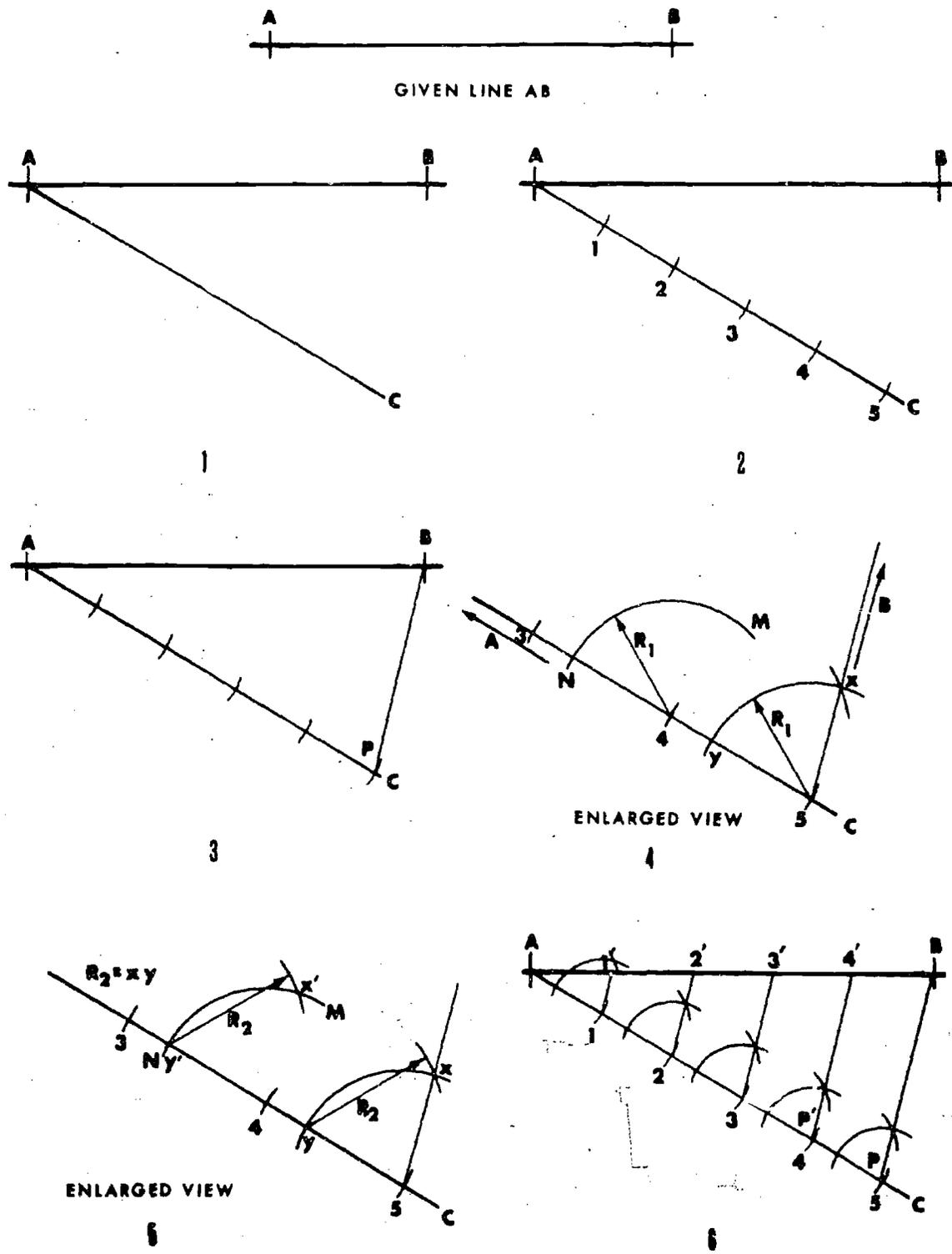


Figure 6-17. Dividing a line into any number of equal parts with a compass and straightedge.

d. Draw a line through points P and Q; this is the required parallel line to given line AB through given point P.

6-20. Drawing a Line Through a Point Parallel to a Given Line Using Triangles

Adjust a triangle to the given line AB (fig. 6-20) with a second triangle as a base. Slide the aligned

triangle to its position at point P and draw the required line.

6-21. Drawing a Line Parallel to and a Given Distance From a Given Line, Using Triangles and Compass

Draw an arc with the given distance R as radius (fig. 6-21) using any point (P) on the given line

AB as center. Then adjust the triangle to line AB , with a second triangle as a base. Slide the aligned triangle to a position tangent to the circular arc and draw the required line.

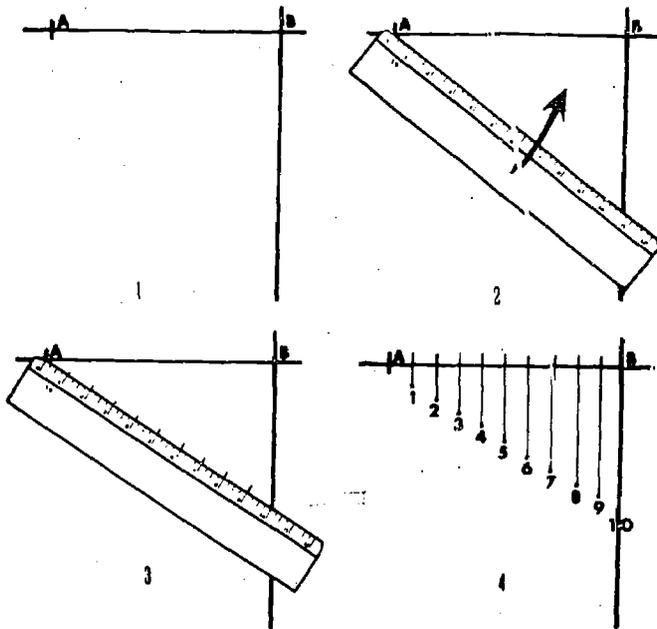


Figure 6-18. Dividing a line into any number of equal parts with a scale, T-square, and triangle.

6-22. Erecting a Perpendicular to a Line From a Given Point With Compass and Straightedge

With given point P as a center and radius R_1 of any convenient length, draw arcs intersecting given line AB , at points X and Y (fig. 6-22). With X and Y as centers and radius R_2 of any convenient length, draw arcs intersecting at point Q . Line PQ is then the required perpendicular.

6-23. Erecting a Perpendicular to a Line From a Given Point With a Triangle and T-Square

Square the given line with the top blade of the T-square. Slide the triangle along T-square blade to the point and draw perpendicular (fig. 6-23).

6-24. Erecting a Perpendicular to a Line at a Given Point on the Line With a Compass and Straightedge

Given the line AB and a point P on the line (fig. 6-24)—

- Select any convenient point O as a center.
- With radius OP and O as center, draw an arc

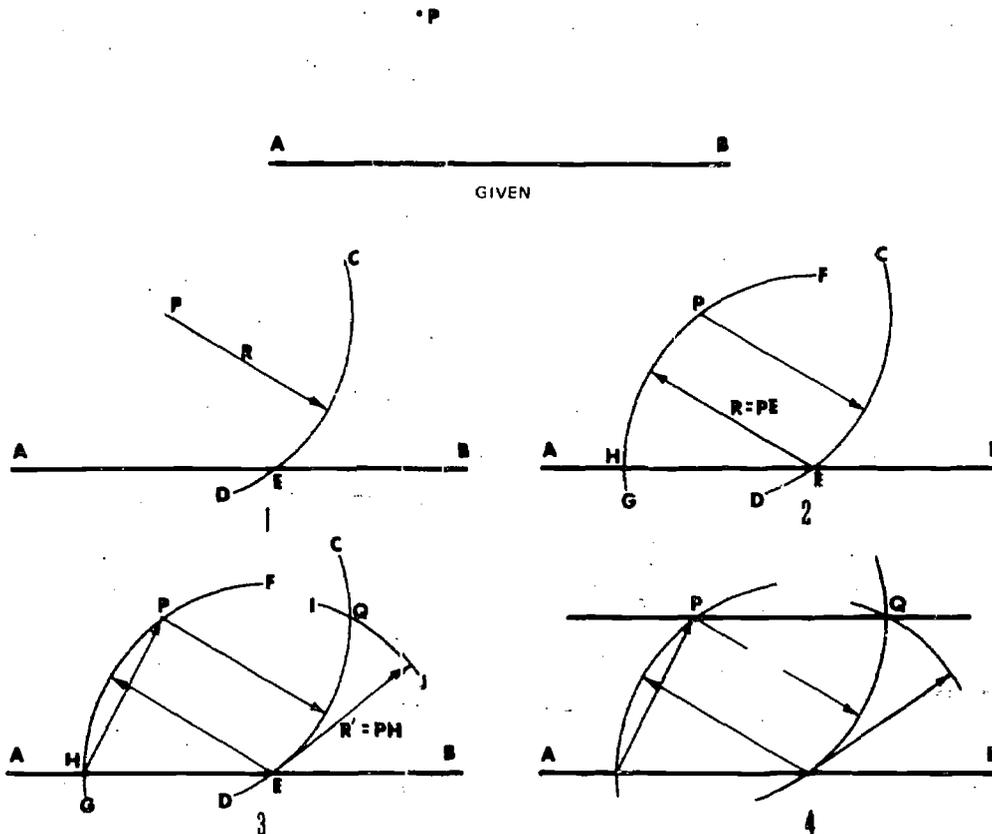


Figure 6-19. Drawing a line through a point parallel to a given line using a compass and straightedge.

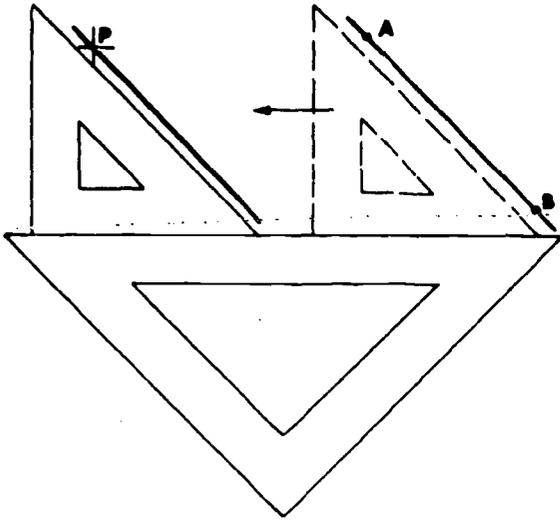


Figure 6-20. Drawing a line through a point parallel to a given line using triangles.

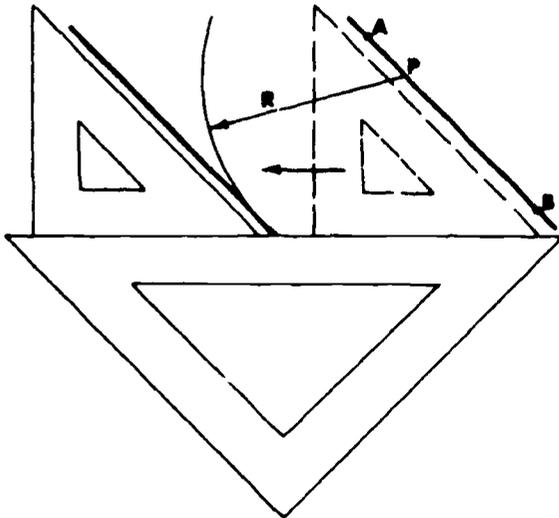


Figure 6-21. Drawing a line parallel to and at a given distance from a given line, using a compass and triangles.

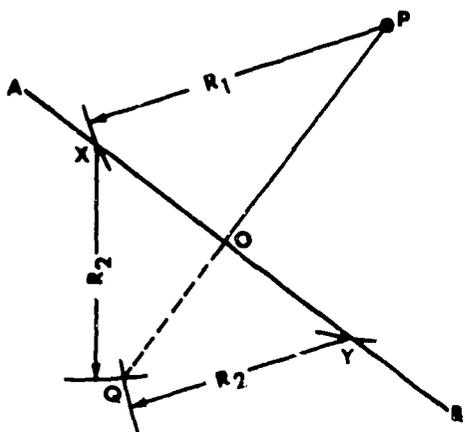


Figure 6-22. Erecting a perpendicular to a line from a given point with a compass and straightedge.

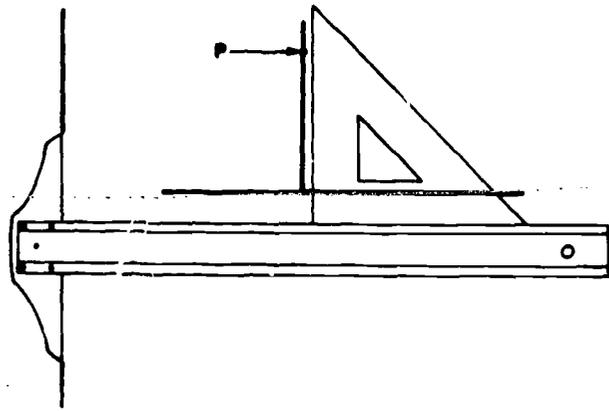


Figure 6-23. Erecting a perpendicular to a line from a given point with a triangle and T-square.

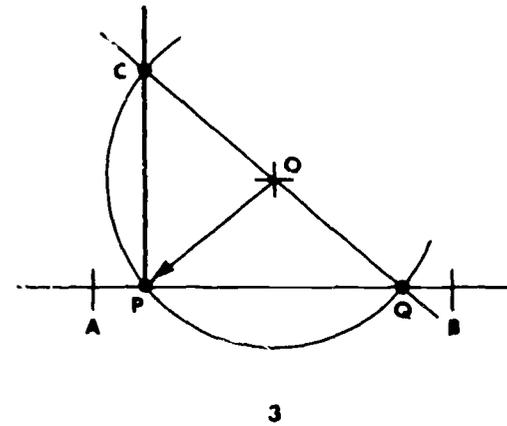
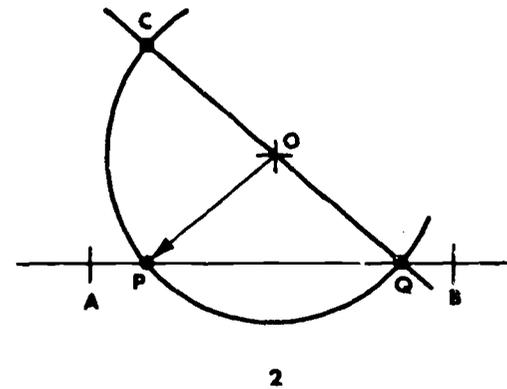
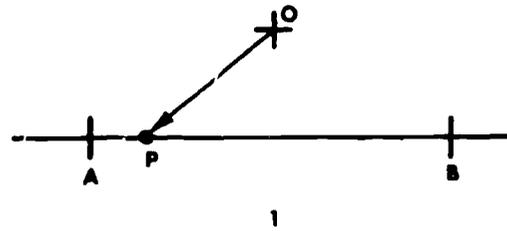


Figure 6-24. Erecting a perpendicular to a line at a given point on the line with a compass and straightedge.

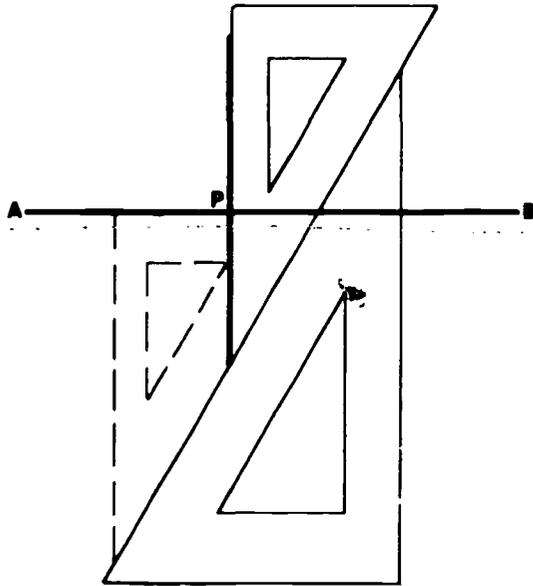


Figure 6-25. Erecting a perpendicular to a line at a given point on the line using a triangle.

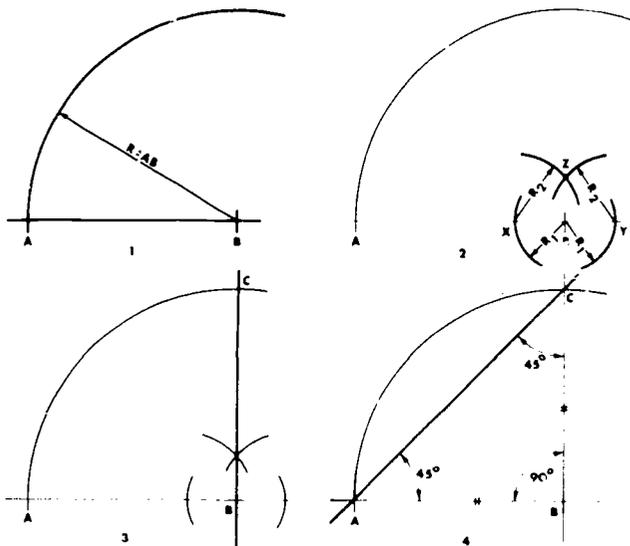


Figure 6-26. Constructing an angle of 45° with a compass and straightedge.

slightly greater than a semicircle establishing point Q on the given line. Extend a line from point Q through point O , intersecting the arc at point C .

c. Connect points P and C , forming the required perpendicular.

6-25. Erecting a Perpendicular to a Line at a Given Point on the Line Using a Triangle

Set a 30° to 60° triangle so that its short side coincides with line AB (fig. 6-25). Place a second triangle against the hypotenuse of the first. Then hold the second triangle firmly and slide the first triangle upward until its vertical edge rests on point P .

6-26. Constructing an Angle of 45° With a Compass and Straightedge

For large construction or when great accuracy is needed, the method of equal legs (fig. 6-26) can be used as described below.

a. With any distance AB on the given line, with the center at B and radius AB draw an arc of more than a quarter circle.

b. Erect a perpendicular to line AB at B .

c. The intersection of the arc and perpendicular is point C .

d. Form a triangle by drawing a line connecting points A and C . The angles at A and C are 45° . The three angles of a triangle total 180° , the perpendicular forms a right angle which is 90° , and equal legs of a triangle form equal angles

6-27. Laying Out Angles With a Compass and Straightedge

Angles in multiples of 30° may be needed for large constructions, and when great accuracy is required the following method can be used (fig. 6-27). On a given line, with radius AB , swing an arc with A as center. With the same radius and B as center, cut the original arc at C . The included angle CAB is 60° , and by bisection (para 6-28) 30° is obtained. For 120° , radius AB is laid off from A and C to D , the line AD is drawn, and the angle DAB is 120° . By bisecting angle DAC , angle FAB is 90° .

6-28. Bisecting an Angle

With point O , the apex of the given angle AB , as a center and with radius R_1 of any convenient length, draw an arc intersecting both sides of the angle (fig. 6-28). With the points of intersection A and B thus formed as centers and with radius R_2 of any convenient length, draw arcs intersecting at point P . Connect points P and O , bisecting the given angle. Repeating this method will divide the angle into 4, 8, 16, 32, and so on.

6-29. Dividing an Angle Into Any Number of Equal Parts

Swing an arc of any convenient radius intersecting AB and AC (fig. 6-29). With dividers, divide the arc into required number of segments. This method is done by trial and error, and is time consuming. Lines drawn from A through these points will divide the angle into the required number of segments. Another method is to divide the number of degrees by the number of divisions desired. For example to divide a 45° angle into 5

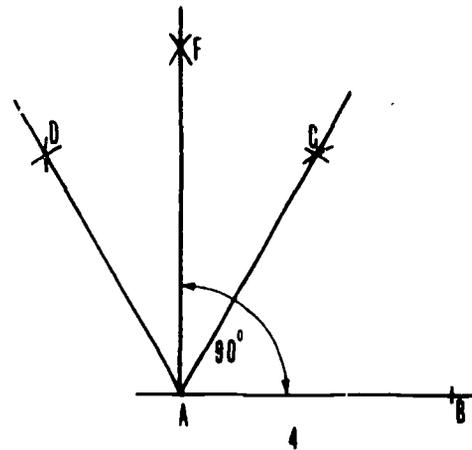
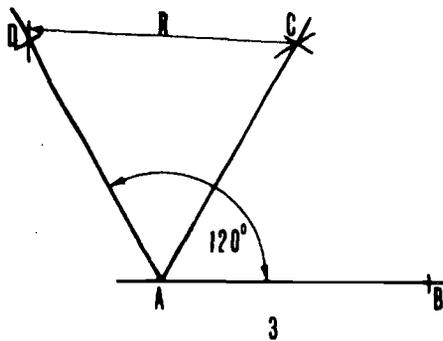
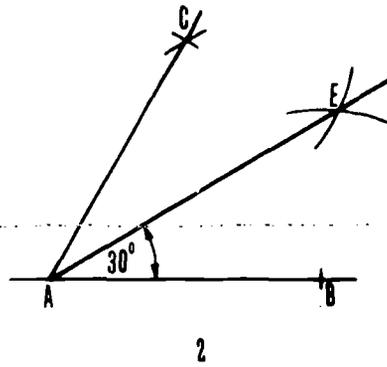
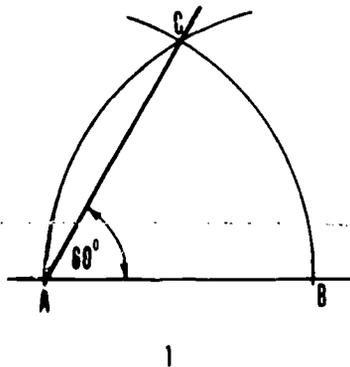


Figure 6-27. Laying out angles with a compass and straightedge.

equal parts, $45 \div 5 = 9^\circ$. Use a protractor and set off 9 degrees 5 times.

6-30. Constructing an Angle Equal to a Given Angle

Draw a line DX of convenient length as one side of the angle to be constructed. With point A as a center and any convenient radius R_1 , strike an arc intersecting both sides of the given angle A at points B and C (fig. 6-30). With point D as center and the same radius R_1 , strike an arc of convenient length, intersecting the line DX at point E . Set compass to the radius R_2 equal to the chord BC , and with point E as the center strike an arc which intersects first arc at point F . Draw line DF , making angle D equal to angle A .

6-31. Constructing an Equilateral Triangle Given One Side Using a Compass and Straightedge

With side AB as a radius and centers at A and B , strike arcs intersecting at C . Draw AC and BC

forming equilateral triangle ABC (1, fig. 6-31). The geometric center can be found by drawing arcs with A and B as centers and radius AB . These will intersect at C . With center at C and radius AB strike arcs to locate points X and Y . Then draw BX and AY which will intersect at O , the geometric center (2, fig. 6-31).

6-32. Constructing an Equilateral Triangle Given One Side, Using a 1-Square and Triangle

Draw line AB . Construct 60° angles at points A and B . The radiating lines will intersect at point C forming an equilateral triangle (fig. 6-32). Construct 30° angles with construction lines at points A and B . The lines will intersect at point O locating the geometric center.

6-33. Constructing an Isosceles Triangle Given Base and One Side

With side AC as a radius and centers A and B , strike arcs intersecting at C . Draw AC and BC forming isosceles triangle ABC (fig. 6-33).

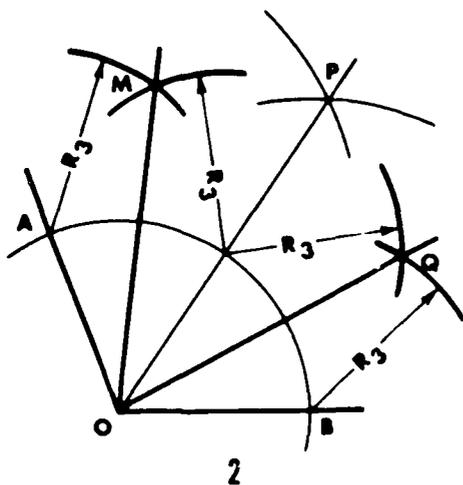
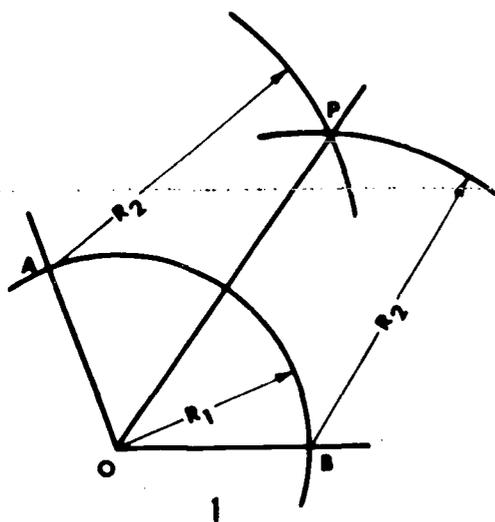


Figure 6-28. Bisecting an angle.

6-34. Constructing a Scalene Triangle Given Three Sides

Given sides A , B , and C , draw one side (2, fig. 6-34). Strike two arcs from the ends of line A with radii one equal to B , and one equal to C . Draw sides C and B from intersection of arcs and the ends of side A .

6-35. Drawing a Right Triangle When Hypotenuse and One Side are Given

Draw a line AB equal to the length of the hypotenuse, bisect it to find point O . With point O as the center and half the length of the hypotenuse as the radius, strike an arc (2, fig. 6-35). With one end of the hypotenuse as the center and the length of the given side AC as the radius, strike

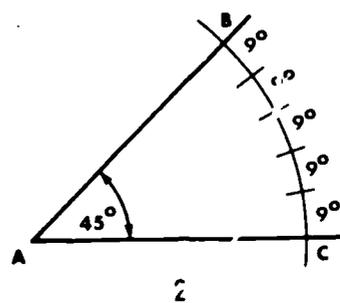
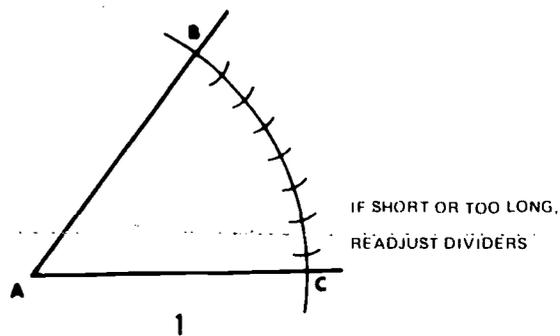


Figure 6-29. Dividing an angle into any number of equal parts.

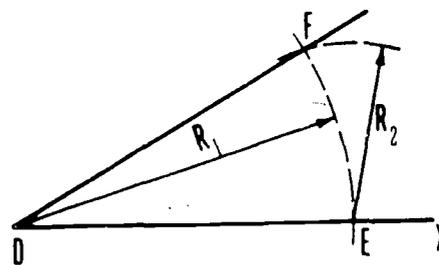
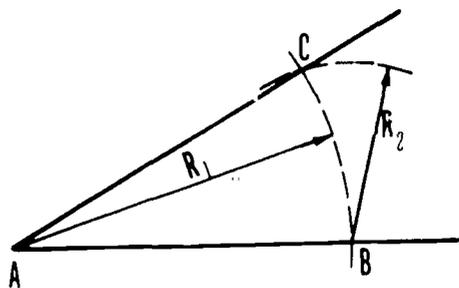


Figure 6-30. Constructing an angle equal to a given angle.

an arc intersecting the first arc (3, fig. 6-35). Connect the intersection of the arcs to the ends of the hypotenuse (4, fig. 6-35).

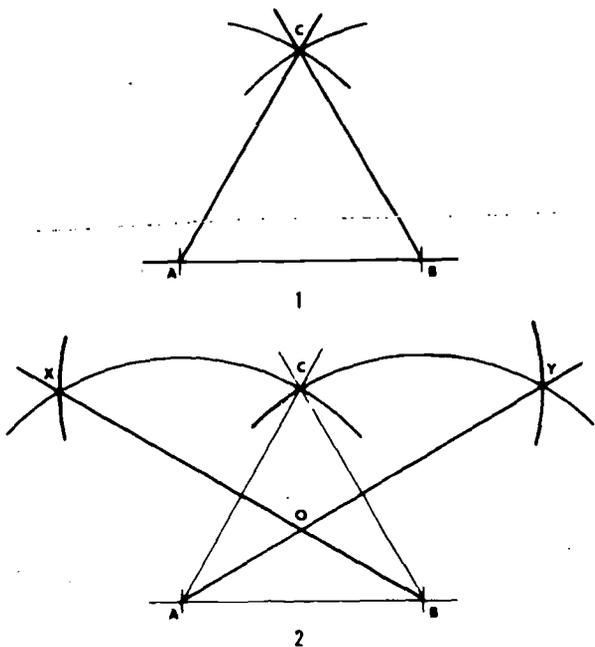


Figure 6-31. Constructing an equilateral triangle given one side, using a compass and straightedge.

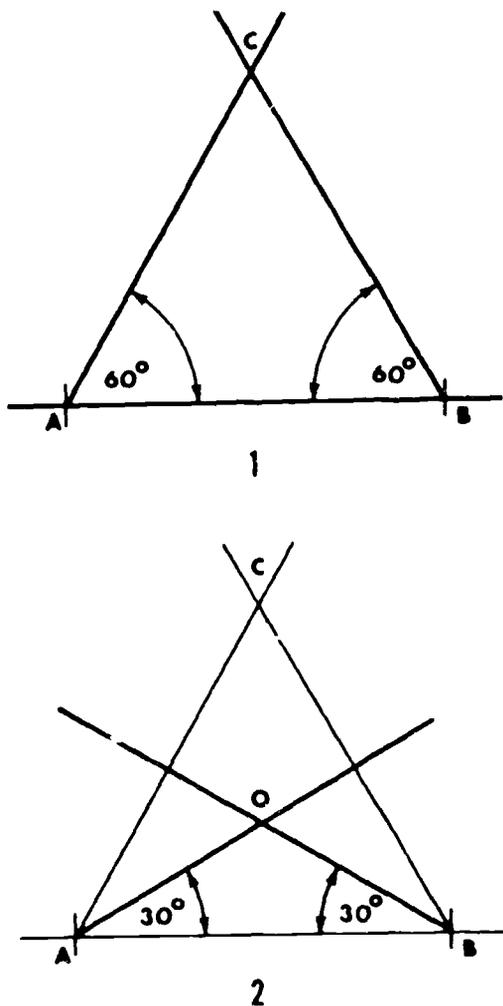


Figure 6-32. Constructing an equilateral triangle given one side, using a T-square and triangle.

6-36. Drawing a Square Given One Side, Using a Compass and Straightedge

- Draw a given side AB . Through point A , construct a perpendicular (1, fig. 6-36).
- With A as center and AB as radius, draw the arc to intersect the perpendicular at C (2, fig. 6-36).
- With B and C as centers, and AB as radius, strike arcs to intersect at D (3, fig. 6-36).
- Draw lines CD and BD (4, fig. 6-36), completing the square.

6-37. Drawing a Square Given One Side, Using a T-Square and Triangle

- Draw the given side AB . Using the T-square and 45° angle triangle, draw lines AC and BD perpendicular to line AB (1, fig. 6-37).
- Draw lines AD and BC at 45° angles to line AB (2, fig. 6-37).
- Draw line CD with T-square (3, fig. 6-37), completing the square.

6-38. Drawing a Square With the Distance Across the Corners Given

- Draw a circle with a radius of half the distance "across the corners" (2, fig. 6-38). The distance "across the corners" is distance measured along the diagonal from opposite corners.
- Draw two diameters at right angles to each other. The intersection of these diameters with the circle are the vertexes of the inscribed square (3, fig. 6-38), connecting the vertexes completes the square.

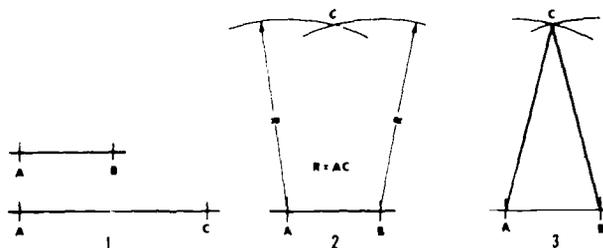


Figure 6-33. Constructing an isosceles triangle given the base and one side.

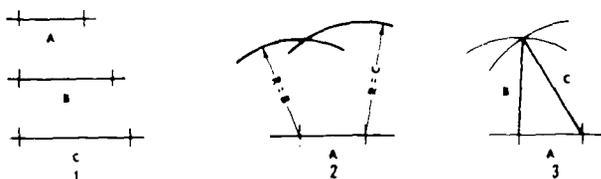


Figure 6-34. Constructing a scalene triangle given three sides.

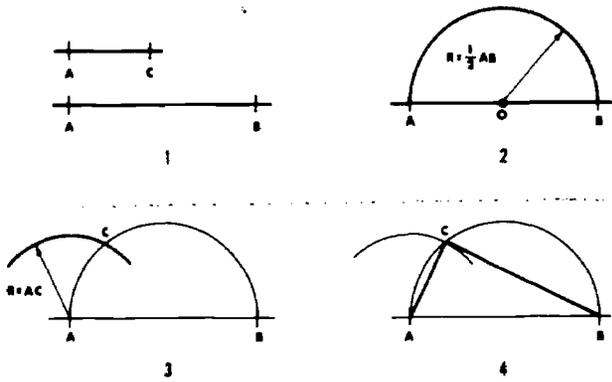


Figure 6-35. Drawing a right triangle when the hypotenuse and one side are given.

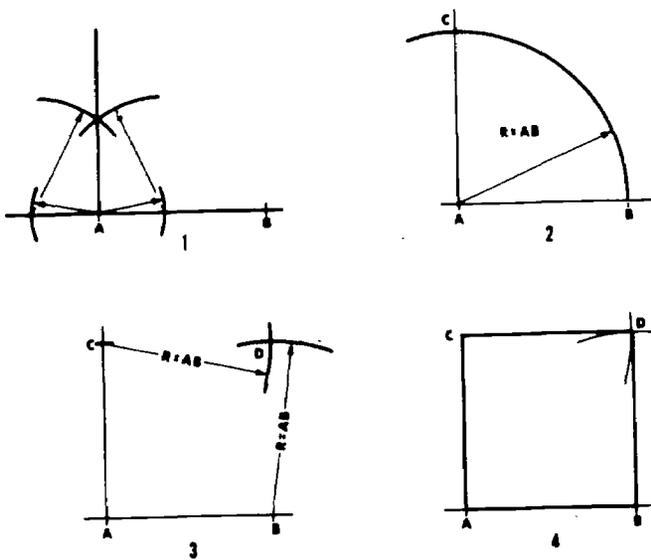


Figure 6-36. Drawing a square given one side, using a compass and straightedge.

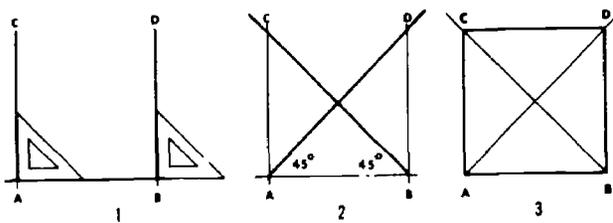


Figure 6-37. Drawing a square given one side, using a T-square and triangle.

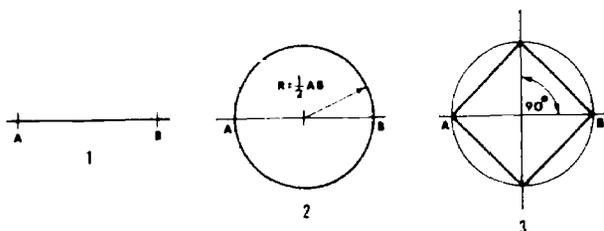


Figure 6-38. Drawing a square with the distance across the corners given.

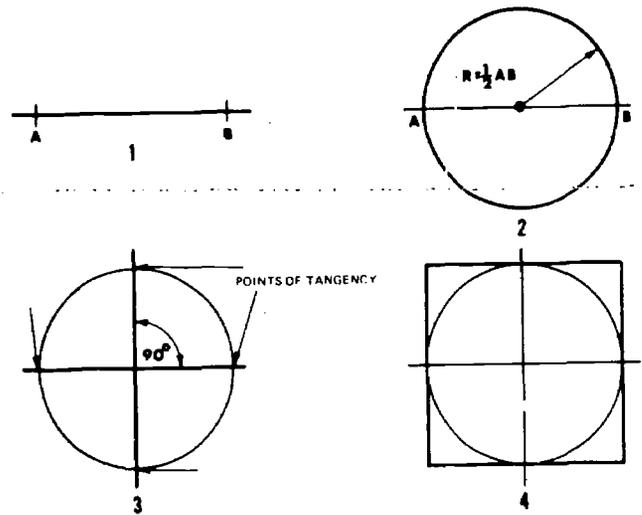


Figure 6-39. Drawing a square with the distance across the flats given.

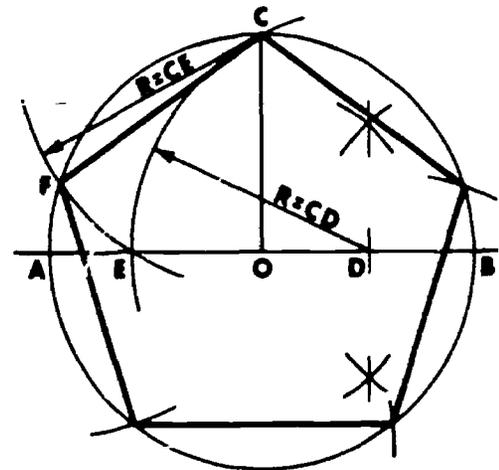


Figure 6-40. Drawing a pentagon inscribed in a given circle with a compass and straightedge.

6-39. Drawing a Square With the Distance Across the Flats Given

a. Draw a circle with a radius of half the distance "across the flats" (2, fig. 6-39). The distance "across the flats" is the distance measured from the center of one side to the center of the opposite side.

b. Draw 2 diameters perpendicular to each other to locate the points of tangency (3, fig. 6-39).

c. Using the T-square and 45° triangle, draw the four sides tangent to the circle (4, fig. 6-39), completing the square.

6-40. Drawing a Pentagon Inscribed in a Given Circle With a Compass and Straightedge

Draw a diameter (AB) of the given circle (fig.

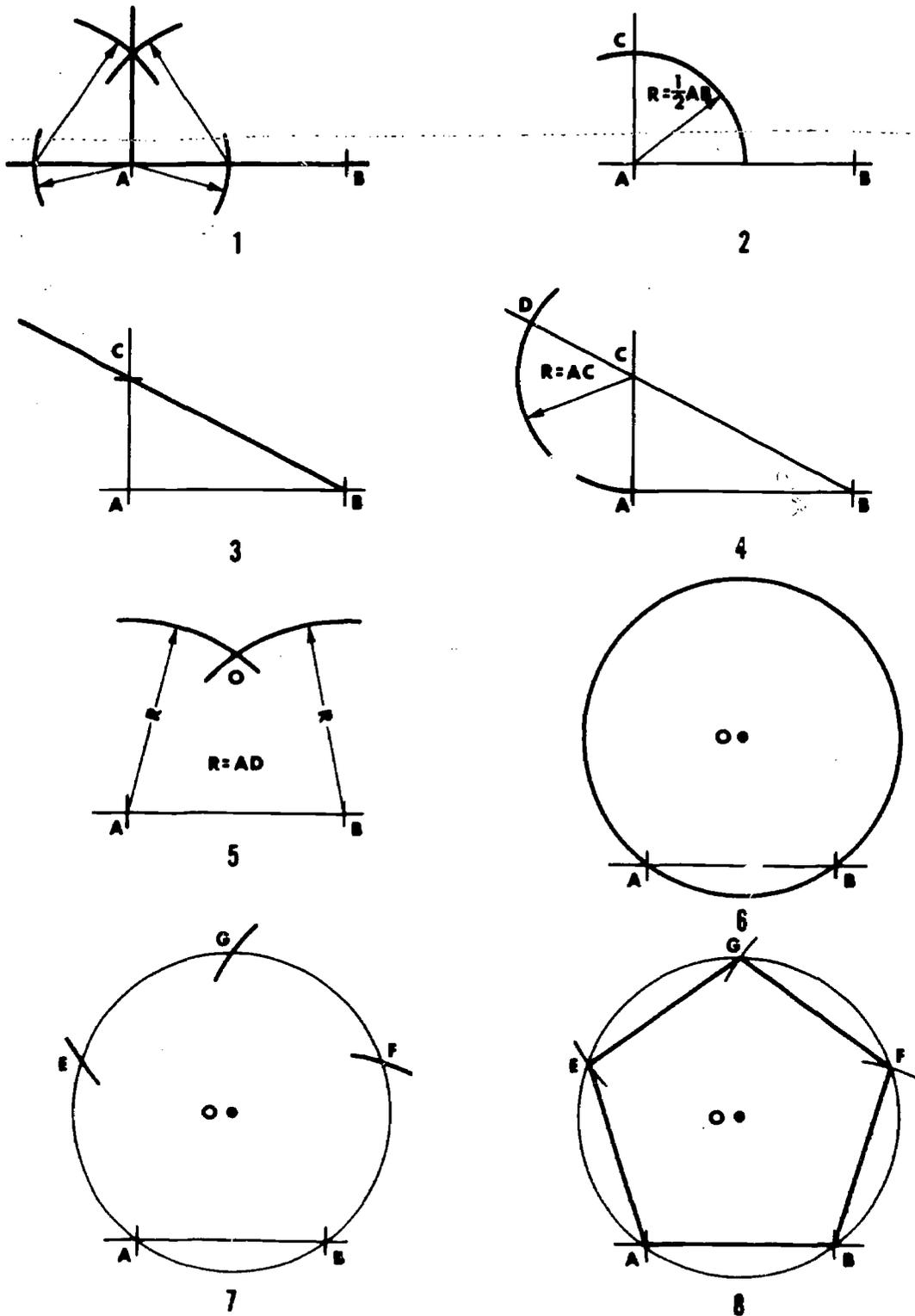


Figure 6-41. Drawing a regular pentagon given one side.

6-40). Draw radius OC perpendicular to the diameter AB . Bisect line OB at point D . With point D as a center and using CD as a radius, draw an arc intersecting the diameter at point E . With point C as a center and using CE as a radius,

draw an arc intersecting the circle at point F . Draw line CF , thus forming one side of the required pentagon. Using the compass, step off distance CF around the circle. Connect the points thus formed to complete the required pentagon.

6-41. Drawing a Regular Pentagon Given One Side Using a Compass and Straightedge

- Draw the given side, line AB . Construct a perpendicular at A (1, fig. 6-41).
- With a radius of $\frac{1}{2} AB$, and A as the center, locate point C (2, fig. 6-41).
- Draw line BC and extend it beyond C (3, fig. 6-41).
- With a radius of AC , and C as the center, locate point D (4, fig. 6-41).
- With radius AD and centers A and B , draw arcs to intersect at O (5, fig. 6-41).
- With the same radius AD and center O draw a circle (6, fig. 6-41).
- Step off AB as a chord to locate points E , F , and G (7, fig. 6-41).
- Connect the points to complete the pentagon (8, fig. 6-41).

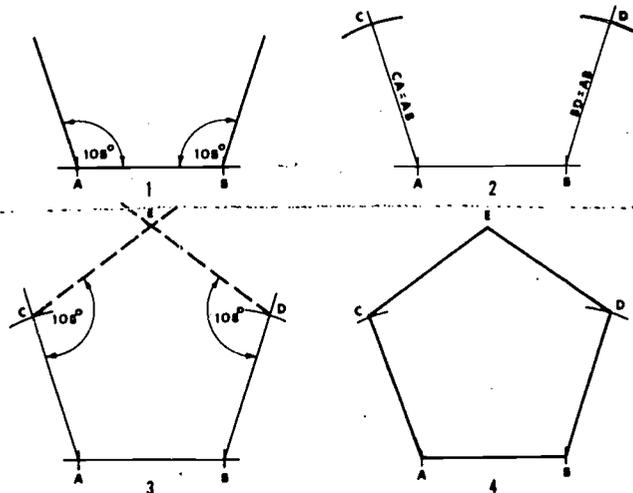
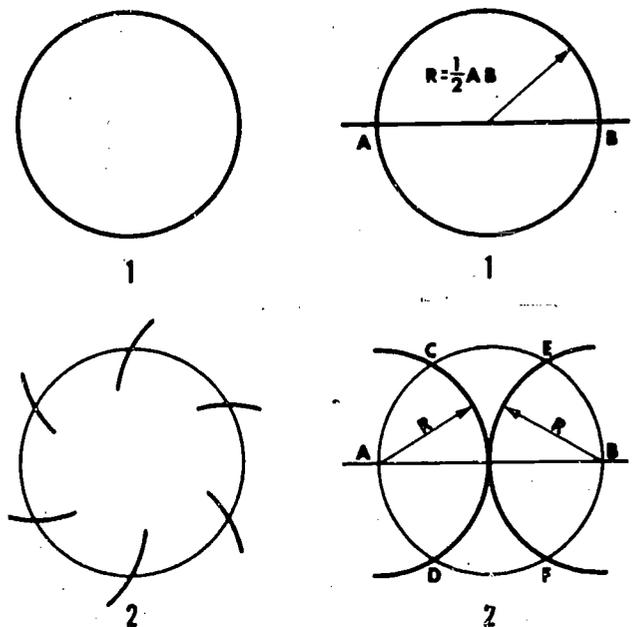


Figure 6-42. Drawing a pentagon given one side using a protractor and straightedge.

6-42. Drawing a Pentagon Given One Side Using a Protractor and Straightedge

- Draw the given side AB , and draw angles of 108° at points A and B (1, fig. 6-42).
- Mark off given side AB to locate points C and D (2, fig. 6-42).
- Measure an angle of 108° at points C and D to locate point E . Connect lines CE and DE (3, fig. 6-42), forming the pentagon.



6-43. Drawing a Hexagon Given the Distance Across the Corners

- With Compass and Straightedge.* Set the compass with radius half the distance given across corners (diameter), and draw the circumscribed circle (a, fig. 6-43). Each side of a hexagon is equal to the radius of the circumscribed circle. Therefore using the compass set at the distance of the radius of the circle, set off the six sides of the hexagon around the circle, and connect the points with straight lines.
- With Compass, T-Square and Triangle—Method One.* Draw a circle with radius $\frac{1}{2}$ the given distance across corners (b, fig. 6-43). With the same radius, and centers A and B , draw arcs to intersect the circle at C , D , E , and F . Complete the hexagon as shown.

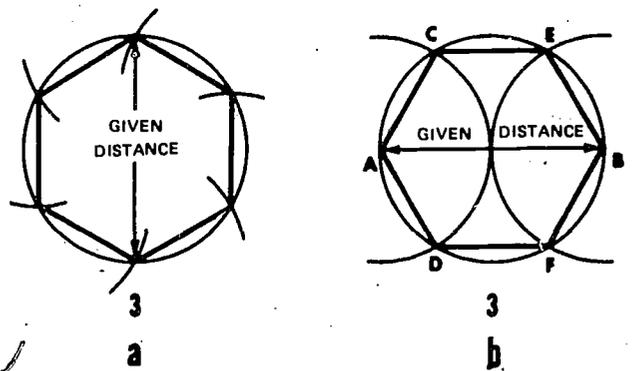


Figure 6-43. Drawing a hexagon given the distance across the corners.

6-43). Then draw diagonals CF and DE at 60° or 30° with horizontal; then with 30° to 60° triangle and T-square, draw the six sides as shown.

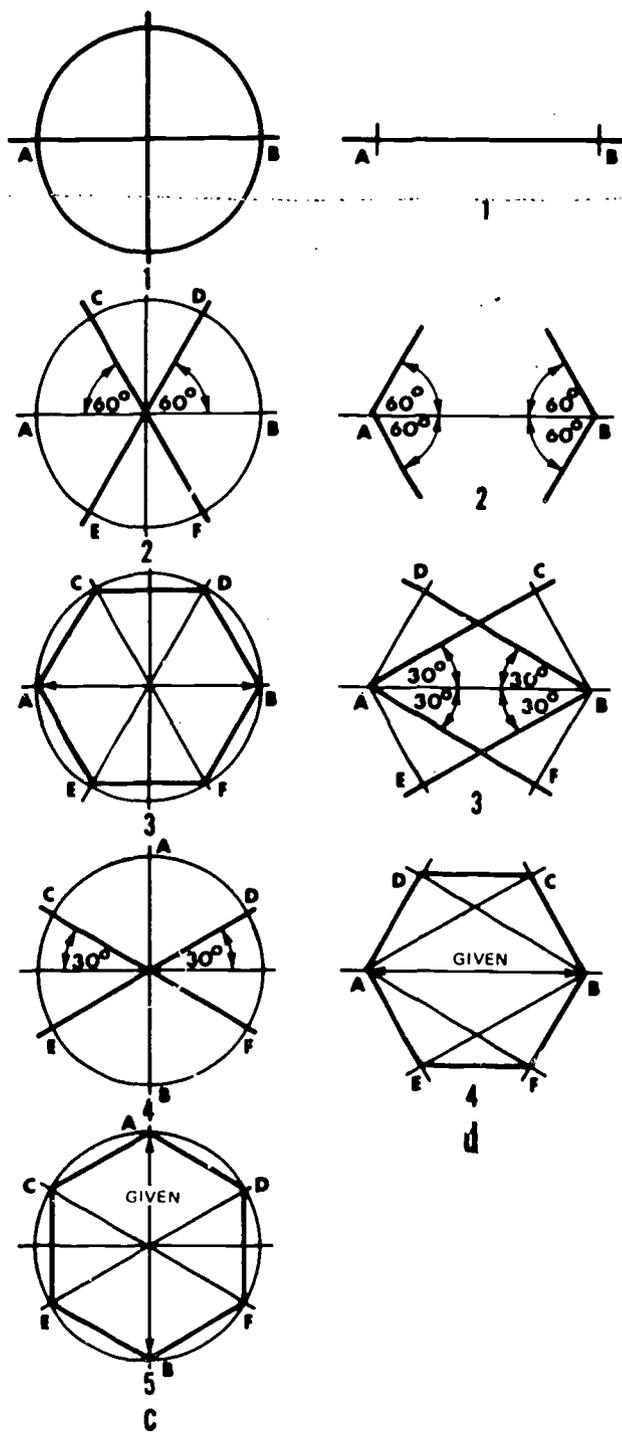


Figure 6-43—Continued

d. With T-Square and Triang'le. Draw given distance across corners, then draw lines with 30° to 60° triangle as shown (d, fig. 6-43). Complete the hexagon as shown.

6-44. Drawing a Hexagon Given the Distance Across the Flats

a. With Compass and Straightedge. Find the midpoint O of given distance AB (a, fig. 6-44). With point O as center and OB as the radius,

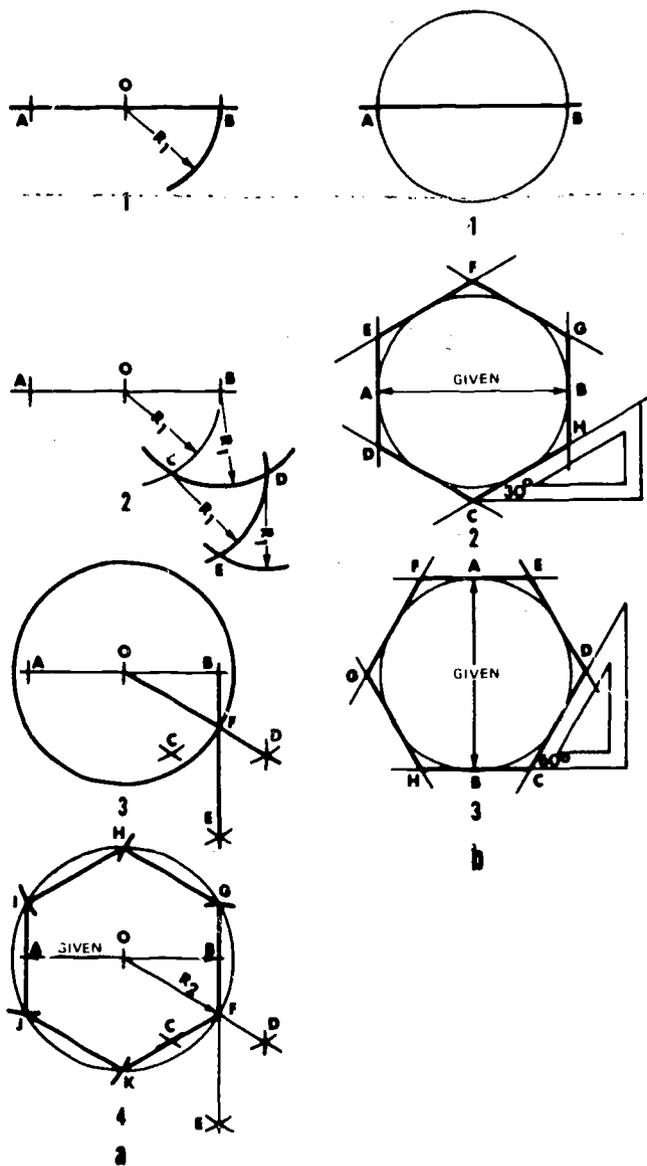


Figure 6-44. Drawing a hexagon given the distance across the flats.

strike arc of at least 60° from point B in a clockwise direction. With point B as center and with the same radius, strike arc intersecting the first arc at point C and extending at least 60° in a counterclockwise direction. With point C as a center and the same radius, strike an arc intersecting the second arc at point D and extending at least 60° in a clockwise direction. With point D as a center and the same radius strike an arc intersecting the third arc at point E . Draw lines BE and OD intersecting at point F . With point O as a center and $OF = R_2$ as the radius, draw a complete circle. Starting at point F and the radius R_2 , step off points G, H, I, J , and K . Connect points F, G, H, I, J , and K to complete the hexagon.

b. With Compass, T-Square, and Triangle. The distance across flats is the diameter of the in-

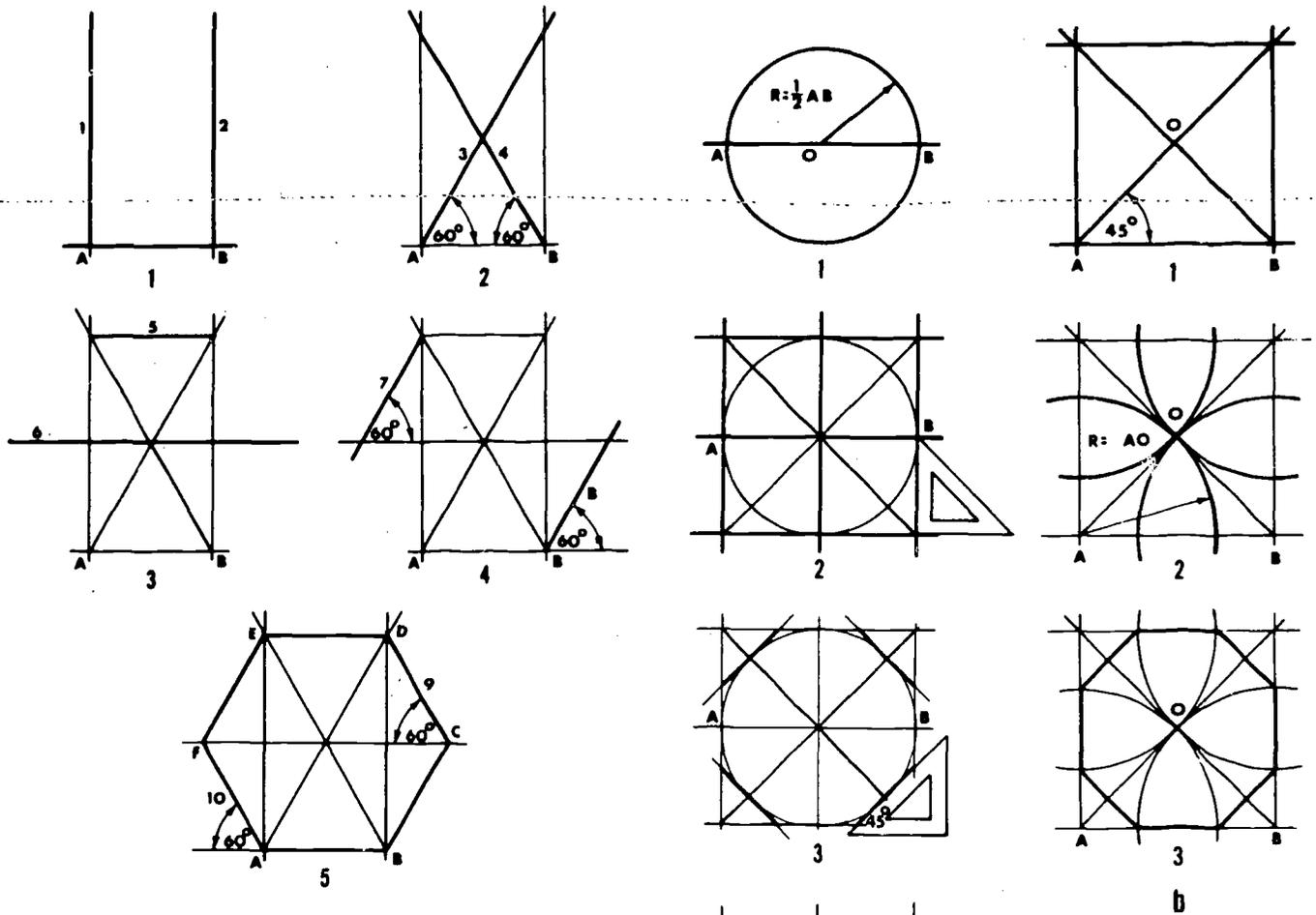


Figure 6-45. Drawing a hexagon given one side.

scribed circle. Draw the circle and using the 30° to 60° triangle draw the tangents to the circle as shown (b, Fig. 6-44).

6-45. Drawing a Hexagon Given One Side

Draw given side AB (fig. 6-45), and then draw construction lines 1 thru 6 as shown. Complete the hexagon by darkening lines 5, 7, 8, 9, 10 and given line.

6-46. Drawing an Octagon Given the Distance Across the Flats

a. Inscribed Circle Method. Draw a circle with radius equal to $\frac{1}{2} AB$ (given distance). Using the T-square and a 45° triangle, draw the eight sides tangent to the circle as shown in a, figure 6-46.

b. Circumscribed Square Method. Construct a square using the given distance as a base and draw the diagonals of the square (b, fig. 6-46). Then using a radius equal to half the diagonal distance and the corners of the square as centers, draw arcs cutting the sides. Complete the octagon as shown.

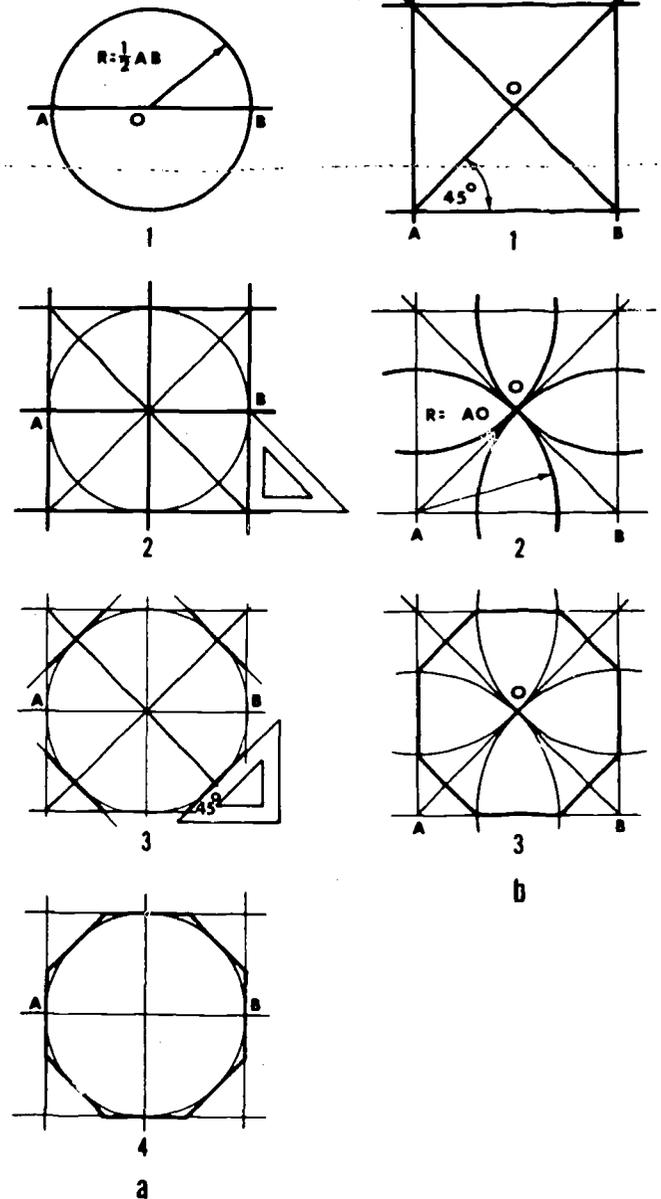


Figure 6-46. Drawing an octagon given the distance across the flats.

6-47. Drawing an Octagon Given One Side

Draw given side AB (fig. 6-47). At points A and B , draw lines outward with a 45° triangle as shown. Strike two arcs with centers at A and B using a radius equal to the distance of the given side. Draw vertical lines upward at points C and D . Mark off the given distance along verticals to locate points E and F . Draw lines inward with a 45° triangle as shown from points E and F . Mark off given distance to locate points G and H . Complete by drawing in line GH .

6-48. Drawing any Regular Polygon Given One Side

a. Draw given side AB (fig. 6-48).

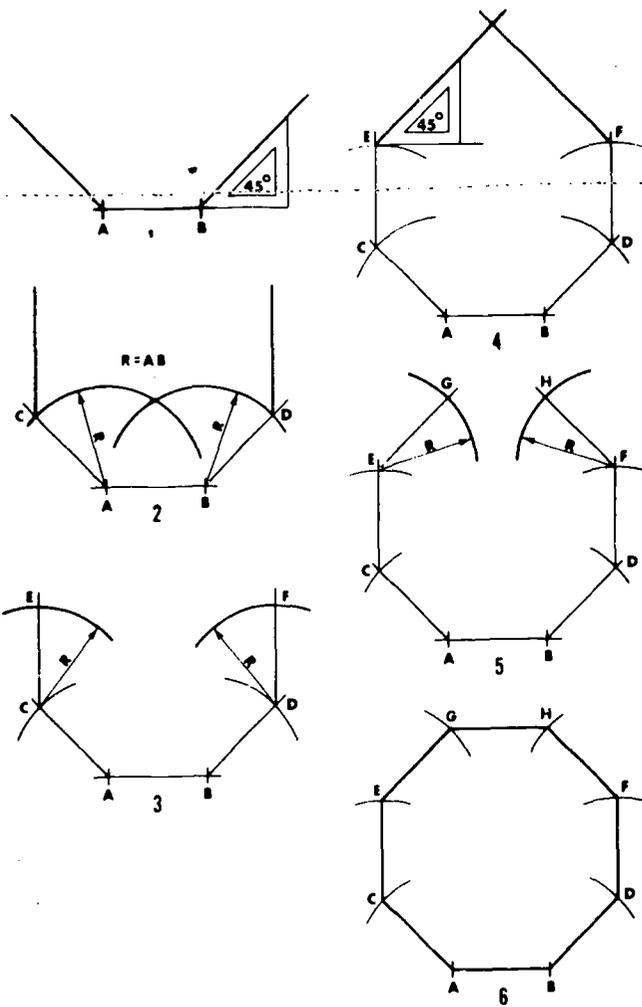


Figure 6-47. Drawing an octagon given one side.

b. With A as center and AB as the radius, draw a semicircle as shown.

c. Divide this semicircle (180°) equally into the number of required sides. For a heptagon, divide into 7 equal parts and draw radial lines from point A as shown. Darken radial line $A-2$. With AB as radius and B as center, cut line $A-6$ at C . With C as center and the same radius, cut $A-5$ at D and so on at E and F .

6-49. Drawing a Regular Polygon Given an Inscribing Circle

a. Draw the circle and divide (fig. 6-49) its diameter into the specified number of equal parts (para 6-16 or 6-17).

b. With ends of the diameter A and B as centers and a radius equal to the diameter AB , draw two arcs intersecting at C .

c. From point C draw a line thru the second division point of the diameter until it crosses the circle at point D .

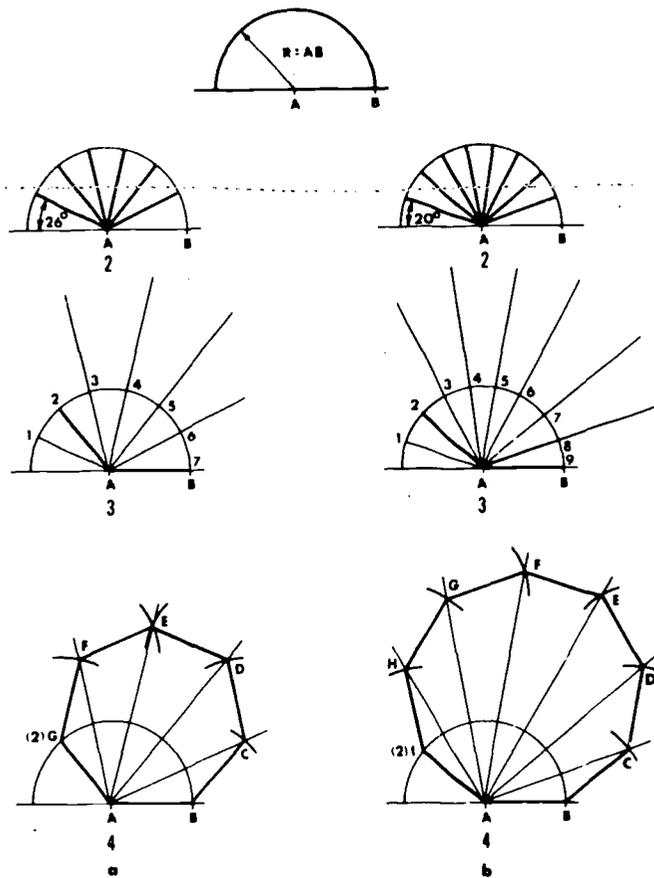


Figure 6-48. Drawing any regular polygon given one side.

d. The chord AD is one side of the polygon. Step off the distance AD around the circle to complete the polygon.

6-50. The Use of the Diagonal

The diagonal can be used in many ways to save drafting time and simplify construction. For example:

a. it can be used to enlarge or reduce geometric shapes (1, fig. 6-50).

b. for drawing inscribed or circumscribed figures (2, fig. 6-50).

c. for locating the center of a rectangle (3, fig. 6-50).

6-51. Transferring a Plane Figure by Geometric Methods

a. *Triangulation.* To transfer a triangle, draw side AB in the new location (a, fig. 6-51). With the ends of the line as centers and the lengths of the other sides of the given triangle as radii, strike two arcs to intersect at C . Join C to A and B and complete the triangle. To transfer other

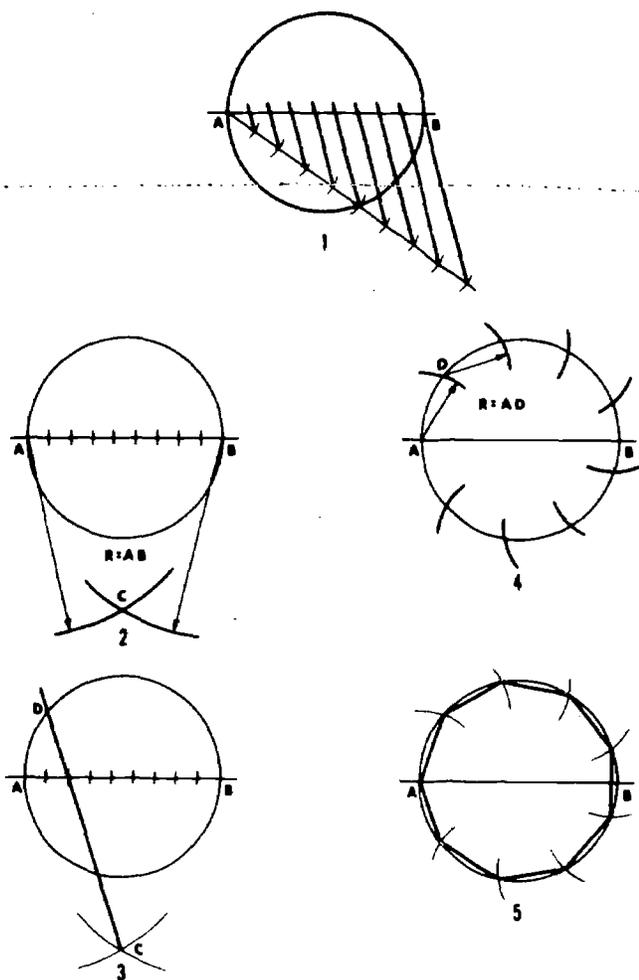


Figure 6-49. Drawing a regular polygon given an inscribing circle.

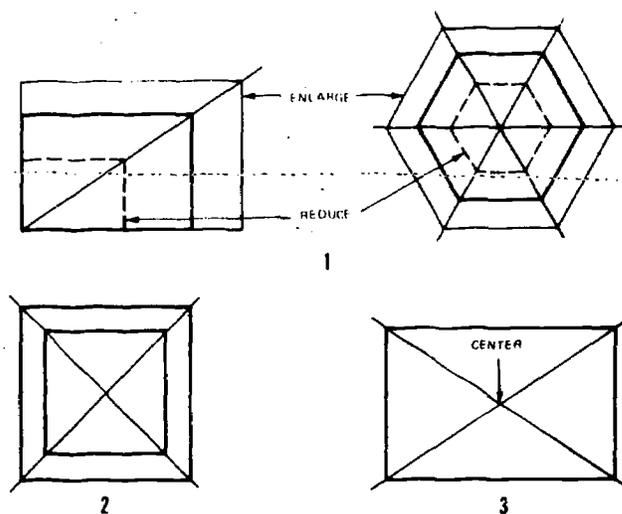


Figure 6-50. The use of the diagonal.

polygons, divide them into triangles (b, fig. 6-51) and transfer each triangle individually.

b. *Rectangle Method.* Circumscribe a rectangle about the given figure (c, fig. 6-51). Draw a congruent rectangle in the new location and locate the vertexes of the given figure along the sides of the new rectangle as shown.

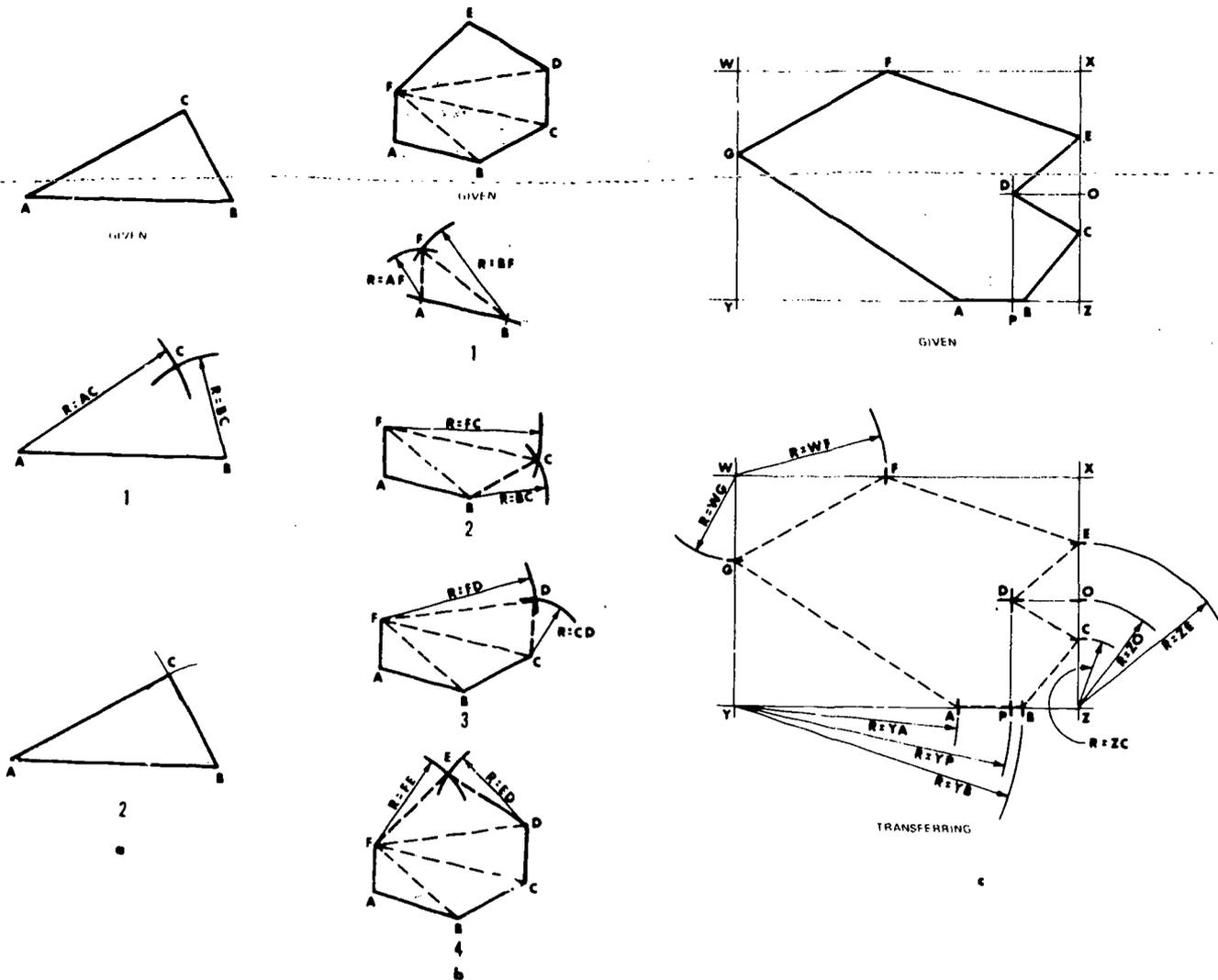


Figure 6-51. Transferring a plane figure by geometric methods.

Section III. CURVE LINE CONSTRUCTION

6-52. Bisecting an Arc

With points A and B as center and radius of any convenient length, strike arcs intersecting at points C and D (fig. 6-52). Draw a line connecting points C and D , locating point O , which is the midpoint of arc AB .

6-53. Locating Arc Centers

Select three points (A , B , and C on the arc or chord (fig. 6-53). Bisect arcs AB and BC ; their perpendicular bisectors will intersect at the arc centers (O).

6-54. Approximating the Length of an Arc

Given the arc AB (fig. 6-54). At A draw a tangent AD and a chord AB . Lay off AC equal to half the chord AB as shown. With center C and radius

CB , draw an arc intersecting AD at E . AE will very nearly be the length of the arc AB .

6-55. Laying Off an Arc the Approximate Length of a Given Straight Line

Given a line AB tangent to the arc at A (fig. 6-55). Lay off along AB the distance AC equal to $\frac{1}{4} AB$. With C as center and a radius CB , draw an arc intersecting the arc at D . The arc AD is very nearly equal to the length of AB .

6-56. Drawing an Arc Tangent

a. Given line AB , point P and radius R (a, fig. 6-56). Draw line DE parallel to the given line at a distance R . At P draw arc with radius R , intersecting line DE at C , the center of the required tangent arc.

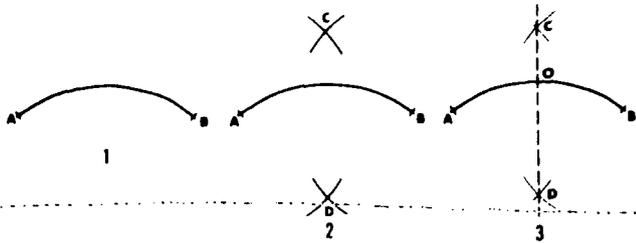


Figure 6-52. Bisecting an arc.

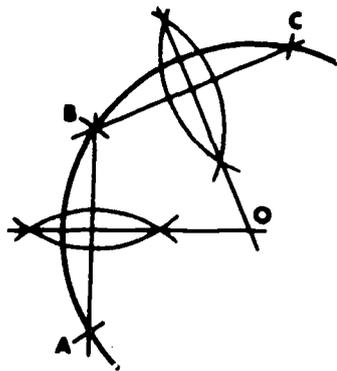


Figure 6-53. Locating arc centers.

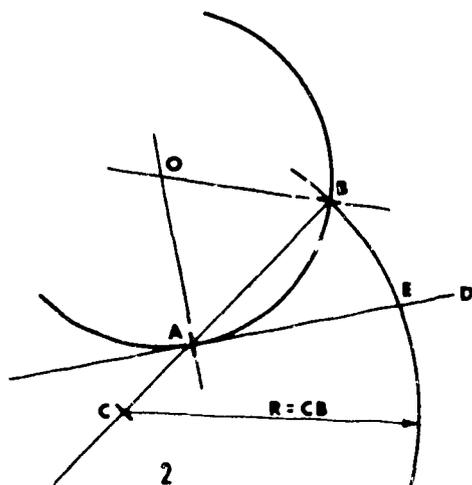
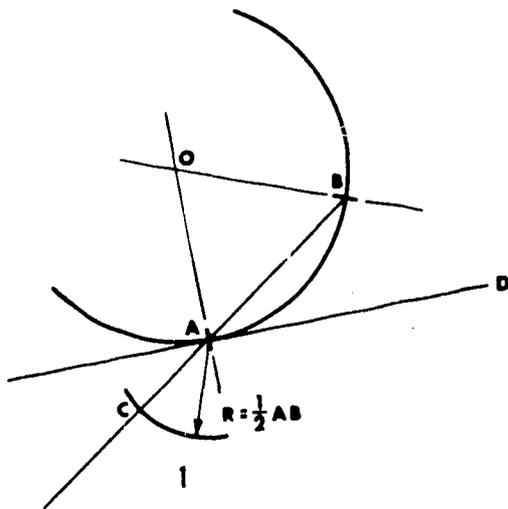


Figure 6-54. Approximating the length of an arc.

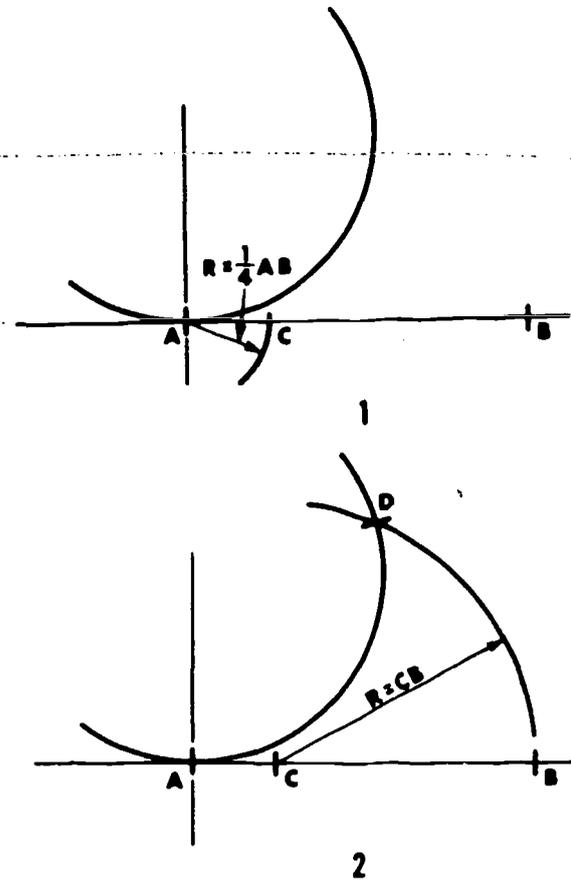


Figure 6-55. Laying off an arc the approximate length of a given straight line.

b. Given line AB , point P , and a tangent point Q on the given line; (b, fig. 6-56). Draw PQ which is a chord of the required arc and construct a perpendicular bisector DE . At Q erect a perpendicular to the given line to intersect line DE at C , the center of the required tangent arc.

c. Given arc with center O , point P , and radius R (c, fig. 6-56). From P strike arc with radius R . From O strike arc with radius equal to that of the given arc plus R . The intersection of the arcs, C , is the center of the required tangent arc.

6-57. Drawing a Tangent Arc to Perpendicular Lines

With given radius R , strike arc intersecting given lines at tangent points T (fig. 6-57). With given radius R and with points T as centers, strike arcs intersecting at C . With C as center and given radius R , draw required tangent arc.

6-58. Drawing Fillets and Rounds

For small radii such as $\frac{1}{8}$ inch R for fillets and rounds, it is not practicable to draw complete tan-

gency constructions. Instead draw a 45° bisector of the right angle (fig. 6-58) and locate the center of the arc by trial along this line as shown.

6-59. Drawing a Tangent Arc to Two Lines That are at Acute or Obtuse Angles

Draw lines parallel to the given lines at distance R , intersecting at C , the required center (a and b, fig. 6-59). From C drop perpendiculars to the given lines to locate points of tangency T . With C as center and with given radius R , draw required tangent arc between the points of tangency.

6-60. Drawing a Tangent Arc to an Arc and a Straight Line

a. Given an arc with radius R_1 , straight line AB , and radius R_2 (a and b, fig. 6-60).

b. Draw a straight line and an arc parallel respectively to the given straight line and the arc at the radius R_2 , to intersect at C , the required center.

c. From C drop perpendicular to given straight line to obtain one point of tangency. Join centers C and O with a straight line to locate the other point of tangency. With C as center and radius R_2 draw the arc.

6-61. Drawing an Arc of Given Radius, Tangent to Two Arcs

a. Given the radius R , of the arc tangent, and R_1 and R_2 the radii of the given arcs (a, fig. 6-61). With point O as a center and a radius equal to R plus R_2 , draw an arc. With point S as a center and a radius equal to R plus R_1 , draw an arc intersecting the first arc at point C . Join centers S and C , O and C , to locate points of tangency (T_1 and T_2). With point C as the center and the given radius R , construct the required arc tangent to the given arcs from point of tangency (T_1) to point of tangency (T_2).

b. Given the radius R of the arc tangent, and R_1 and R_2 the radii of the given arcs (b, fig. 6-61). With A and B as centers, strike arcs $R - R_1$ (the

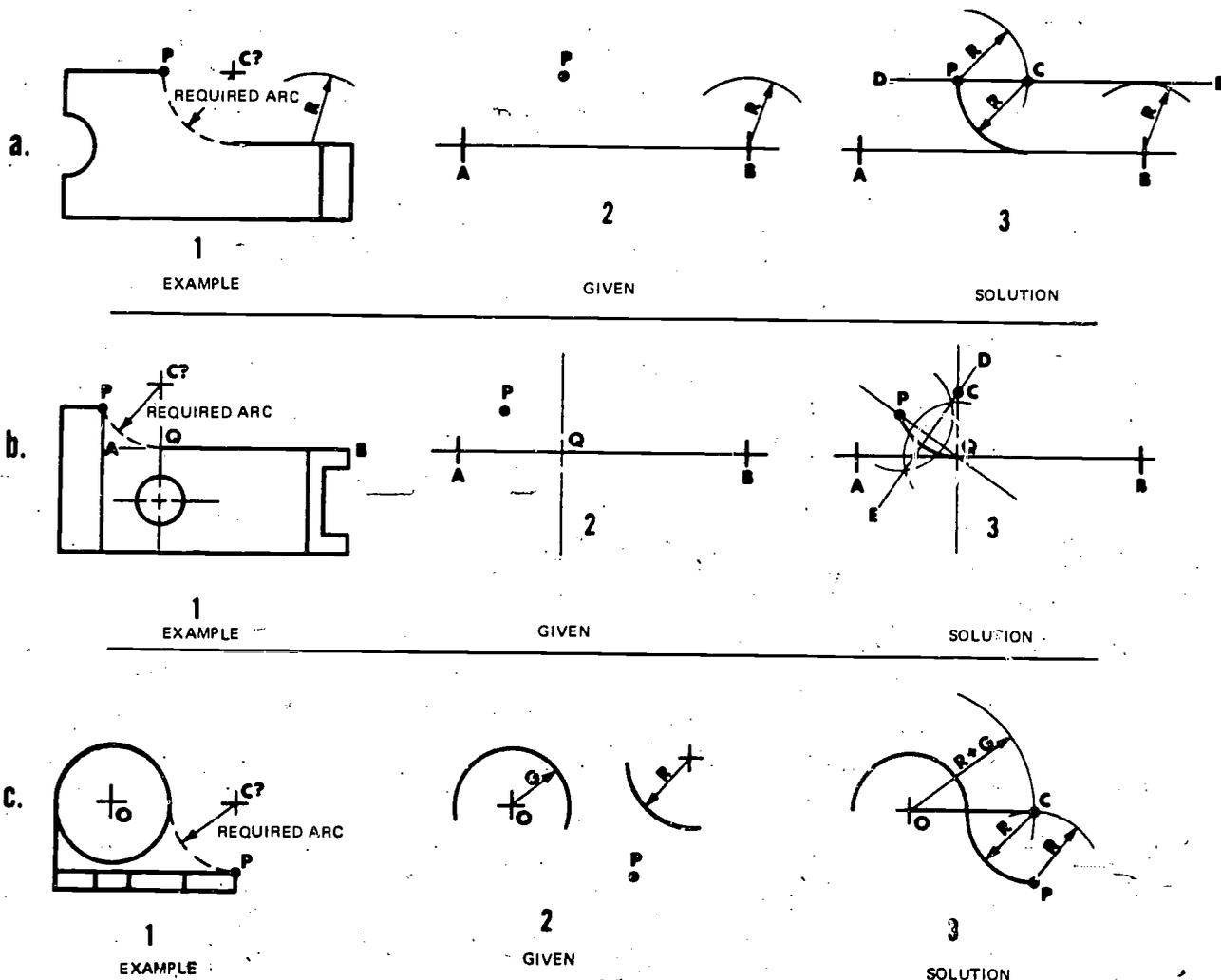


Figure 6-56. Drawing an arc tangent.

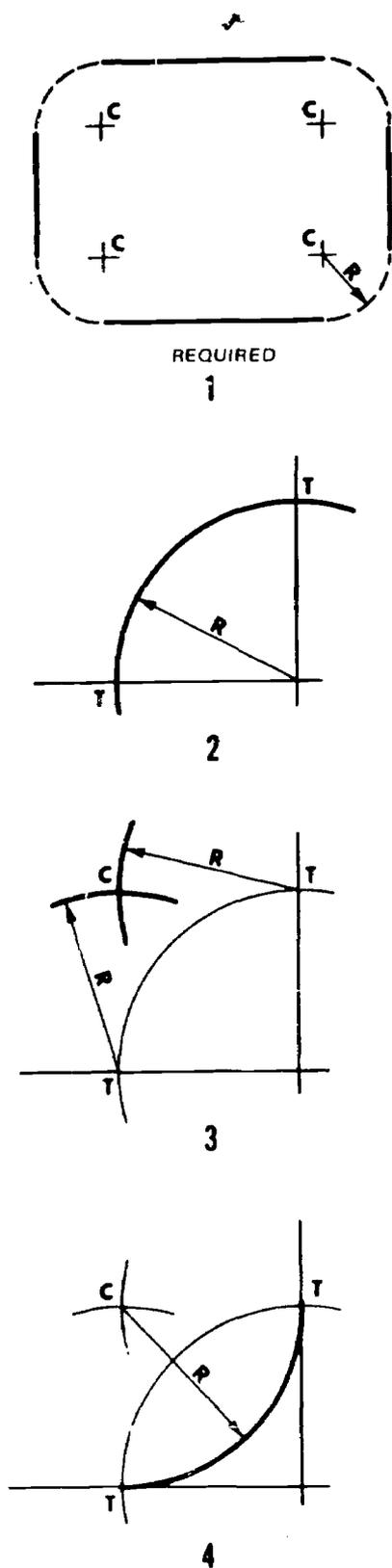


Figure 6-57. Drawing an arc, tangent to perpendicular lines.

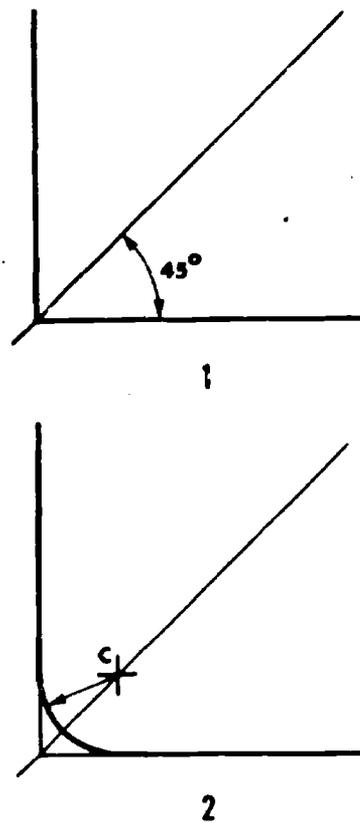


Figure 6-58. Drawing fillets and rounds.

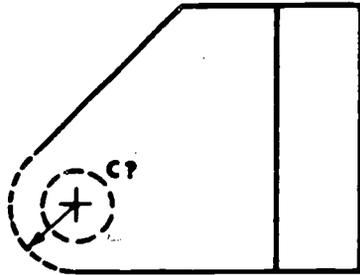
given radius minus of small arc) and $R - R_2$ (given radius minus radius of large arc) intersecting at C , the center of the required tangent arc. Lines between centers CA and CB extended determine points of tangency, T . Draw required arc tangent from point of tangency (T_1) to point of tangency (T_2).

6-62. Drawing an Arc, Tangent to Two Arcs and Enclosing One

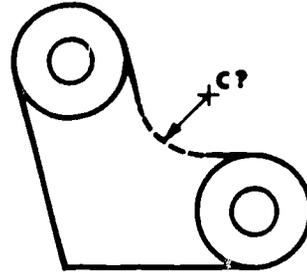
Given points P and Q , and radii R_1 , R_2 and R_3 (fig. 6-62). With point P and Q as centers, strike arcs $R_3 - R_2$ (given radius minus radius of small arc) and $R_3 + R_1$ (given radius plus radius of large arc) intersecting at C , the center of the required tangent arc. Lines between centers CP and CQ (extended) determine points of tangency, T .

6-63. Drawing a Reverse Curve Between Two Lines

Let parallel lines AB and DC represent the given lines (fig. 6-63). Draw line AC intersecting the given lines at points A and C . Bisect the line AC locating point E . Erect perpendiculars from the given lines at points A and C . Bisect lines AE and EC , intersecting the perpendiculars at points F



EXAMPLE



EXAMPLE

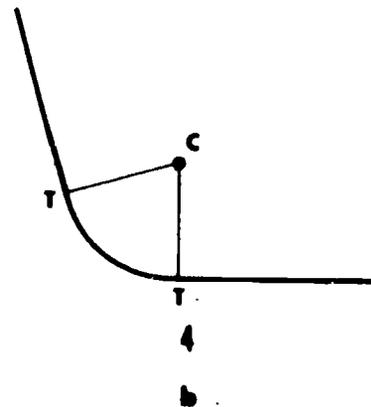
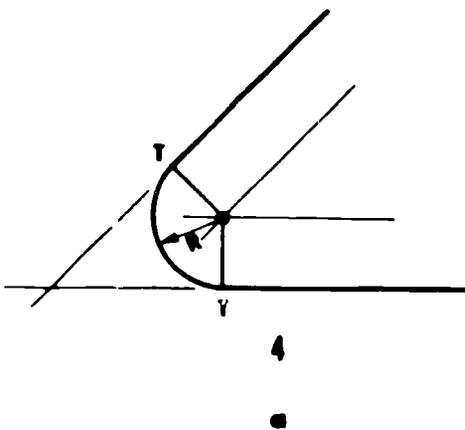
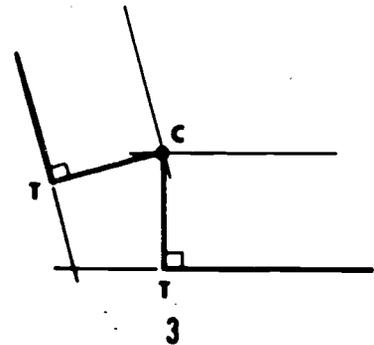
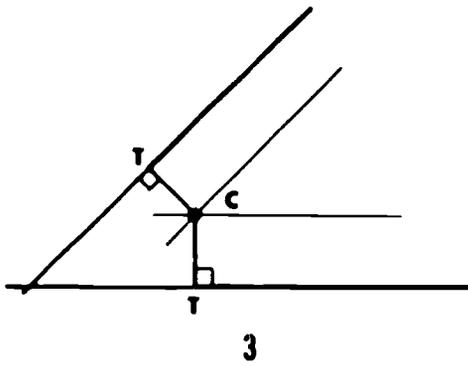
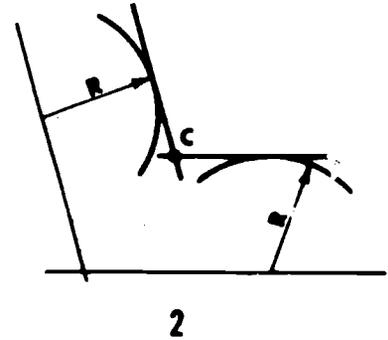
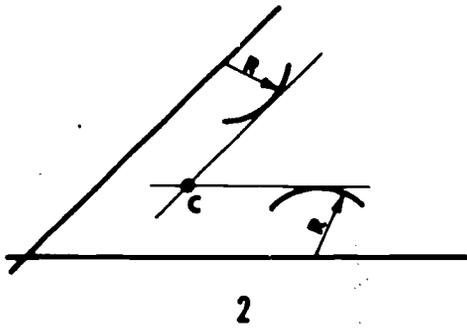
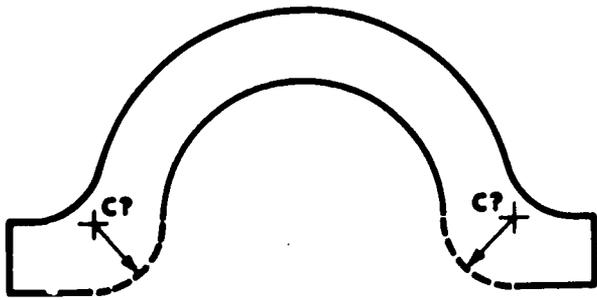
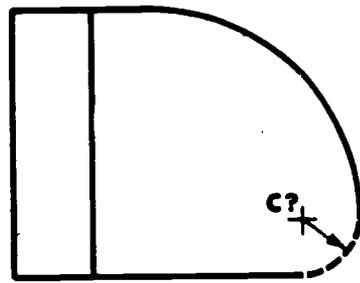


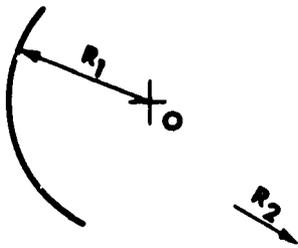
Figure 6-59. Drawing an arc, tangent to two lines that are at acute or obtuse angles.



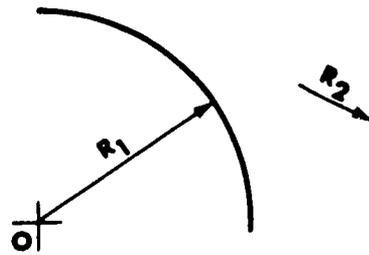
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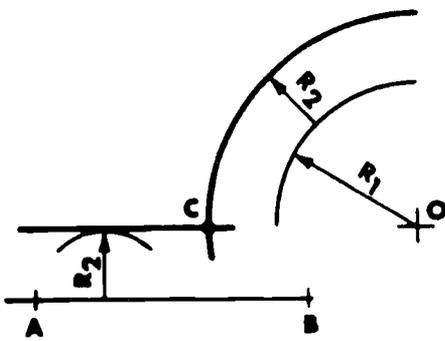
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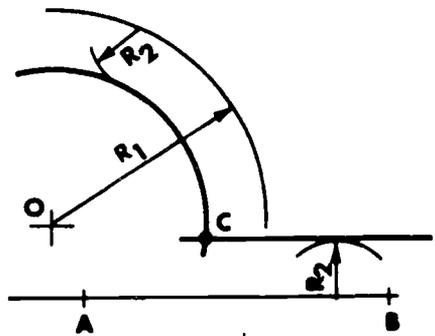
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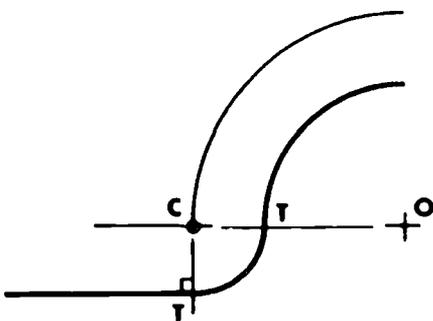
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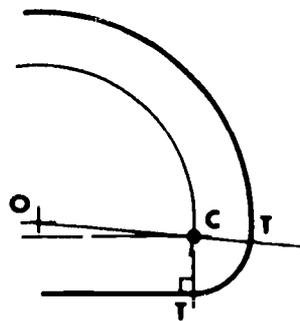


3



4

a



4

b

Figure 6-60. Drawing an arc, tangent to a circle, and a straight line.

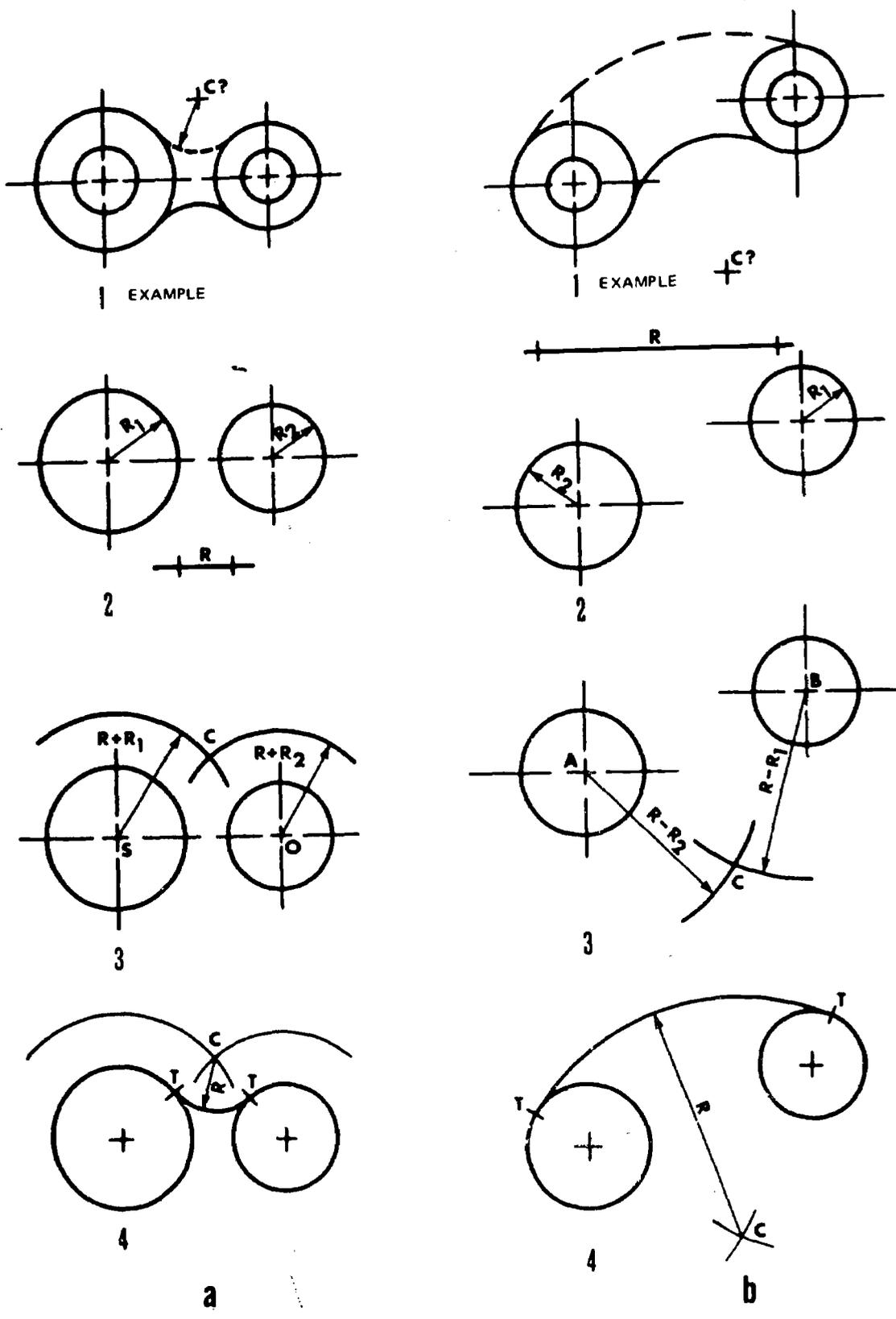
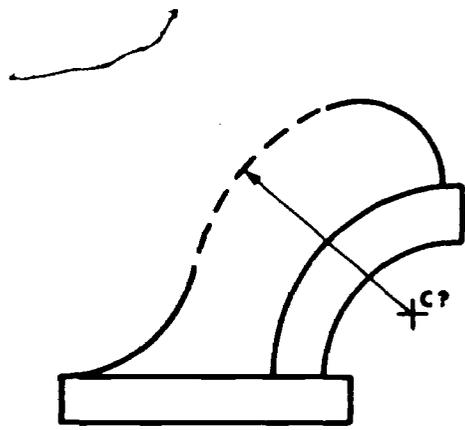
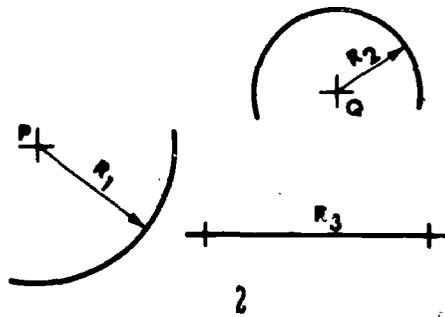


Figure 6-61. Drawing an arc of given radius, tangent to two arcs.

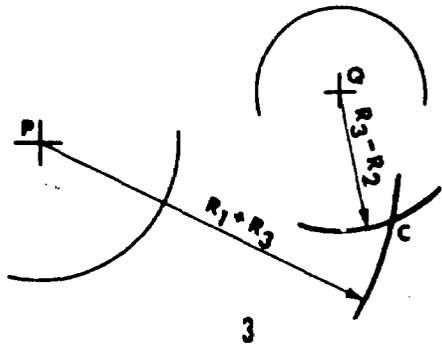


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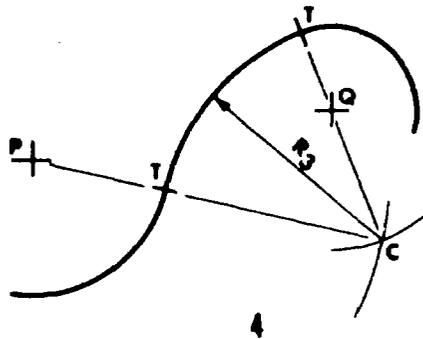
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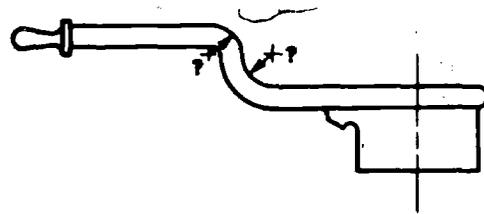
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Figure 6-22. Drawing an arc, tangent to two arcs and enclosing one.

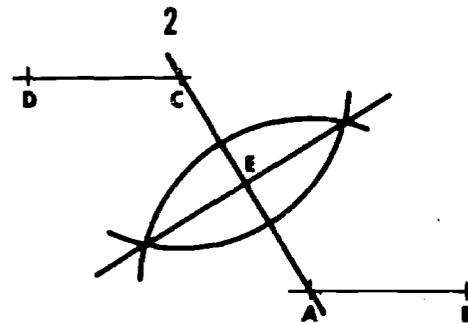
and G. With points F and G as centers and a radius of FE or GE, construct the required reverse arcs.

6-64. Drawing a Curve, Tangent to Three Intersecting Lines

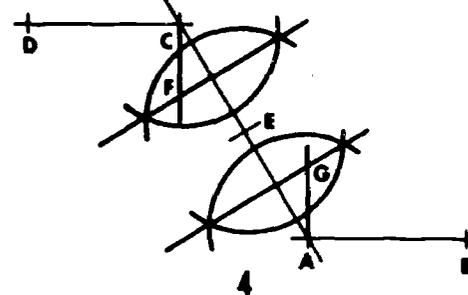
Let AB, BC, and CD be the given lines (fig. 6-64).



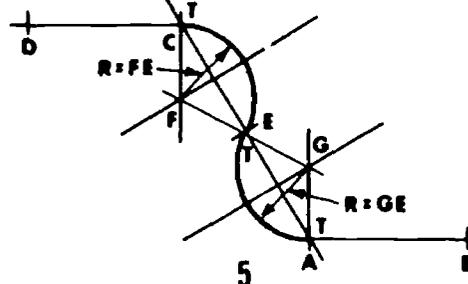
1 EXAMPLE



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4

Figure 6-63. Drawing a reverse curve between two lines.

Select point of tangency, T, at any point on line BC. Make BP equal to BT, and CS equal to CT and erect perpendiculars at points P, T, and S. Their intersections O₁ and O₂ are the centers of the required tangent arcs.

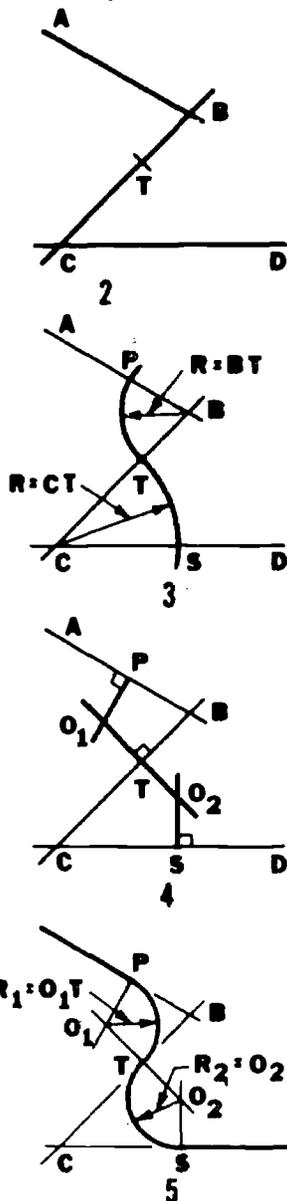
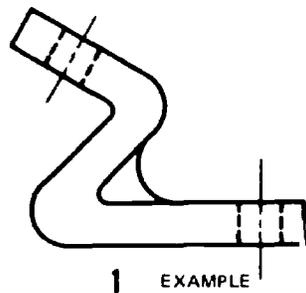


Figure 6-64. Drawing a curve, tangent to three intersecting lines.

6-65. Drawing a Series of Tangent Arcs Conforming to a Curve

Sketch lightly the approximate smooth curve required. By trial, find a radius, R , and a center, C , produce an arc AB which closely follows that por-

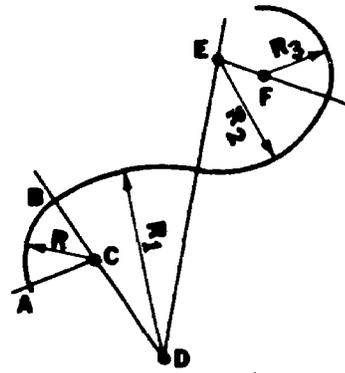


Figure 6-65. Drawing a series of tangent arcs conforming to a curve.

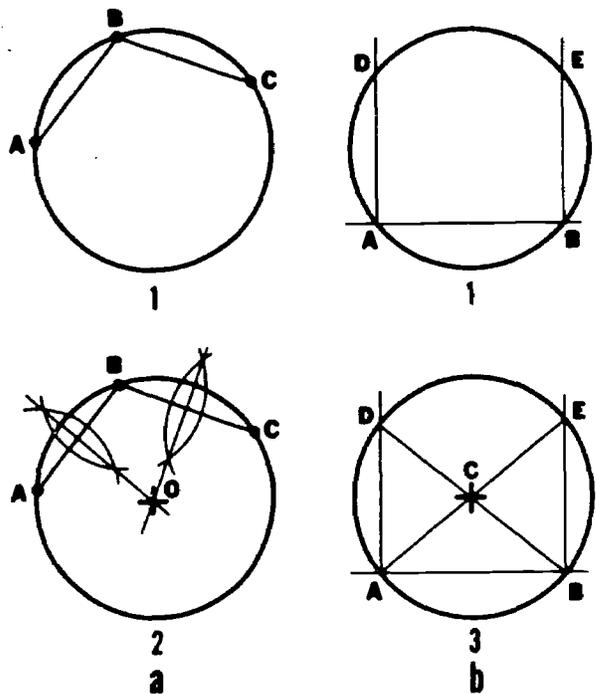


Figure 6-66. Finding the center of a circle.

tion of the sketched curve. The successive centers D , E , and F , will be on the lines joining the centers and the points of tangency as shown in figure 6-65.

6-66. Finding the Center of a Circle

a. *With Compass.* Draw any two chords AB and BC (a, fig. 6-66). Bisect these chords. The point of intersection of these bisectors will locate the center of the circle.

b. *With T-Square and Triangle.* Draw any chord AB horizontally (b, fig. 6-66). Draw perpendiculars at points A and B , cutting the circle at points D and E . Draw diagonals DB and EA . The intersection of these diagonals will be the center of the circle.

6-67. Drawing a Circle Through Three Points

Draw lines AB and BC connecting the three given points (fig. 6-67). Construct the perpendicular bisectors of these lines locating point of intersection, *O*. Using *O* as center and the distance *OA* as radius, draw the required circle through the three given points.

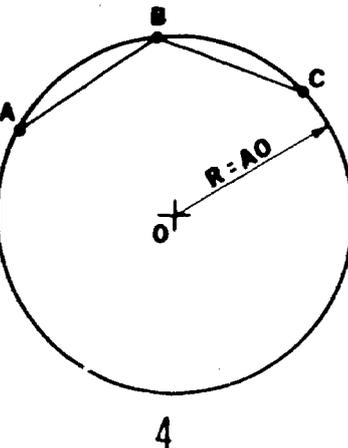
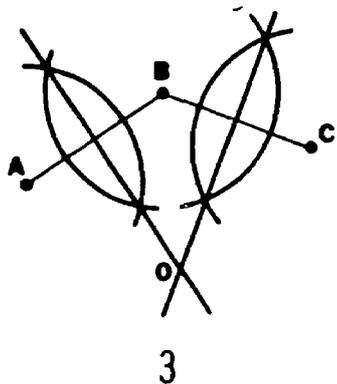
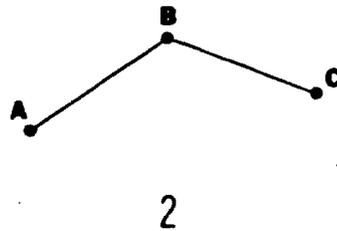
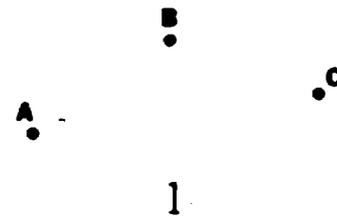


Figure 6-67. Drawing a circle through three points.

6-68. Drawing a Tangent to a Circle at a Given Point

Given point *P* on the circumference of a circle with *R* as the radius (fig. 6-68). With *P* as the center and the radius *R* strike an arc about 90° intersecting the circumference at point *A*. With point *A* as the center and the same radius, strike an arc of about 90° intersecting first arc at point *B*. With point *B* as the center and the same radius, strike an arc intersecting the second arc at point *C*. Connect points *P* and *C* forming the required tangent.

6-69. Drawing Two Tangents to a Circle From a Given Point

Given a circle and a point *P* outside the circle (fig. 6-69). Draw line *OP* and bisect it, locating point *C*. With point *C* as the center and *OC* as the radius, draw arcs intersecting the circle at points *T* and *T'*. To the points of intersection thus formed, draw the required tangents from point *P*.

6-70. Drawing Tangents to Two Circles

a. Belt Around Two Pulleys Type 1—T-Square and Triangle. Move the triangle and T-square as a unit until one side of the triangle is tangent, by inspection, to the two circles (a, fig. 6-70); then slide the triangle until the other side passes through the center of the other circle, and mark the point of tangency. Finally slide the triangle back to the tangent position, and draw the tangent lines between the two points of tangency. Draw the second tangent line in a similar manner.

b. Cross Belt Around Two Pulleys Type 2—With Compass and Straightedge. Draw a line through center of circles *O* and *S* (b, fig. 6-70). Erect perpendiculars *OA* and *SB* at centers of circles. Draw line *AB* intersecting line *OS* at point *P*. Bisect lines *OP* and *PS*, providing points *C*₁ and *C*₂. With point *C*₁ as the center and using *OC*₁ as a radius, draw arcs intersecting the circumference of the circle at points 1 and 2. With point *C*₂ as the center and using *C*₂*S* as a radius, draw arcs intersecting the circumference of the second circle at points 3 and 4. Connect the intersections points 1, 2, 3, and 4 as shown to form the required tangents (cross belt).

6-71. Constructing a True Ellipse

a. Pin and String Method. This method is mentioned first as it closely follows the description of an ellipse. However, this method is not accurate enough for general drafting. Given the major and minor axes (a, fig. 6-71), locate foci points *F*₁ and *F*₂ (c below). Drive pins at points *D*, *F*₁ and *F*₂, and tie an unelastic thread or cord tightly around the three pins. Remove pin *D*, and move a

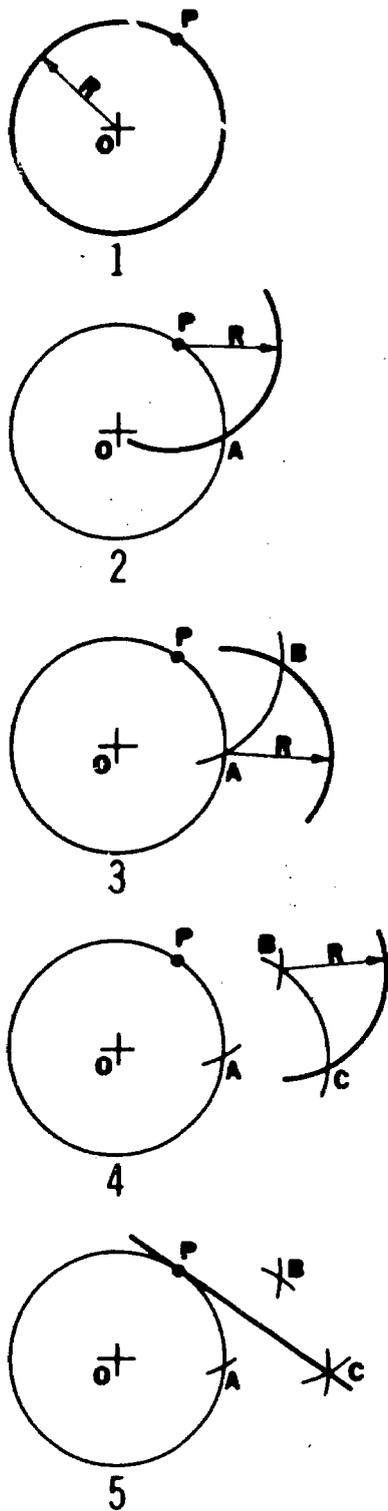


Figure 6-68. Drawing a tangent to a circle at a given point.

marking point in the loop, keeping the cord taut. This will describe a true ellipse, "a point moving so that the sum of its distances from two points (foci) is constant and equal to the major axis."

b. *Trammel Method.* Prepare a long trammel and short trammel from a small strip of stiff paper or cardboard (b, fig. 6-71). Set off on the edge

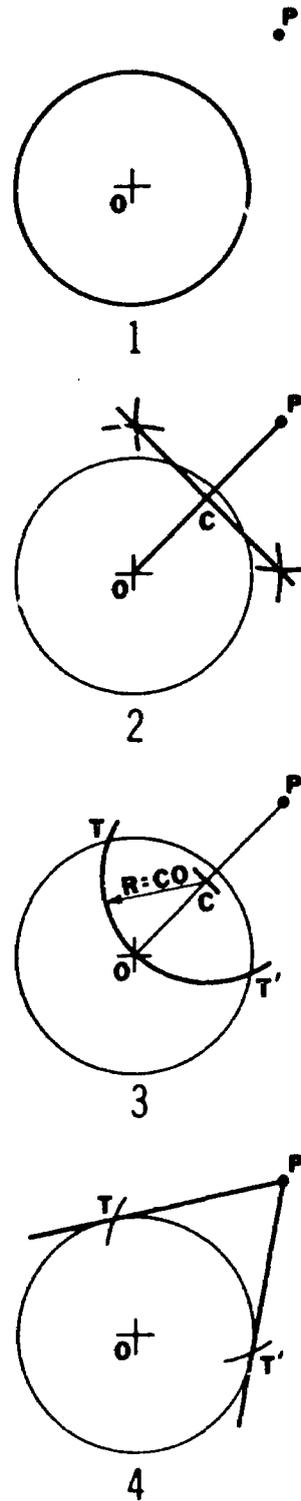


Figure 6-69. Drawing two tangents to a circle from a given point.

of the trammel distances equal to the semimajor and semiminor axes. The long trammel has them end to end; while the short trammel has them overlapped. In either case, place the trammel so that two of the points (one from each axis) are on the respective axes, as shown; the third point will then be on the curve and can be marked with a small dot. Find additional points by moving the

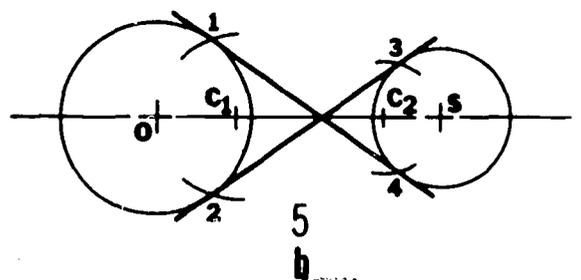
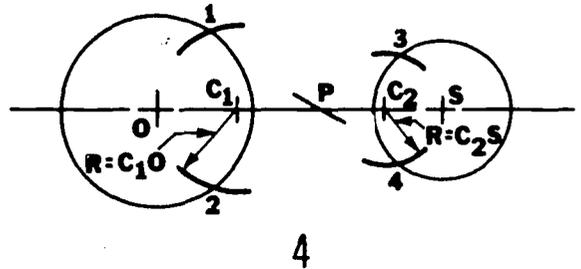
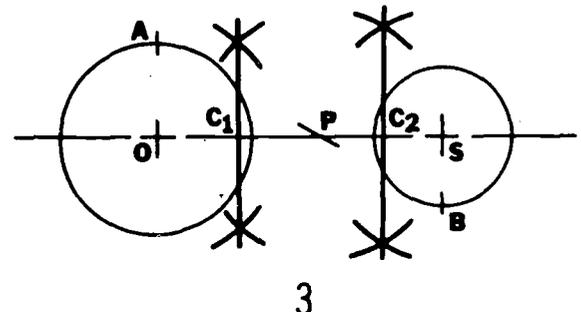
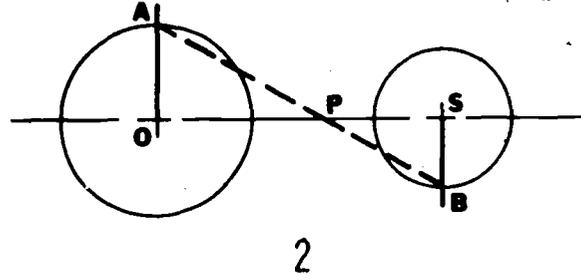
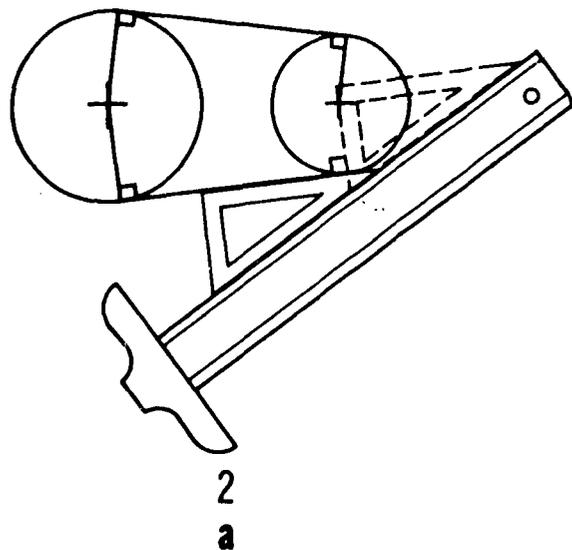
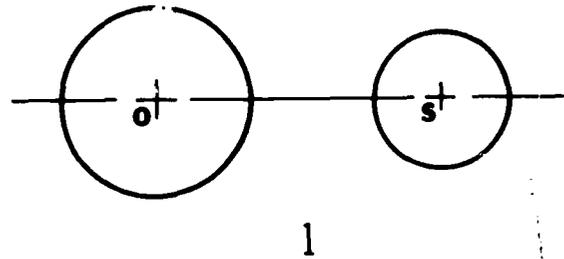
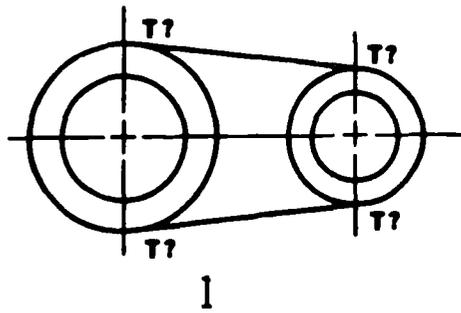
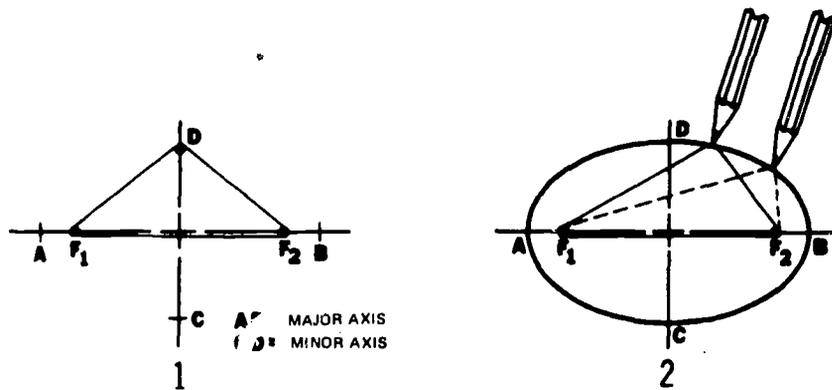


Figure 6-70. Drawing two tangents to two circles.

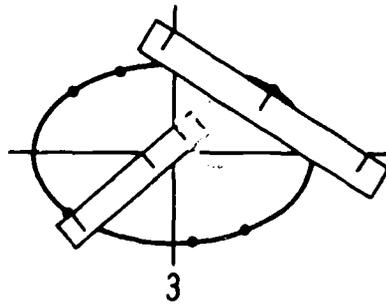
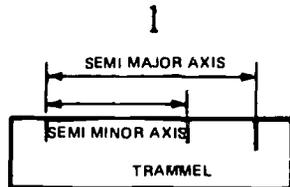
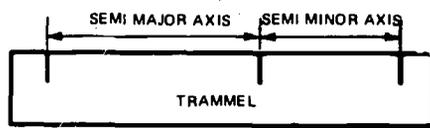
trammel to other positions, always keeping the two points exactly on the respective axes. Extend the axes to use the long trammel. Find enough points to insure a smooth and symmetrical ellipse.

c. Geometrical Method. Draw the major (M_1M_2) and minor (m_1m_2) axes (c, fig. 6-71). To find foci F_1 and F_2 , strike arcs with a radius equal to half

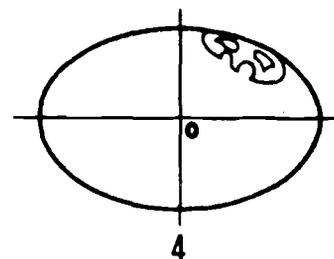
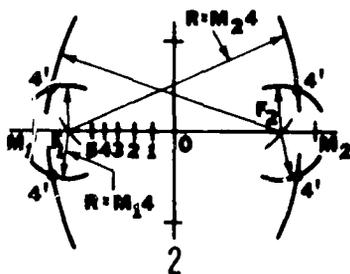
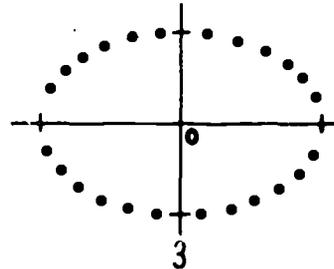
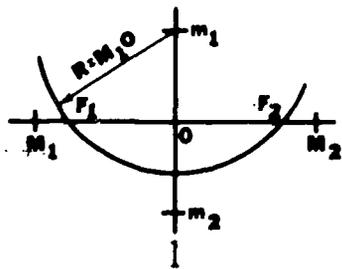
the major axis (M_1O or M_2O) and with the centers at the ends of the minor axis, intersecting on the major axis at points F_1 and F_2 . Between F_1 and O on the major axis, mark at random a number of points, spacing those nearer to the circumference closer together, equal to the number of points desired in each quadrant of the ellipse.



a



b



c

Figure 6-71. Constructing a true ellipse.

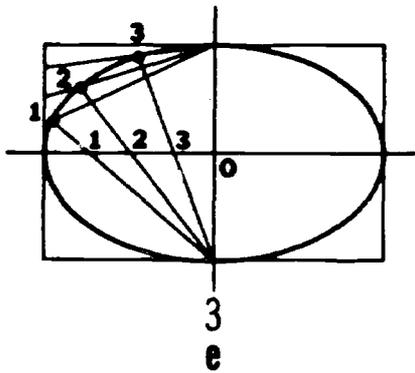
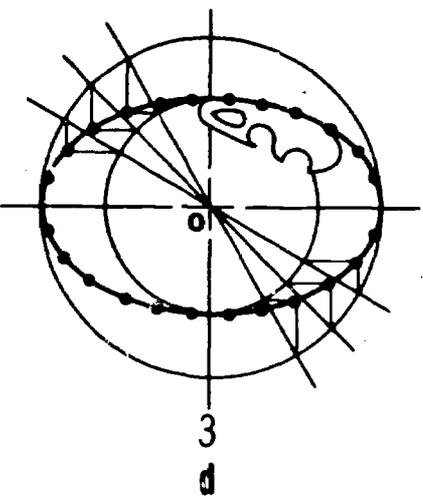
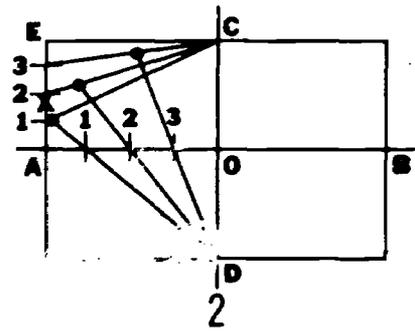
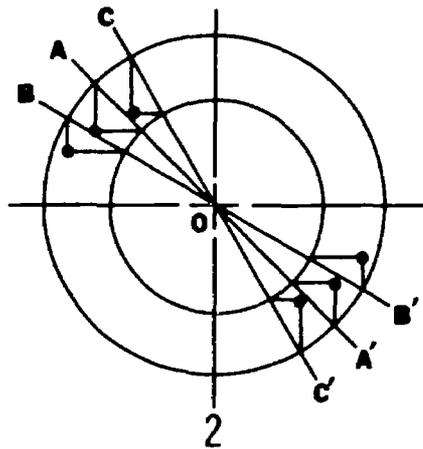
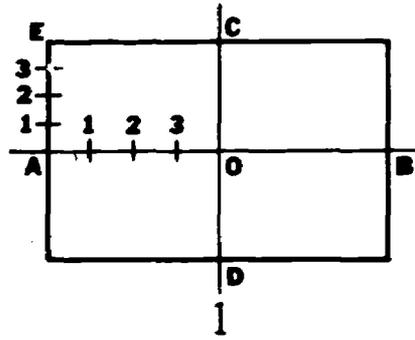
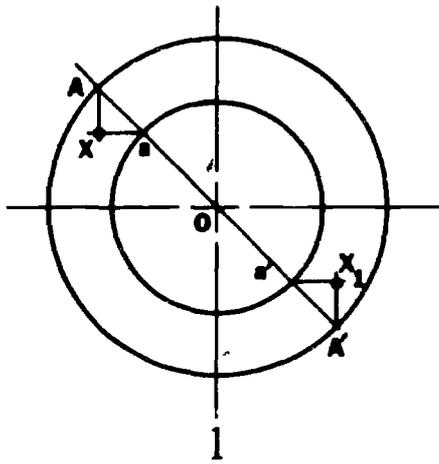
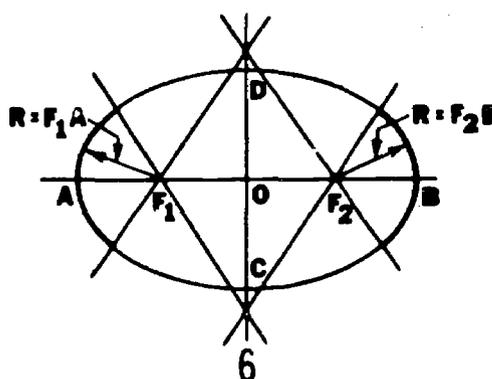
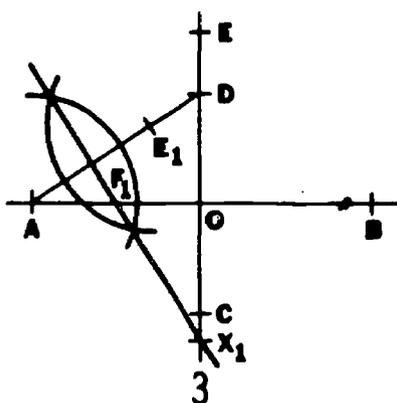
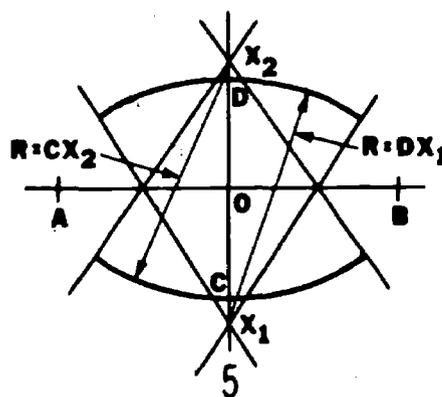
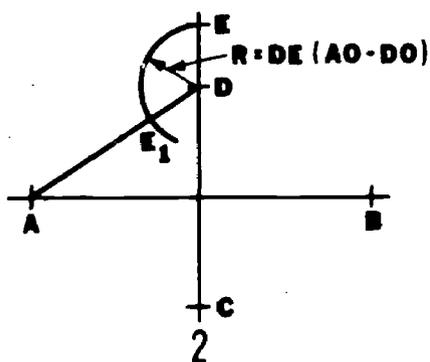
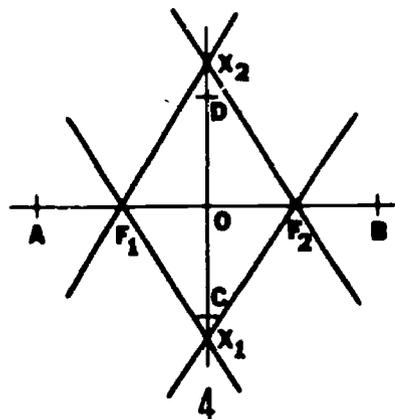
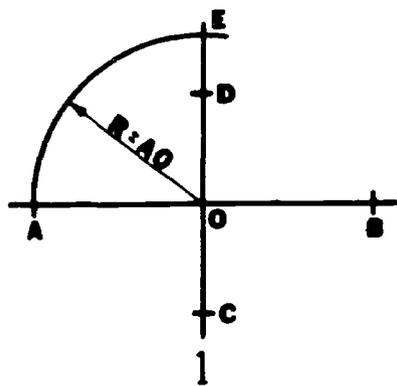


Figure 6-71—Continued.

Begin construction with any one of these points, such as 4. With F_1 and F_2 as the centers and the radii $4-M_1$ and $4-M_2$, respectively, strike four points $4'$, as shown. Repeat with other remaining points. Sketch the ellipse lightly through points; then heavy-in the final ellipse with the aid of the angular curve.

d. Concyclic-Circle Method. Draw two circles with the major and minor axes as diameters (d, fig. 6-71), then draw any diagonal, AA' , through center O . From points A and A' on the large circle, draw lines AX and $A'X_1$ parallel to the minor axis. From points a and a' on the small circle, draw lines aX and $a'X_1$ parallel to the major axis.



2

Figure 6-72. Constructing an approximate ellipse.

The intersections X and X_1 are points on the ellipse. Draw as many additional diagonals as needed and complete as above.

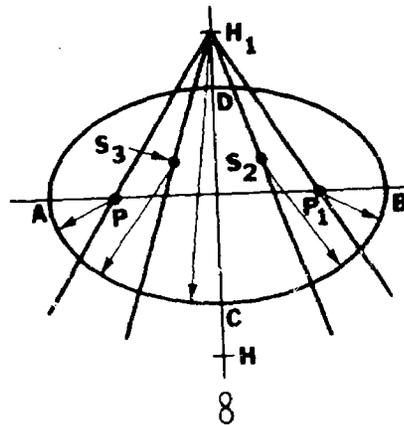
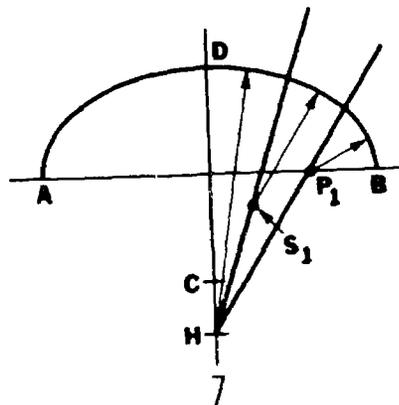
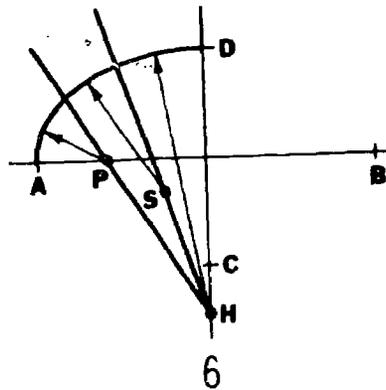
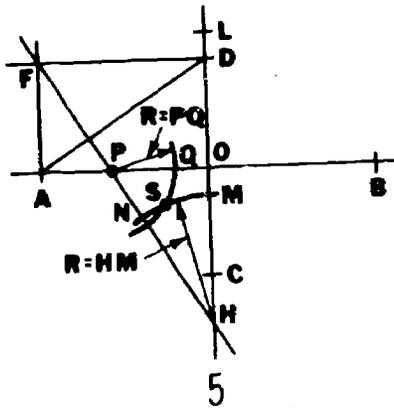
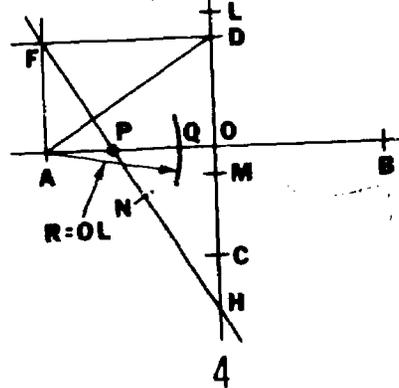
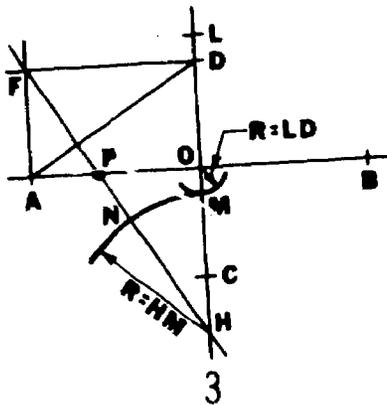
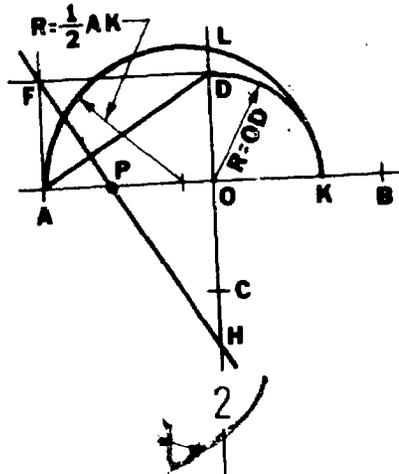
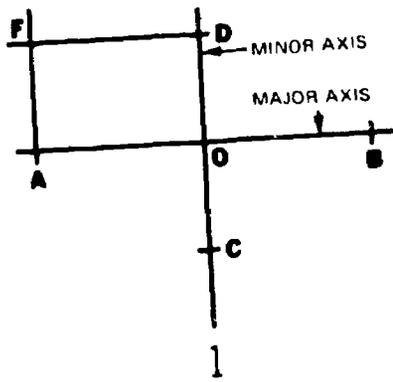
e. Rectangle Method. Draw the major and minor axis and a rectangle with the length and height of the major and minor axis as shown in *e*, figure 6-71. Divide AO and AE into the same number of equal parts, and draw lines through these points as shown. The intersection of like-numbered lines will be points on the ellipse.

Locate points in the remaining three quadrants in the same way, connect points and complete as above.

6-72. Constructing an Approximate Ellipse

a. Four-Center Method. This method works best if the major and the minor axis are nearly equal. Draw the major and minor axis (*a*, fig. 6-72).

(1) Construct arc with radius AO to locate E .



b

Figure 6-72.—Continued.

(2) Draw AD , then find the difference of the major and minor semiaxes, $AO - DO = DE$. Locate E_1 as shown.

(3) Draw a perpendicular bisector AE_1 and extend it to intersect the major and minor axes at F_1 and X_1 .

(4) Transfer points F_1 and X_1 , equidistance from the center on the opposite side of the major and minor axes with a compass and locate points F_2 and X_2 . Connect the four centers ($F_1, F_2, X_1,$ and X_2) as shown to locate points of tangency.

(5) With X_1 as the center and a radius DX_1 , strike an arc as shown.

(6) With F_1 as the center and a radius F_1A strike an arc as shown. Repeat at remaining two centers, X_2 and F_2 .

b. Eight-Center Method. This method is used if a closer approximation is desired. Draw the major and minor axes and rectangle $AFDO$ (b, fig. 6-72). Draw diagonal AD and a line from F perpendicular to AD , intersecting the major axes at P and the extension of the minor axis at H . Lay off OK equal to OD , with a radius equal to $\frac{1}{2}AK$; draw a semicircle intersecting the extension of the minor axis at L . Construct OM equal to LD . With center H and radius HM , draw the arc MN . From A , along AB , lay off AQ equal to OL . With P as center and radius PQ , draw an arc intersecting MN at S ; the $P, S,$ and H are centers for $\frac{1}{4}$ of the eight-center approximate ellipse. Locate points in the remaining three quadrants and complete.

6-73. Drawing a Tangent to an Ellipse

a. At a Given Point on the Curve. Draw lines from the given point P to the foci (a, fig. 6-73). The line bisecting the exterior angle of these focal radii is the required tangent.

b. From a Point Outside. Find the foci F_1 and F_2 (b, fig. 6-73). With given point P as the center and a radius PF_2 , draw the arc SF_2Q . With F_1 as the center and a radius AB , strike an arc cutting the first arc at points Q and S . Connect QF_1 and SF_1 . The intersections of these lines with the ellipse at T_1 and T_2 will be the tangent points to the ellipse from point P .

6-74. Drawing a Parabola

a. Geometrical Method—Given Focus F and Directrix AB . Draw a line DE parallel to the directrix and at any distance CZ from it (a, fig. 6-74). With center at F and radius CZ , strike arcs to intersect the line DE at points Q and R , which are points on the parabola. Add as many points as

necessary by drawing additional lines parallel to line DE as shown. A tangent to the parabola at any point G bisects the angle formed by the focal line FG and the line SG perpendicular to the directrix.

b. Parallelogram Method—Given the Span and Rise. Divide side AB into any even number of equal parts (b, fig. 6-74), and divide each side AD and BC into half as many parts. Draw lines as shown in the figure. The intersection of like-numbered lines are points on the parabola. Draw a smooth curve through the intersections to complete the parabola.

c. Finding the Focus F , Given Points $P, Q,$ and V of a Parabola. Connect points P and Q which intersect the axis at point C . Using VC as radius and V as center, locate A (c, fig. 6-74). Draw tangent AP . Construct the perpendicular bisector of AP , which intersects the axis at F , the focus of the parabola.

6-75. Drawing a Hyperbola

a. Pin and String Method. Given foci F_1 and F_2 and transverse axis AB (a, fig. 6-75). Fasten a string at F_2 and C , its length equal to $F_1C - AB$. Point C is any point, its distance from F_1 depends on the desired extent of the hyperbola. Fasten the straightedge at F_1 . The straightedge revolves about F_1 . Keep the pencil point moving against the straightedge and the string. The string must be kept taut at all times.

b. Geometrical Method. Given foci F_1 and F_2 and transverse axis AB , select any point X_1 on the transverse axis (b, fig. 6-75). With centers at F_1 and F_2 and BX_1 as a radius, strike the arcs DE and GH . With the same centers and AX_1 as a radius, strike arcs to intersect the first arcs at the points $Q, P, S,$ and T , which are points of the required hyperbola. To find additional points of the hyperbola, select another point, X_2 , then using BX_2 , and AX_2 , as new radii and the original foci, establish the additional points as shown.

c. Drawing a Tangent to a Hyperbola at a Given Point. Draw lines from point P to foci forming angle F_1PF_2 (c, fig. 6-75). The bisector of this angle is the required tangent.

6-76. Drawing a Cycloid

a. A cycloid is generated by a point on the circumference of a circle which rolls along a straight line. The circumference of a circle is divided into 8 equal parts with each radius numbered (a, fig. 6-76). A straight line equal to the length of the

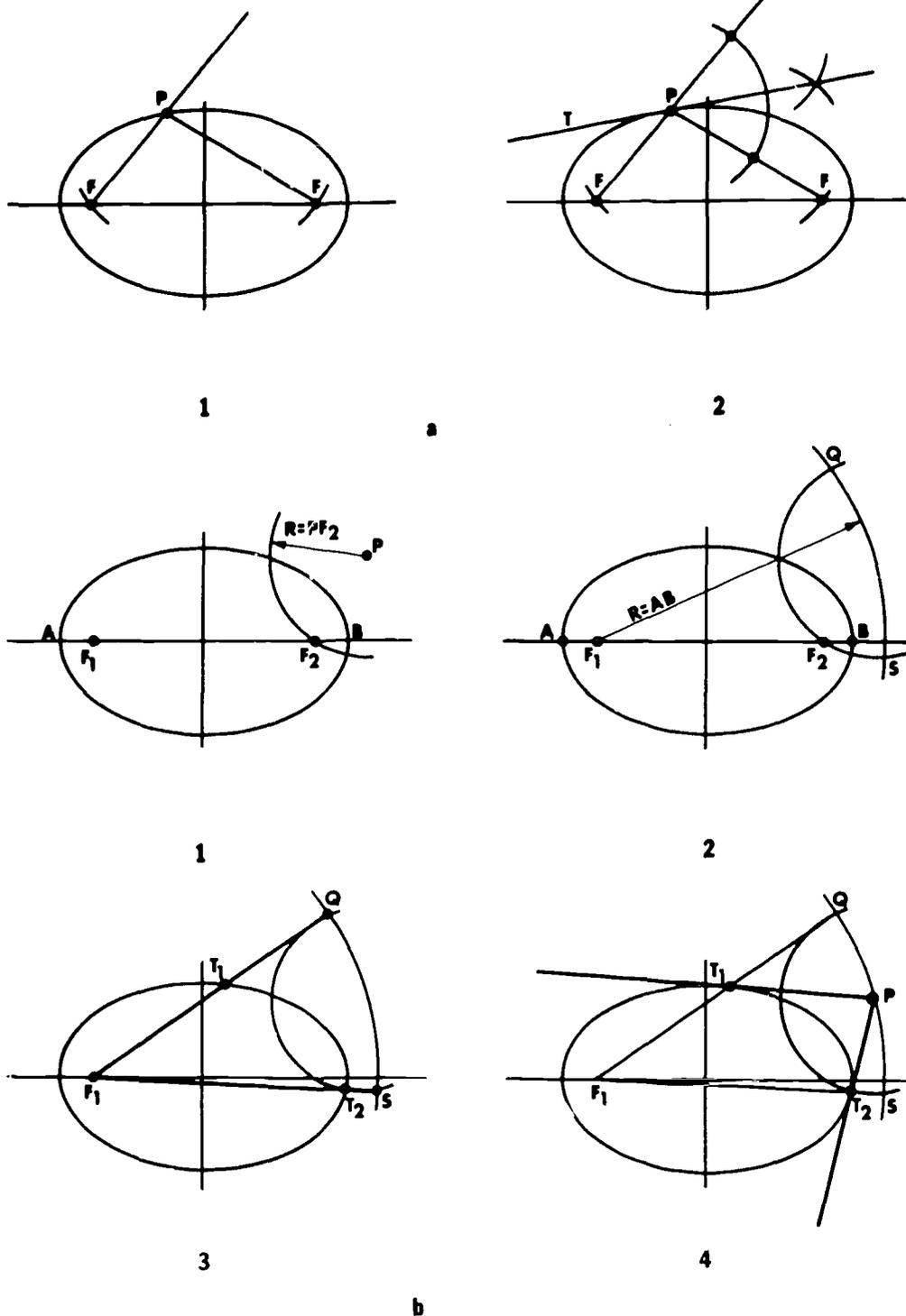


Figure 6-73. Drawing a tangent to an ellipse.

circumference representing one complete cycle or revolution is drawn. The straight line is marked indicating the position of the 8 radii and spaced to equal the length of the arc between each radius. (In other words, the straight line is the rectified length of the circumference, marked with the rectified length of each arc.) Study carefully the location of the center at each position and the location of the point on the circumference. In position

1, the center is on column one, and radius 1 is on the line. As the wheel (circle) revolves to position 2, the center moves to column 2, and the radius 1 rises. As the center moves to position 3, the radius 1 rises to the level of the centerline. In position 4, the radius rises again, and at position 5, it is at the highest point. At positions 6 through 8, the radius falls back to the line completing one cycle. The point has now generated a cycloid curve.

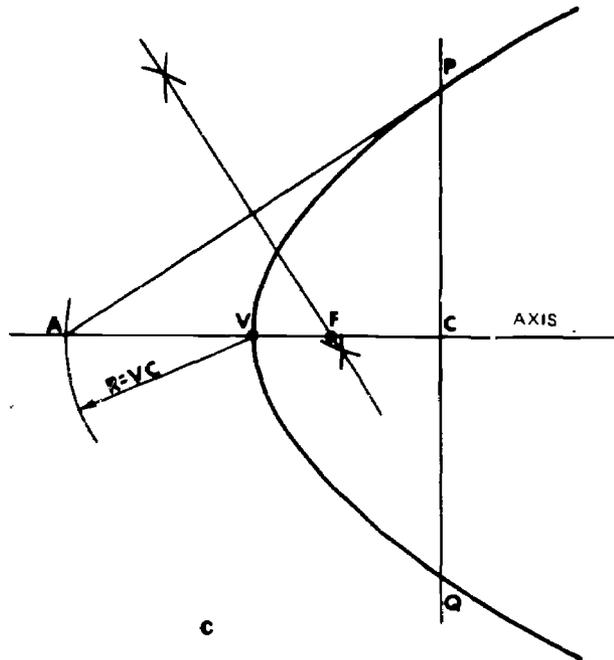
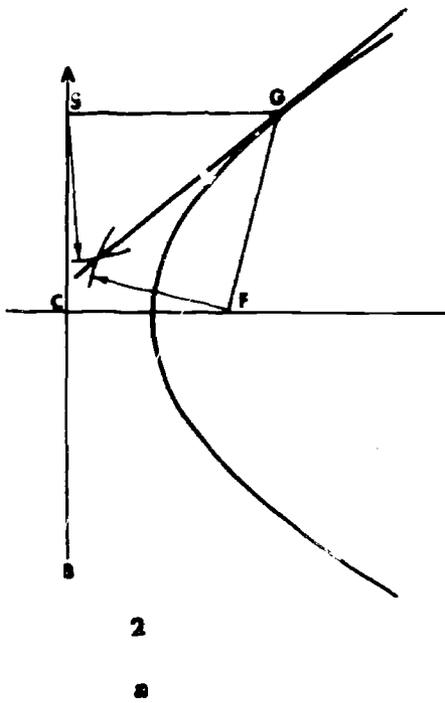
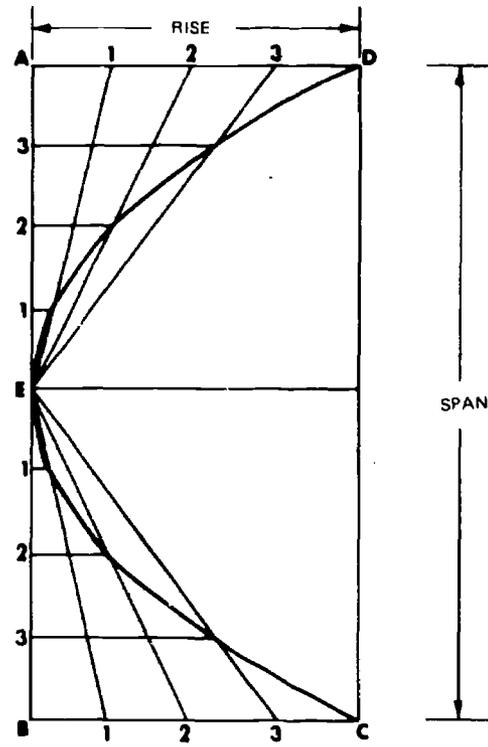
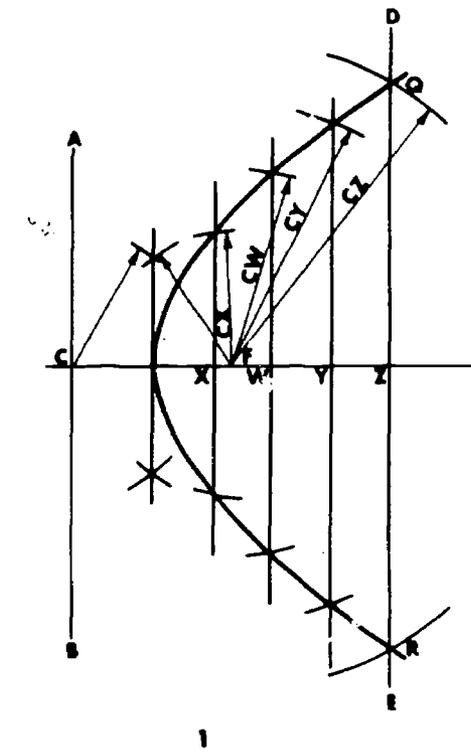


Figure 6-74. Drawing a parabola.

b. In b, figure 6-76, notice that the point starts at the point of tangency of radius 1, at position one; rises to the level of the point of tangency of radius 2, at position two; and so on. Therefore, if we have parallel lines indicating the level of rise for each position and the center of each arc

for each position we can locate the position of the point generating the cycloid curve. The intersection of these parallel lines and the arcs drawn from each center at the various positions will locate the points on the cycloid curve.

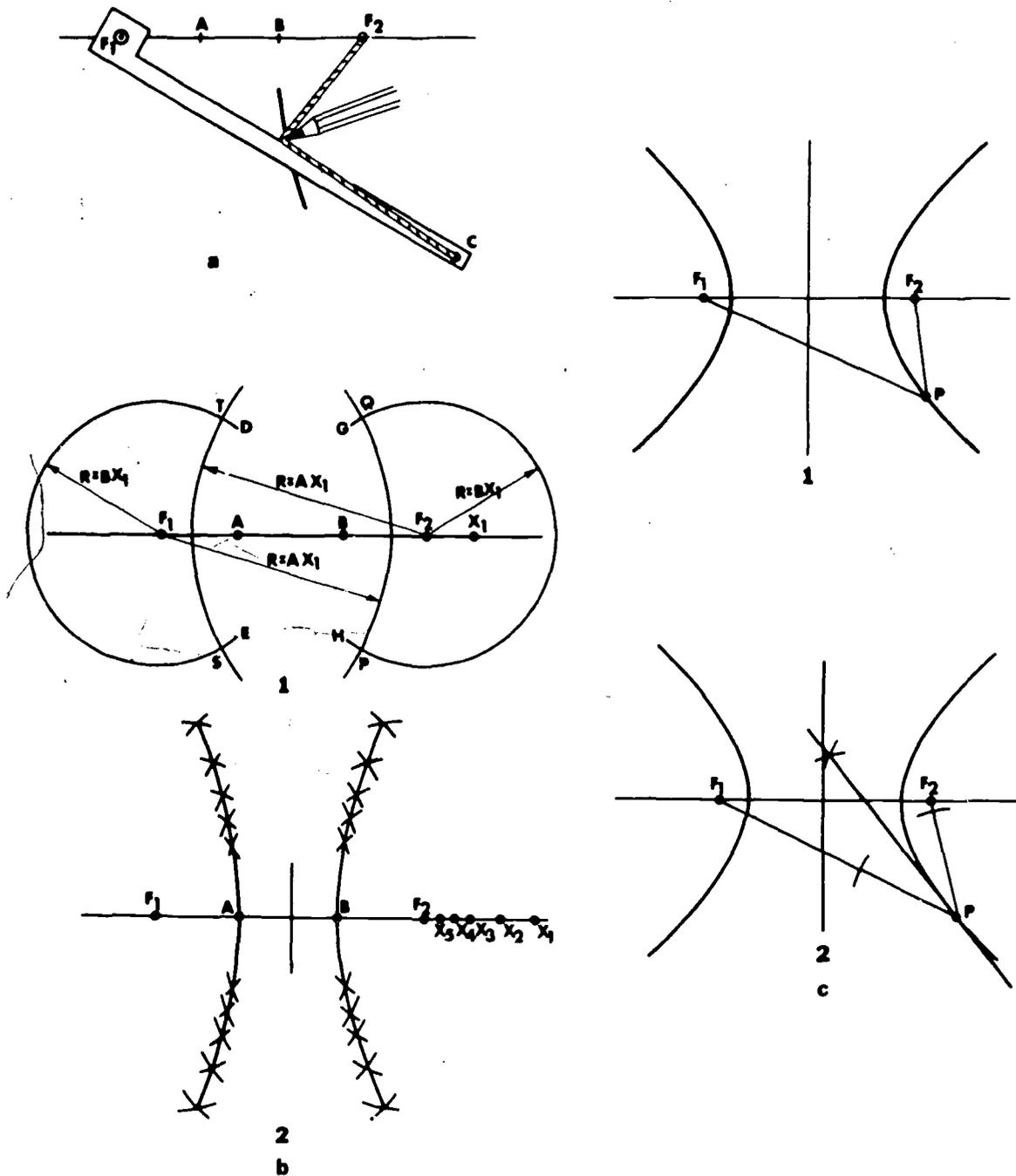


Figure 6-75. Drawing a hyperbola.

c. In drawing the cycloid (b, fig. 6-76) proceed as follows:

(1) Divide the rolling circle into any convenient number of parts and number each radius. Using these divisions, lay off on the tangent, the rectified length of the circumference and number columns 1, 2, 3, etc., and after the last number add 1'.

(2) Draw the centerline parallel to the circumference line and mark off the position of the centers as shown. From the radii of tangency draw lines parallel to these lines.

(3) With a compass, set to the radius of the rolling circle, at the center 1 intersect line one. Then, at center two, intersect line two, and so on.

(4) After the half way point, the points will descend.

(5) With an irregular curve, smooth out and draw the cycloid curve.

6-77. Drawing an Epicycloid

An epicycloid curve is generated by a point on the circumference of a circle which rolls along the

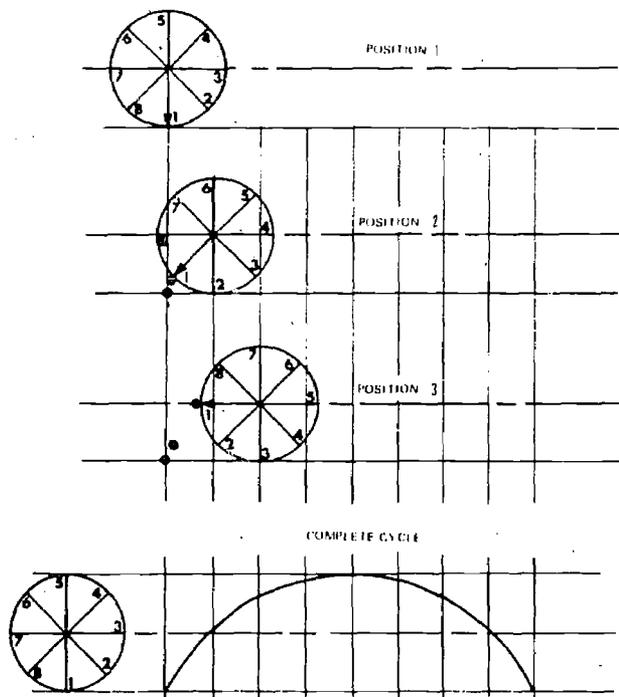


Figure 6-76. Drawing a cycloid.

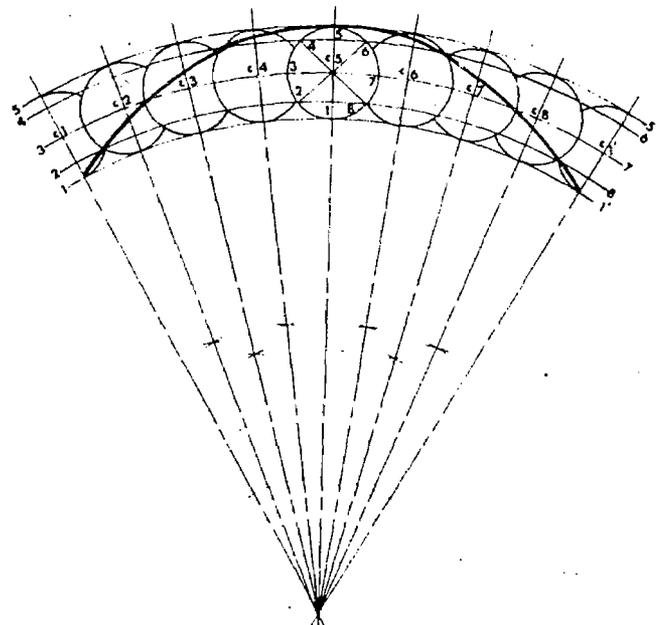


Figure 6-77. Drawing an epicycloid.

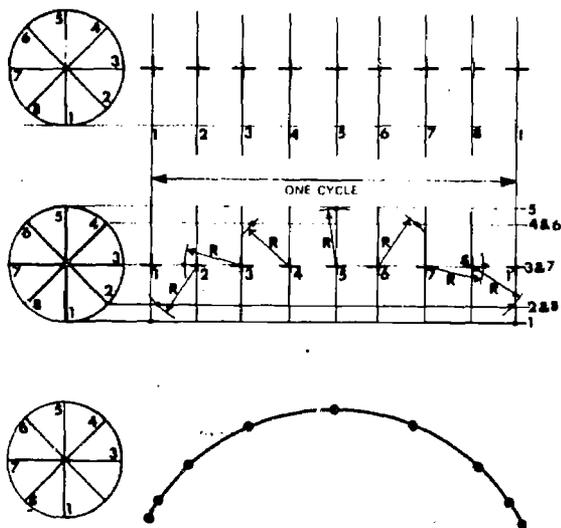


Figure 6-78. Drawing a hypocycloid.

lar to the epicycloid curve and is illustrated in figure 6-78.

6-79. Drawing an Involute

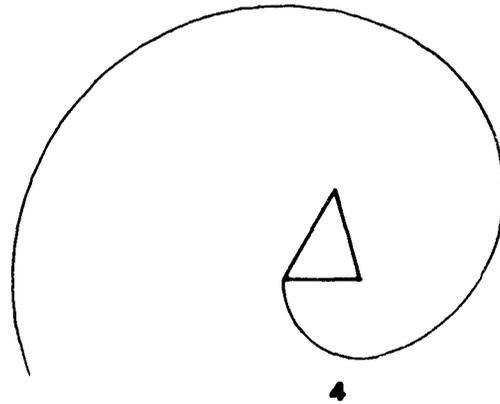
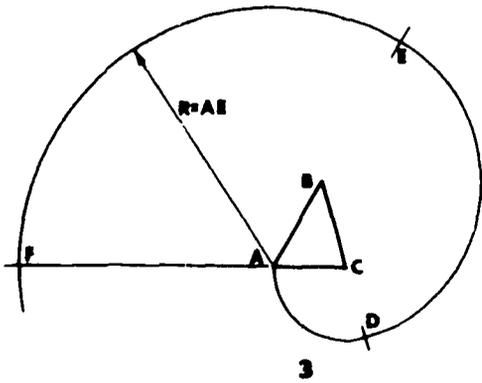
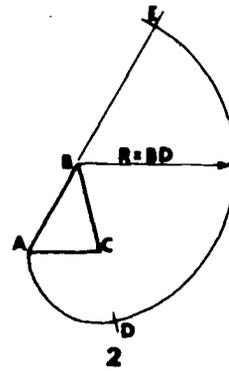
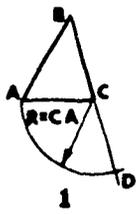
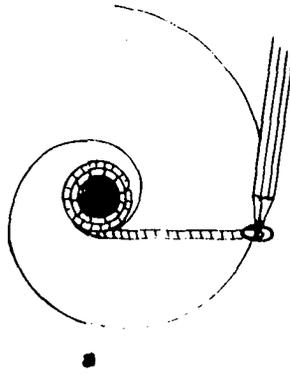
a. *Pin and String Method.* Wrap a string around a polygon or circle with a loop at the end of the string for a pencil point (a, fig. 6-79). Insert the pencil point in loop and draw involute as the string unwinds.

b. *Involute of a Regular Polygon or Circle.* Let ABC be the given triangle (b, fig. 6-79). With CA as a radius and C as the center, strike the arc AD , intersecting the extension of line BC at point D .

convex side of a larger circle. The epicycloid curve is drawn similar to the cycloid curve except that curved lines are used instead of straight lines. Figure 6-77 illustrates the drawing of this curve.

6-78. Drawing a Hypocycloid

A hypocycloid curve is generated by a point on the circumference of a circle which rolls along the concave side of a larger circle. This curve is simi-



b

Figure 6-79. Drawing an involute.

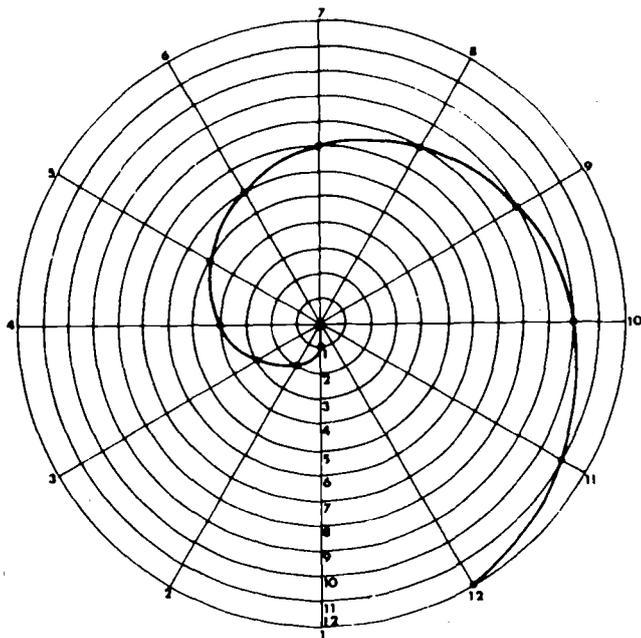


Figure 6-80. Drawing the spiral of Archimedes.

With BD as radius and B as the center, strike the arc DE intersecting the extension of line AB at point E . Continue until a figure of the required size is completed. The same method is used for a square or any regular polygon. For a circle or arc, divide the circumference into a number of equal parts, drawing a tangent at each division point, setting off along each tangent the length of the corresponding circular arc and drawing the required curve through the points set off on the tangents.

6-80. Drawing the Spiral of Archimedes

Divide a circle into any number of equal parts, drawing the radii and numbering them (fig. 6-80). Divide the radii into the same number of equal parts numbering from the center (concentric circles), zero being the center. Draw concentric arcs between the intersection of 1-1 (radius 1, circle 1) and 2-2 (radius 2, circle 2) and continue until required spiral is completed. The Archimedean spiral is the curve of the heart cam

used for converting uniform rotary motion into uniform reciprocal motion.

6-81. Drawing a Helix

a. Cylindrical. Draw two views of the cylinder upon which the helix is described—the circular and rectangular views (a, fig. 6-81).

(1) Divide the circle of the base into any number of equal parts. On the rectangular view of the cylinder, set off the lead and divide it into the same number of equal parts as the base (12 in this case). The lead is the distance measured parallel to the axis traversed by the point in one revolution. When the generating point has moved $1/12$ of the distance around the cylinder, it will have risen $1/12$ of the lead; when it has moved half-way around the cylinder, it will have risen half the lead, and so on. Points on the helix are found by projecting up from point 1 in the circular view to line 1 in the rectangular view, from point 2 in the circular view to line 2 in the rectangular view, and so on.

(2) The helix shown is a right-hand helix.

(3) In the left-hand helix, the visible portions of the curve are inclined in the opposite direction, i.e., downward to the right.

b. Conic. The curve of a conic helix (b, fig. 6-81) is plotted in the same manner as the cylindrical helix, except that the vertical lines in the rectangular view of the cylinder are converging at the apex of the triangle and are not parallel to the sides.

6-82. Transferring Curved Figures

a. Grid Method. Figures that have free curves can be copied, enlarged or reduced by the use of a grid (a, fig. 6-82). To enlarge a figure to double size, draw the containing rectangle or all small squares double their original size. Then draw the lines through the corresponding points in the new set of squares.

b. Circles and Arcs. For circles and arcs, locate the centers and transfer as shown in b, figure 6-82.

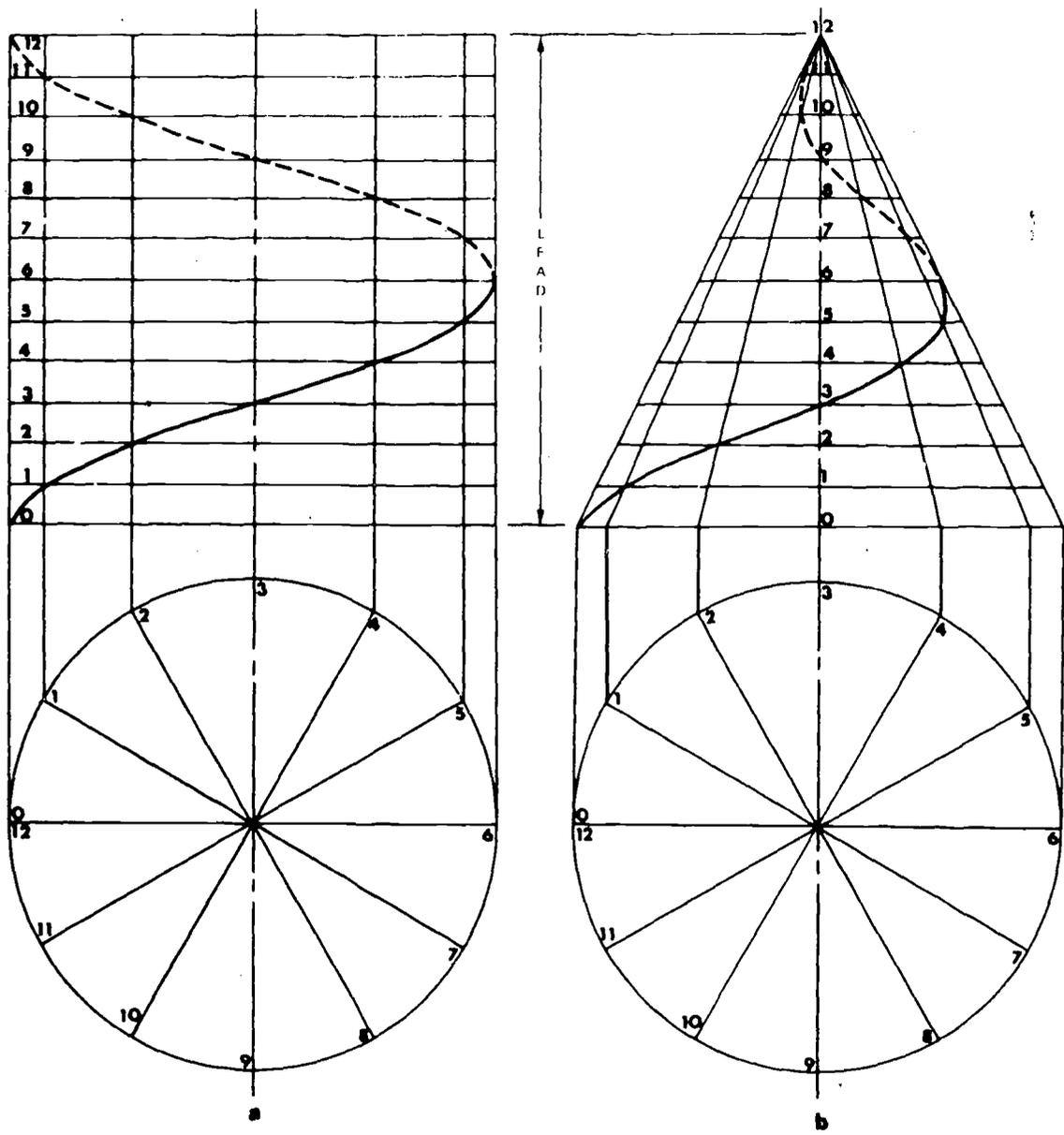
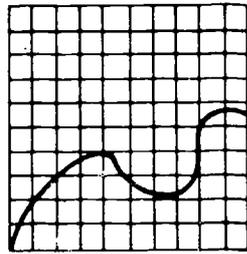
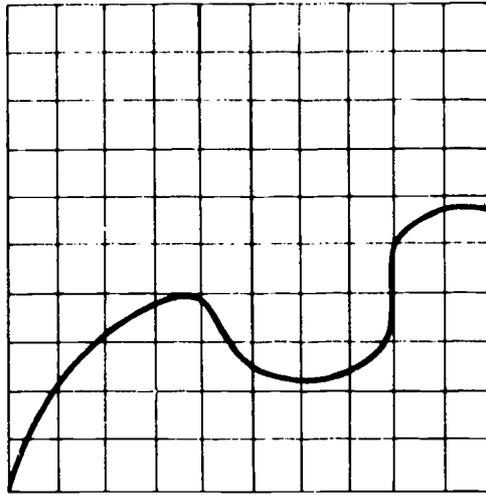


Figure 6-81. Drawing a helix.

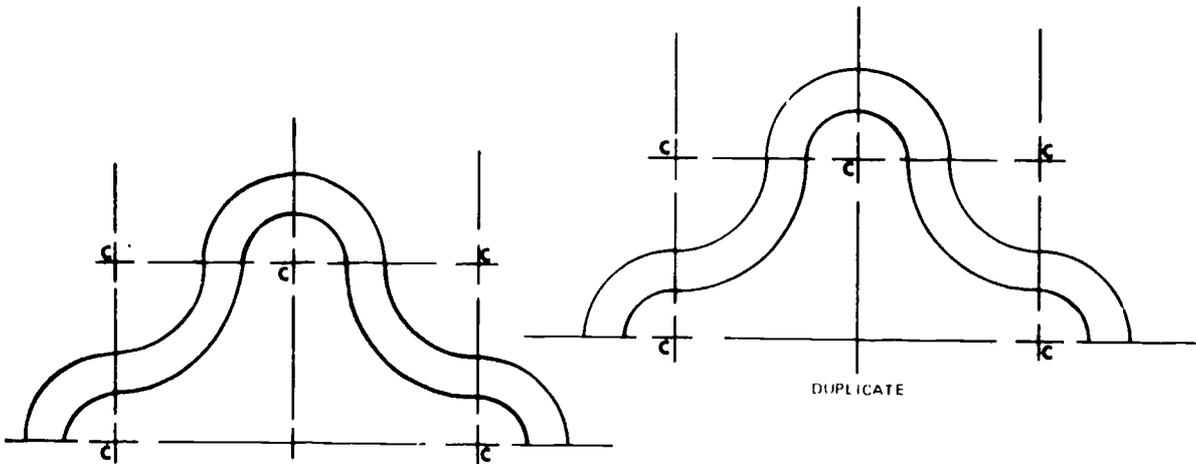


ORIGINAL



ENLARGEMENT

a



ORIGINAL

DUPLICATE

b

Figure 6-82. Transferring curved figures.

CHAPTER 7

INTERSECTIONS AND DEVELOPMENTS

Section I. GEOMETRICAL SURFACES

7-1. Introduction

a. The draftsman encounters drawings of structures which have intersecting surfaces. He must be able to determine the line of *intersection* between these surfaces. He must show how these surfaces can be *developed* so that they can be fabricated.

b. Since most structures are bounded by geometric surfaces or combinations of them, the draftsman should be familiar with the types of surfaces and the nomenclature.

7-2. Types of Geometrical Surfaces

A *surface* is a geometrical magnitude having two dimensions. A geometric surface is generated by the motion of a geometrical line, either straight or curved, called the *generatrix*. Any position of the generatrix is called an *element* of the surface. The *directrix* is the direction in which the end or ends of the line (the generatrix) moves, or in more technical terms, the directrix is the line or curve with which a generatrix of a surface remains in contact. Geometrical surfaces may be classified under two broad categories: ruled surfaces (para 7-3) and double-curved surfaces (para 7-4).

7-3. Ruled Surfaces

Ruled surfaces are surfaces generated by a straight line moving according to certain rules. These can be further divided into plane, single-curved, and warped surfaces.

a. *Plane.* A plane surface is generated by a straight line moving so that one point touches another straight line as it moves parallel to its original position. Illustrated in figure 7-1 are geometrical solids having plane surfaces that can be unfolded and developed. These plane surfaces are called faces. When the faces are all regular polygons, the solids are called regular polyhedra. The edges of these solids are the *lines of intersection* of the faces.

(1) A *tetrahedron* is a solid bounded by 4 polygonal plane surfaces that are equilateral triangular faces.

(2) A *cube* is a solid bounded by six square sides.

(3) An *octahedron* is a solid bounded by eight equilateral triangles.

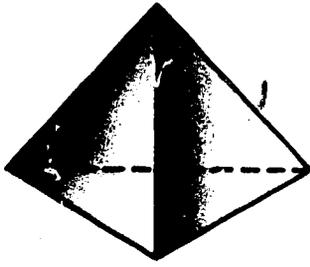
(4) A *dodecahedron* is a solid bounded by twelve pentagons.

(5) An *icosahedron* is a solid bounded by twenty equilateral triangles.

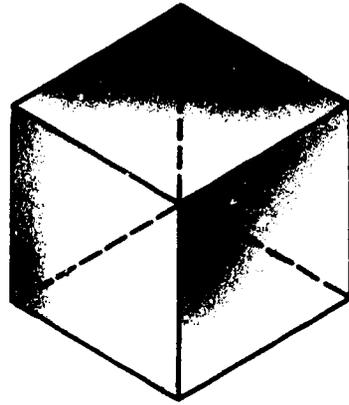
(6) A *prism* is a polyhedron (fig. 7-2) whose bases or ends are parallel polygons and whose lateral faces are parallelograms. A *right prism* is one whose lateral faces are squares or rectangles; all others are called *oblique prisms*. The axis of right prisms are at right angles to the bases or ends. The axis of a prism is a straight line connecting the centers of the bases. A *truncated prism* is that portion of a prism lying between one of its bases and a plane which cuts all its lateral edges.

(7) A *pyramid* is a polyhedron (fig. 7-3) whose base is a polygonal plane and whose other surfaces are triangular planes meeting at a point called the *vertex*. The *axis* is a line passing through the vertex and the midpoint of the base. A pyramid is *right* if the altitude coincides with the axis; it is *oblique* if they do not coincide. A *truncated pyramid* is that portion of a pyramid lying between the base and a cutting plane not parallel to the base and cuts all the lateral edges. The *frustum* of a pyramid is that portion of a pyramid lying between the base and a cutting plane parallel to the base and cuts all the lateral edges.

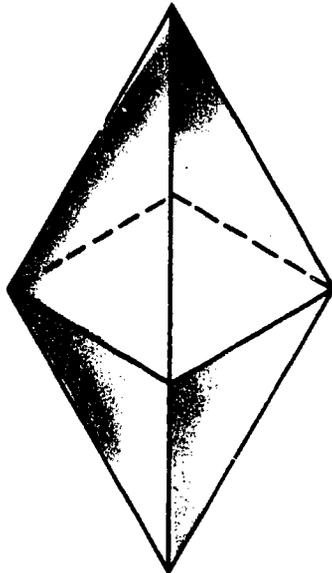
b. *Single-Curved.* A single-curved surface is generated by a straight line moving in such a manner that any two adjacent positions of the generatrix lie in the same plane. The following solids (fig. 7-4) having single-curved surfaces are developable and can be unrolled to coincide with a plane.



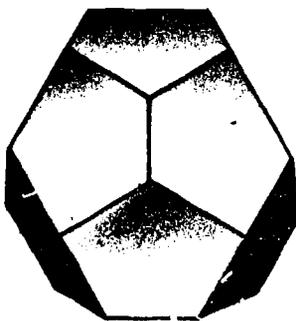
Tetrahedron
(4 triangles)



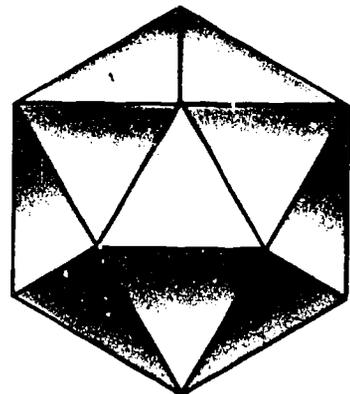
Hexahedron
(Cube)
(6 squares)



Octahedron
(8 triangles)

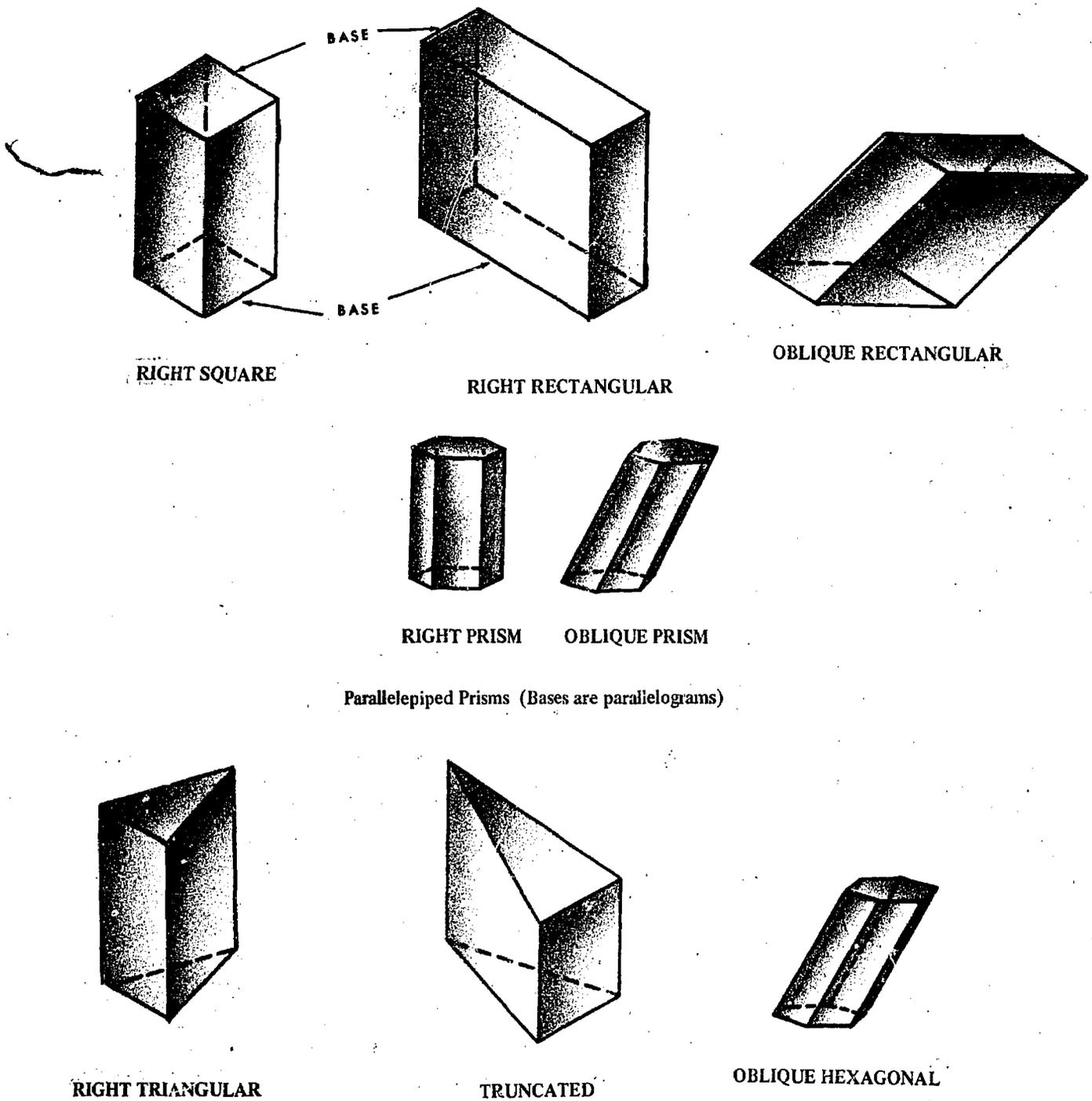


Dodecahedron
(12 pentagons)



Icosahedron
(20 triangles)

Figure 7-1. Solids having plane surfaces—5 platonic regular solids.



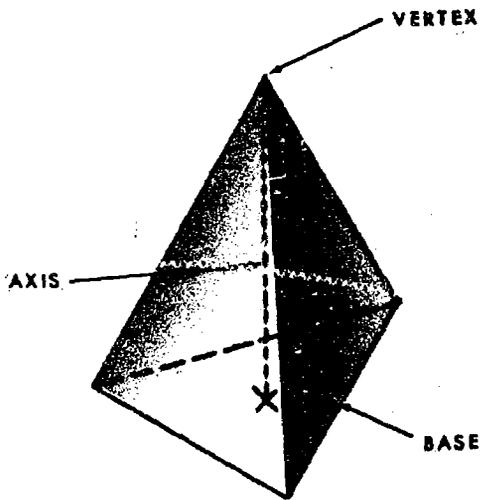
Parallelepiped Prisms (Bases are parallelograms)

Figure 7-2. Solids having plane surfaces—prisms.

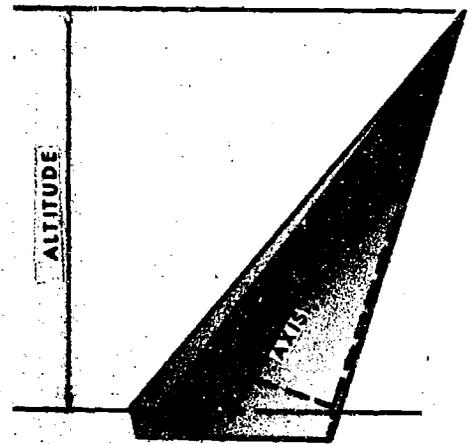
(1) *Cylinder*. A cylinder is a single-curved surface generated by the motion of a straightline generatrix remaining parallel to itself and constantly intersecting a curved directrix. The various positions of the generatrix are elements of the surface. It is a *right* cylinder when the elements are perpendicular to the bases, an *oblique* cylinder when they are not. A *truncated* cylinder is that portion of a cylinder which lies between

one of its bases and a cutting plane which cuts all the elements. The axis is the line joining the centers of the bases.

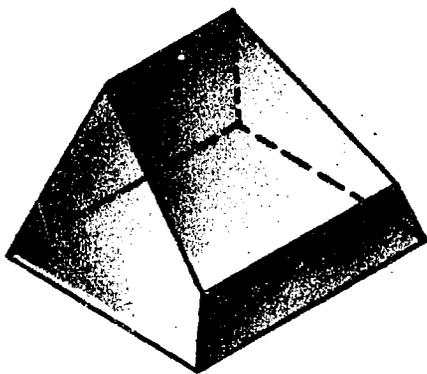
(2) *Cone*. A cone is a single-curved surface generated by the movement, along a curved directrix, of a straight-line generatrix, one point of which is fixed. The directrix is the base, and a fixed point is the vertex of the cone. Each position of the generatrix is an element of the surface. The



**RIGHT TRIANGULAR
PYRAMID**



**OBLIQUE
PENTAGONAL
PYRAMID**



**TRUNCATED
PYRAMID**



**FRUSTRUM OF A
PYRAMID**

Figure 7-3. Solids having plane surfaces—pyramids.

axis is a line connecting the vertex and the center of the base. The altitude is a perpendicular dropped from the vertex to the base. A cone is *right* if the axis and altitude coincide; it is *oblique* if they do not coincide. A *truncated* cone is that

portion of a cone lying between the base and a cutting plane which cuts all the elements. The *frustrum* of a cone is that portion of a cone lying between the base and a cutting plane parallel to the base which cuts all the elements.

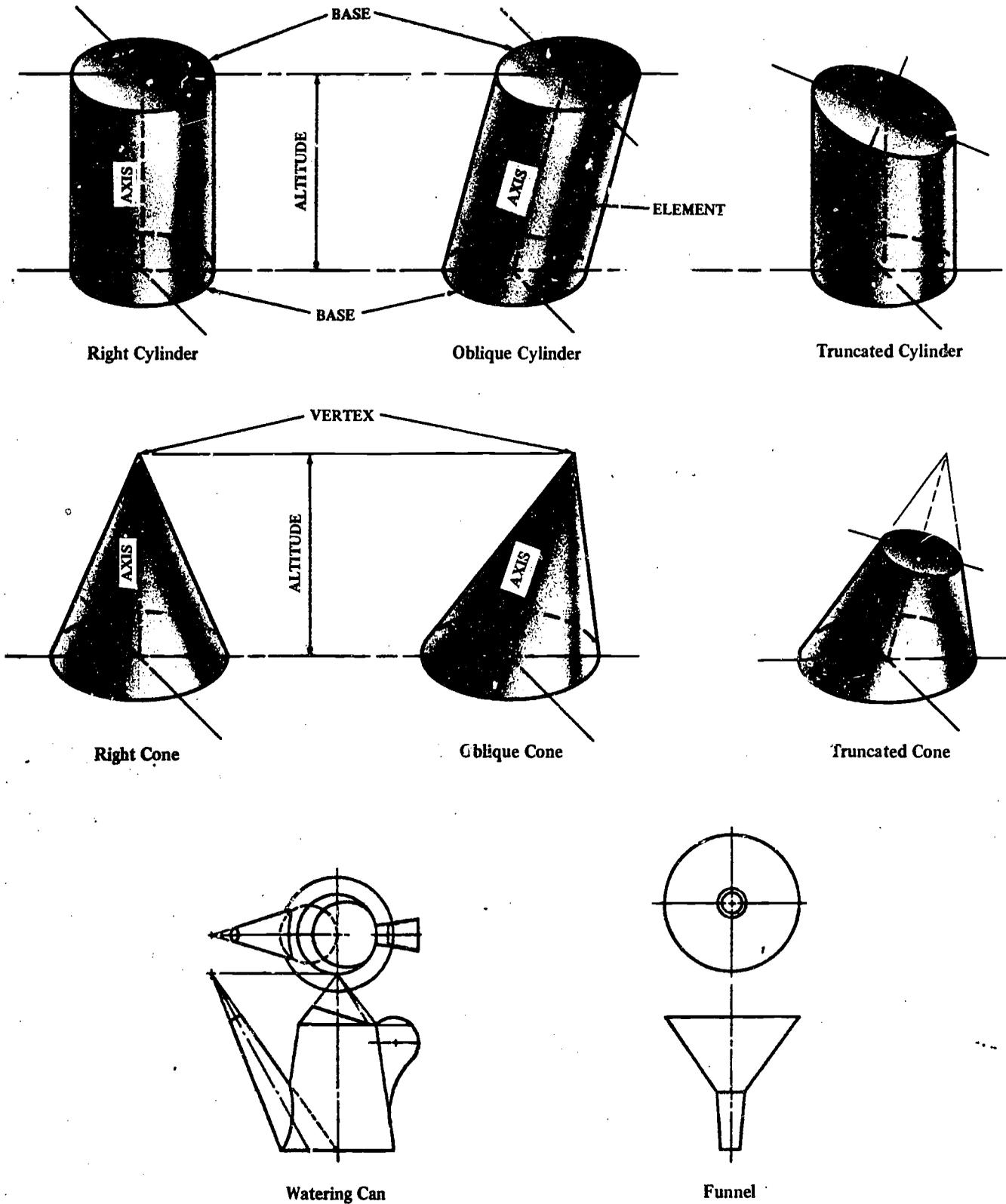
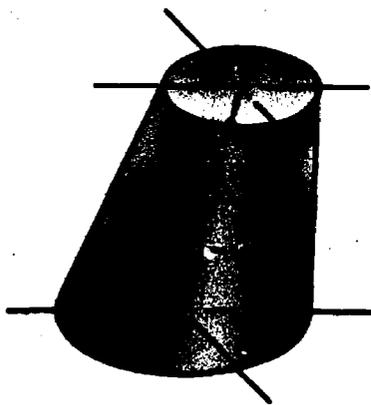


Figure 7-4. Single curved surfaces.

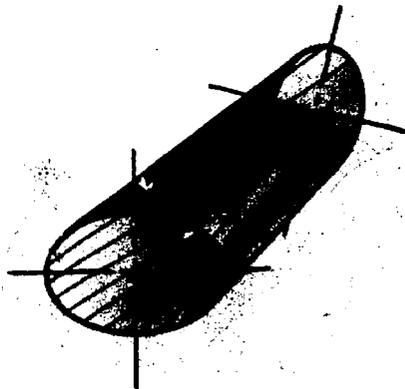
(3) *Convolute*. A convolute is a single-curved surface generated by the movement of a straight-line generatrix along two curved directrix. The

helical convolute is generated by a straight line moving so that it is always tangent to the helix.

c. Warped. A warped surface (fig. 7-5) is gen-



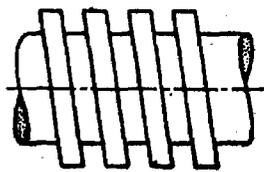
Frustrum of A Cone



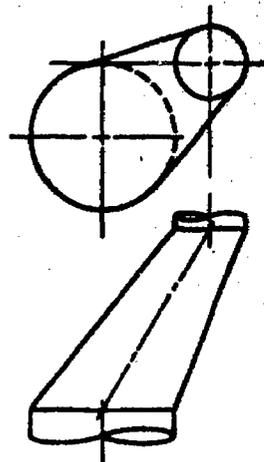
Convolute
(Elements Following
Two Curved Directrix)



Helical Convolute
(Elements Always Tangent to Helix)



Helical Convolute



Pipe Reducer Section
(Example of Convolute)

Figure 7-4—Continued.

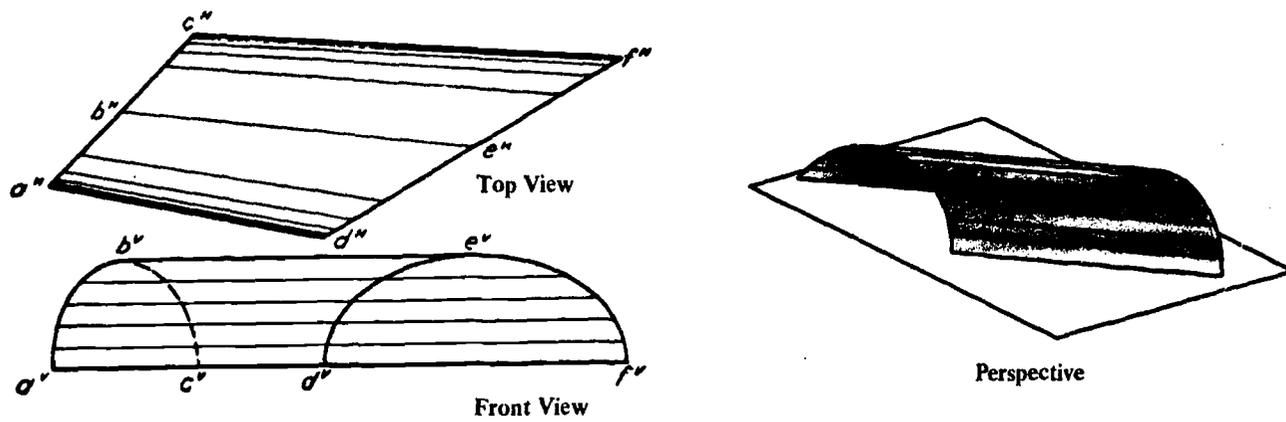
erated by a straight line moving in such a manner that it does not lie in the same plane in any adjacent positions, such as hyperbolic paraboloid, cylindroid, conoid, helicoid, hyperboloid. These surfaces are not developable (para 7-5). Many exterior surfaces on an airplane or automobile are warped surface.

(1) *Hyperbolic paraboloid.* The hyperbolic paraboloid (or warped quadrilateral) is a surface generated by a straight line, moving so that it always touches two nonparallel, nonintersecting lines, and remains parallel to a plane director. It is a doubly ruled surface because it has two sets of linear directrices, two plane directors, and two sets of generating lines. The hyperbolic paraboloid is used in the design of the bow of a boat. Another

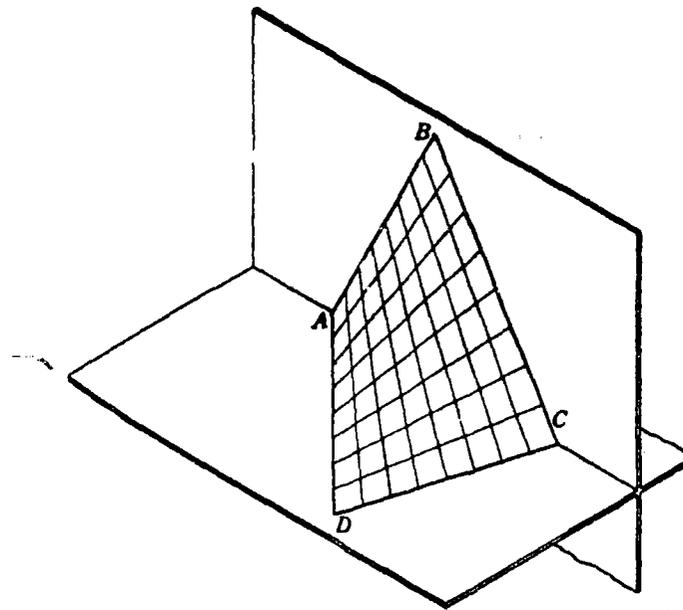
practical application is when there are two slopes at different levels and angles to be connected, the transition piece between these two slopes is a hyperbolic paraboloid.

(2) *Cylindroid.* The cylindroid is a surface generated by a straight line moving so that it always remains parallel to a plane director and at the same time touches two plane curves, not lying in the same plane. These curves are usually parts of circles or ellipses. The most common cylindroid used in construction is in arch construction where the plane director is likely to be the horizontal plane, though it is not a requirement of the definition. Any plane director and any plane curves not lying in the same plane can be used.

(3) *Conoid.* The conoid is a warped surface



CYLINDROID



HYPERBOLIC PARABOLOID

(Warped Quadrilateral)

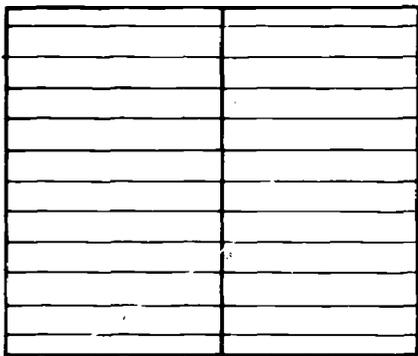
Figure 7-5. Warped surfaces.

having a plane director and two linear directrices, one of which is a straight line and the other a curve. If the straight-line directrix is parallel to the plane of the curved directrix and also perpendicular to the plane director, the surface is called a *right conoid* (fig. 7-6). A common application of this form is where a roof must change from a curved to a flat surface.

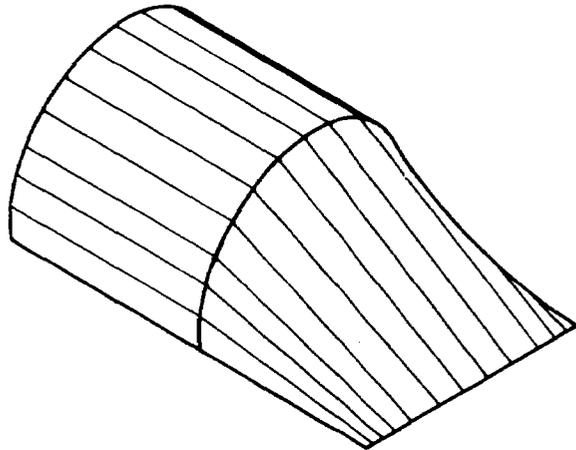
(4) *Helicoid*. The helicoid is a surface generated by a right line moving so that it always touches a helix and making a constant angle with

its axis. If the generatrix is perpendicular to the axis of the helix, the surface is a *right helicoid* as the surface of a square thread as shown in the central portion of the gate valve (fig. 7-7). If the generatrix is inclined to the axis, it is an oblique helicoid such as the surface of a V-thread as shown in the bottom portion of the gate valve.

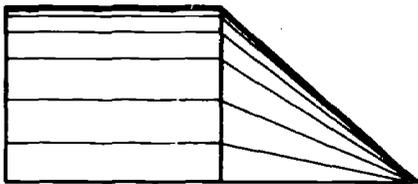
(5) *Hyperboloid of revolution*. The hyperboloid of revolution is generated by a right line that revolves about another nonparallel, nonintersecting right line as an axis. It may also be generated



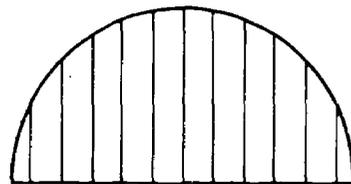
TOP VIEW



PERSPECTIVE

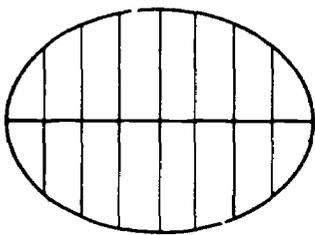


SIDE VIEW

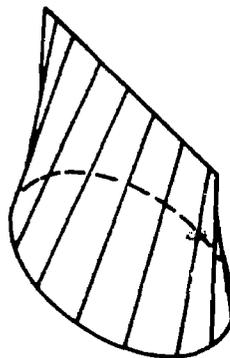


FRONT VIEW

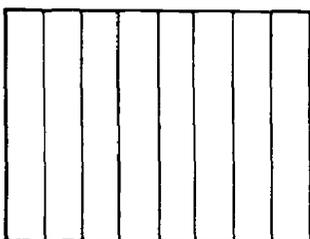
①



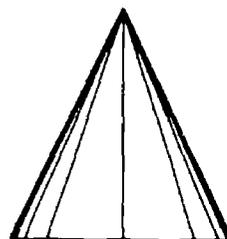
TOP VIEW



PERSPECTIVE



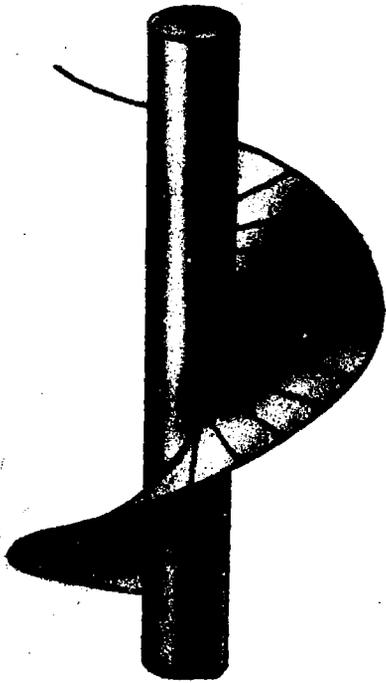
SIDE VIEW



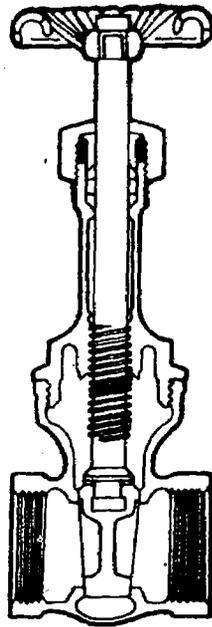
FRONT VIEW

②

Figure 7-6. Right conoid.



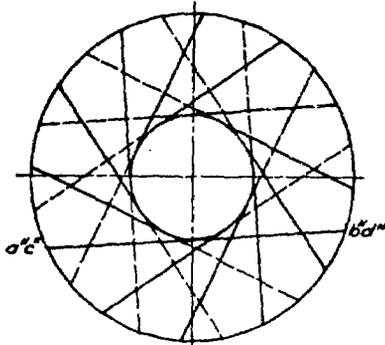
Right Helicoid



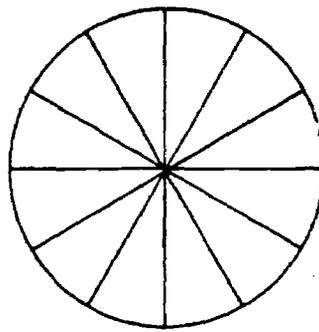
Gate Valve



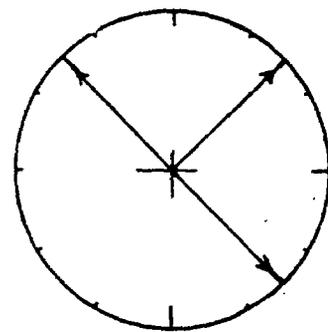
Oblique Helicoid



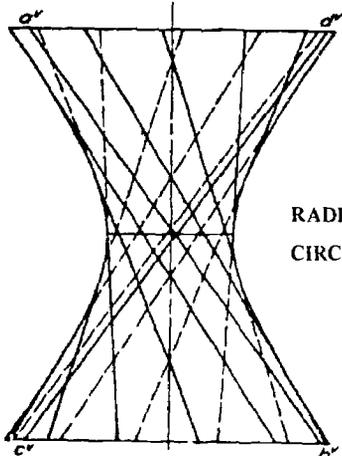
Hyperboloid of Revolution



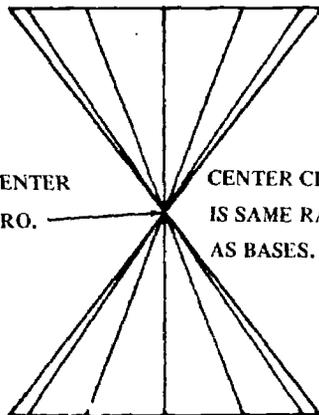
Cone



Cylinder



RADIUS OF CENTER
CIRCLE IS ZERO.



CENTER CIRCLE
IS SAME RADIUS
AS BASES.



Figure 7-7. Helicoid and hyperboloid of revolution.

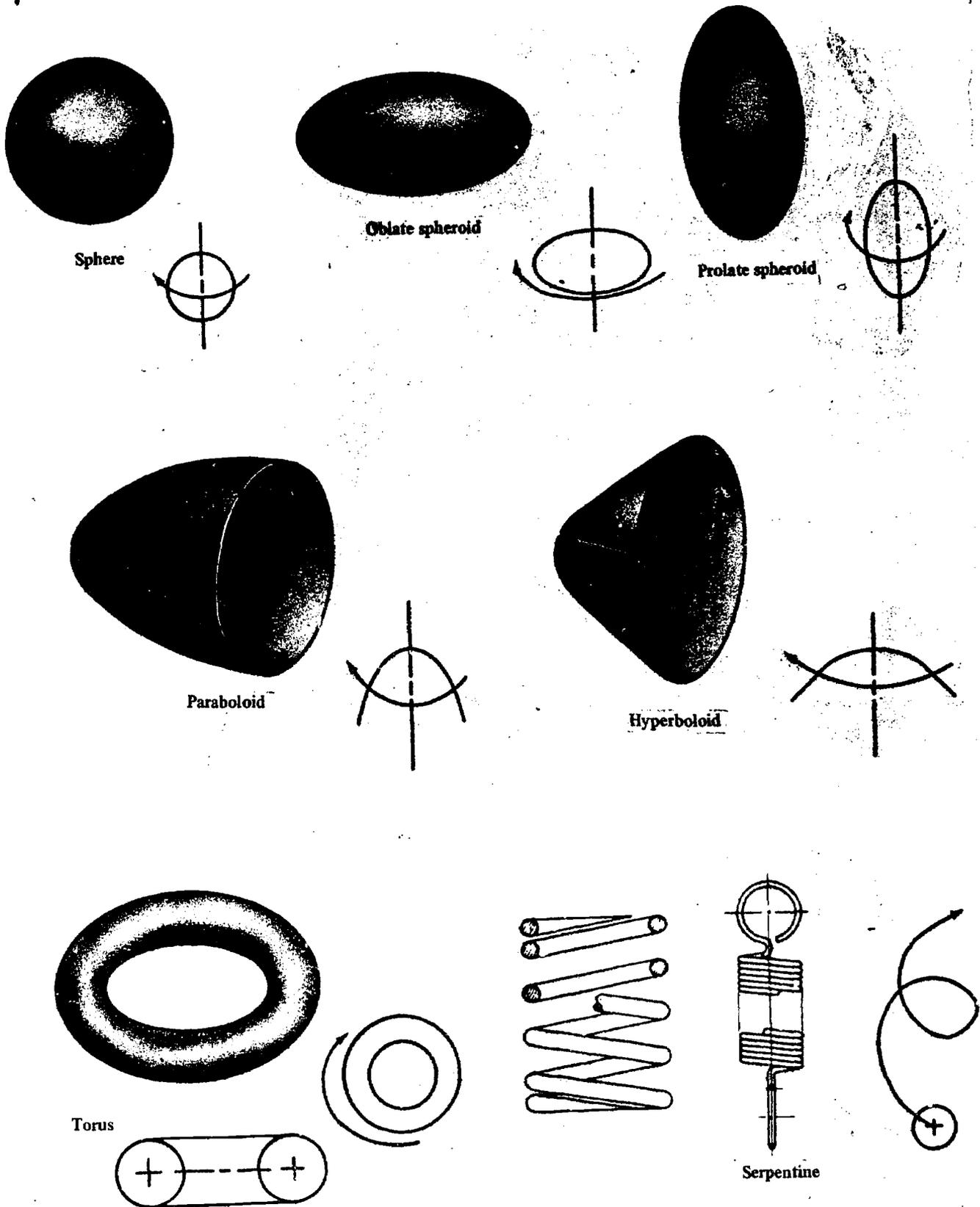


Figure 7-8. Double-curved surfaces.

by a line touching three circles whose planes are perpendicular to a common axis through their centers. When the radius of the middle, or gorge, circle becomes zero, the surface is a cone, and when this radius becomes the same as the radius of the other two circles, the surface is a cylinder. Thus the cone and cylinder become the limits of the hyperboloid of revolution. Since this is a surface of revolution, a plane passed perpendicular to the axis of revolution cuts a circle from the surface. The surface is doubly ruled since two different lines may be revolved about the axis to give the same surface. These lines make equal angles with the base but slope in opposite directions (fig. 7-7).

7-4. Double Curved Surfaces

Double curved surfaces are surfaces generated by a curved line moving according to some mathematical formula or law. The commonest forms are surfaces of revolution such as a sphere, oblate spheroid, prolate spheroid, paraboloid, hyperboloid and torus. Double-curved surfaces as well as warped surfaces are not developable. They may be developed approximately by dividing them into sections and substituting for each section a developable surface; that is a plane or a single-curved

surface. If the material used is sufficiently pliable, the flat sheets may be stretched, pressed, stamped, spun, or otherwise forced to assume the desired shape. Nondevelopable surfaces are often produced by a combination of developable surfaces which are then formed slightly to produce the required shape (fig. 7-8).

a. Sphere. A sphere is generated by a circle revolving about its axis.

b. Ellipsoid.

(1) An *oblate spheroid* is generated by an ellipse revolving about its *minor* axis.

(2) A *prolate spheroid* is generated by an ellipse revolving about its *major* axis.

c. Paraboloid. A paraboloid is generated by a parabola revolving about its axis.

d. Hyperboloid. A hyperboloid is generated by a hyperbola revolving about its transverse axis. (Compare with hyperboloid of revolution, paragraph 7-3c(5)).

e. Torus. A torus is generated by a circle with its center revolving along the circumference of a larger circle.

f. Serpentine. A serpentine is generated by a circle with its center moving along a helix.

Section II. INTERSECTIONS

7-5. Introduction

a. The topic of intersections and developments can be a complex and lengthy subject when covered completely. This text is concerned only with the basic coverage of this subject. However, the methods presented here form the basis for a more complete treatment.

b. The *line of intersection* is the line joining all points common to two surfaces which intersect. The degree of accuracy needed in establishing a line of intersection between two surfaces varies with the problem conditions. In some problems, such as in the design of ducts, the tolerances are such that scaled drawings of the structure can be used in determining the line of intersection and in developing the surfaces. Other problems, such as the design of plates for the hull of a ship, require that the intersections be determined and the developments made on full-size drawings which are often laid out on the floor of a large room called a loft room. In the aircraft industry, developments frequently must be accurate to 0.005 of an inch due to the need to avoid turbulent air flow over intersecting surfaces.

c. Intersections need not be the intersection of *tangible* surfaces; instead, the designer may be interested in shaping moving parts so that they do not conflict with one another. Here, the designer would be working with *intangible surfaces* generated by the moving parts. Or, he might want to design a stationary piece so as to allow the passage of a moving part; in this case, the designer would be working with both tangible and intangible surfaces.

d. In making orthographic drawings, it is necessary to represent the *lines of intersection* between the various surfaces of a variety of objects. Almost every line on a drawing is a line of intersection, generally the intersection of two planes, giving a straight line, or of a cylinder and a plane, giving a circle or ellipse. The term "intersection of surfaces" refers, however, to the more complicated lines that occur when geometric surfaces such as planes, cylinders, and cones intersect each other. These lines of intersection are shown by one of two basic ways: (1) *conventional intersections*, ordinarily used to represent a fillet, round, or runout, or (2) *plotted intersections*, used when

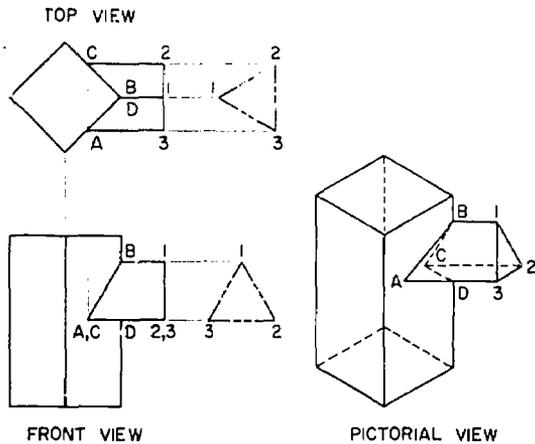


Figure 7-9. Intersection of two prisms.

an intersection must be located accurately for purposes of dimensioning or for development of the surfaces.

e. In sheetmetal work, whenever two pieces intersect, the intersections must be found before the piece can be developed. In addition, a draftsman must be able to determine the line of intersection to represent objects accurately. Almost all problems can be solved by resolving the objects into a combination of geometric shapes. The simplest problems are those involving two objects, both of which are bounded by plane surfaces. In such cases, the view in which an intersecting surface appears as a line allows an observer to determine by inspection the points through which a given line is penetrated by the lines of the other surfaces. Problems involving intersections between two single-curve or double-curved surfaces can be solved by drawing element lines on one lateral surface near the line of intersection. Points are established wherever the element lines intersect the other surface, which determine the line of intersection because they are common to both surfaces. The usual method of determining the line of intersection of any two surfaces is to pass a series of imaginary cutting planes through the objects in a direction perpendicular to the principal plane of projection. Each plane is passed to cut the simplest lines from each surface. One or more points on the line of intersection will be established by the intersection of lines cut from each surface by a plane.

7-6. Intersection of Two Prisms

The pictorial view in figure 7-9 shows the edges of the triangular prism piercing the faces of the rectangular prism at points A, B, and C. These points are called the critical points, or vertices, of the intersection. Draw two related orthographic

views. The top and front views were selected in figure 7-9. The side view could be used instead of either top or front views, but a third orthographic view is not necessary. It may be helpful to sketch an end view of the triangular prism as shown by 1, 2, 3 in figure 7-9. The edges of the triangular prism in the top view intersect the faces of the rectangular prism in points A, B, C, and D. Project points A, B, C, D to front view and extend the edges of the triangular prism in the front view, thus locating the points A, B, C, and D.

7-7. Intersection of Two Cylinders

When two objects having curved surfaces intersect, their line of intersection is an irregular curve, which must be plotted by passing a series of construction planes cutting each object. Two orthographic views are selected, and points of the intersection are determined by projection between the two views. Figure 7-10 illustrated the steps in plotting the intersection of two cylinders as follows:

- a. A series of construction planes are passed through both cylinders parallel to their centerline.
- b. The first plane through the centerlines of both cylinders cuts the small cylinder in elements numbered 1 and 7, and the large cylinder in element numbered 8.
- c. When these elements are projected to the front view they intersect in points lettered A and G.
- d. The second plane parallel to the first, cuts the small cylinder in elements numbered 2 and 6, and the large cylinder in element numbered 9.
- e. When these elements are projected to the front view they intersect in points B and F.
- f. Likewise the plane through elements 3 and 5 on the small cylinder and element numbered 10 on the large cylinder, intersect in the front view in points C and E.
- g. The plane tangent to the small cylinder in element numbered 4 cuts the large cylinder in element numbered 11, and these elements intersect in point D. A French curve is used to draw the line of intersection through points A, B, C, D, E, F, and G.

7-8. Intersection of a Plane and a Right Cone

When one object having plane surfaces intersects an object with curved surfaces, the line of intersection is a curved line. Figure 7-11 illustrates some of the various intersections which may re-

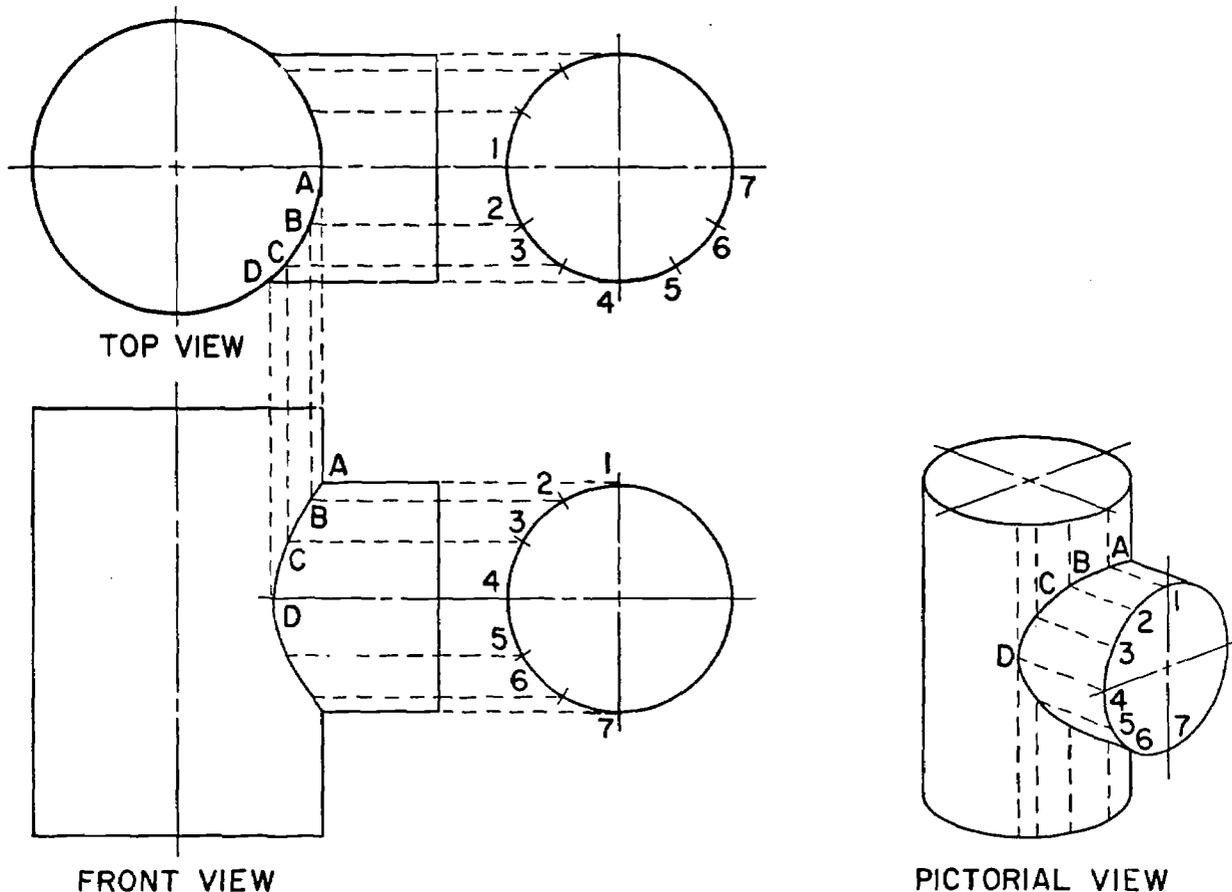


Figure 7-10. Intersection of two cylinders.

sult from the intersection of a plane and a right circular cone. If the plane is parallel to the base and cuts all elements of the cone, the intersection is a circle (A, fig. 7-11). If the plane is not parallel to the base and cuts all elements, the intersection is an ellipse (B, fig. 7-11). If the plane is parallel to an element of the cone, the intersection is a parabola (C, fig. 7-11). If the plane is parallel to the axis of the cone, it cuts both nappes, and the intersection is a hyperbola (D, fig. 7-11). Some special cases not shown are a point, a single straight line, and two intersecting straight lines.

7-9. Intersection of a Prism and a Cone

The practical method of determining the intersection between a prism and a cone by passing a series of cutting planes is shown in figure 7-12. Each face of the prism will cut the cone in a hyperbola (step 3, fig. 7-12) and the intersection will be a series of six hyperbolic curves joined end to end. Two related orthographic views are necessary in order to plot points on the intersection. In figure 7-12 the top and front views are used. The top view shows the regular hexagonal prism A, B,

C, D, E, F centered at O, the vertex of the cone. The procedure for plotting points on the intersection is as follows:

a. In the top view, draw a circle circumscribing the hexagon. Project the points A and D, the ends of the diameter, to the front view where the projection lines meet the side elements of the cone at A' and D'. Draw cutting plane I-I, which is the circle on edge, through A' and D'. Also project points B and C to the points B' and C' on the plane I-I. The intersection of a plane parallel to the base of a cone is a circle as shown at step one in figure 7-12.

b. In the top view inscribe a circle within the hexagon. Project this circle to the front view by projecting the end points of its diameter to the side elements of the cone, where it appears on edge as the cutting plane II-II. Also mark the points G, H, and J, the points where the inscribed circle is tangent to the faces of the prism, in the top view, and project points G, H, and J to the points G', H' and J' on the plane II-II, thus locating the high points of each hyperbolic curve.

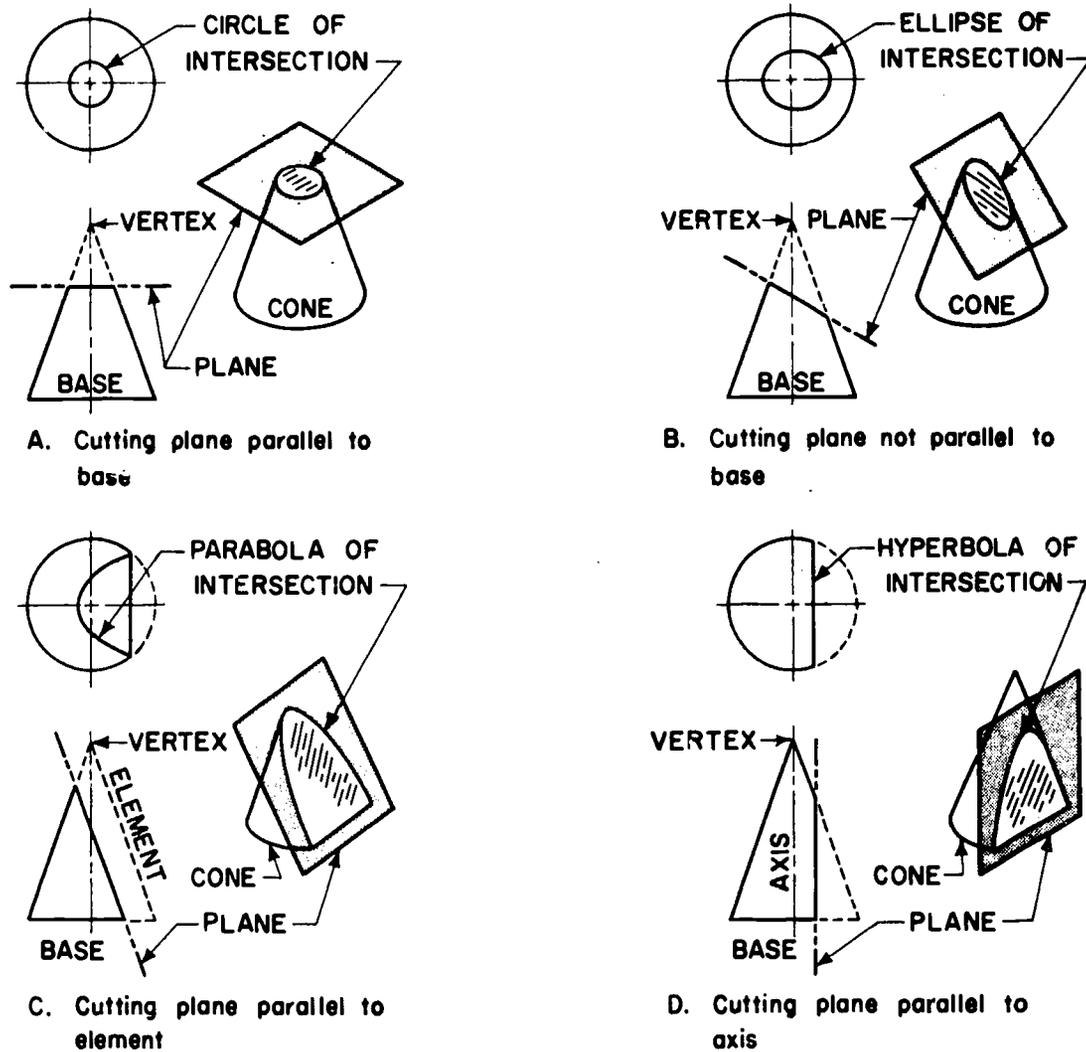
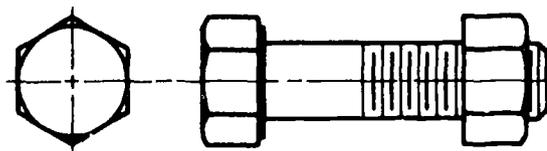
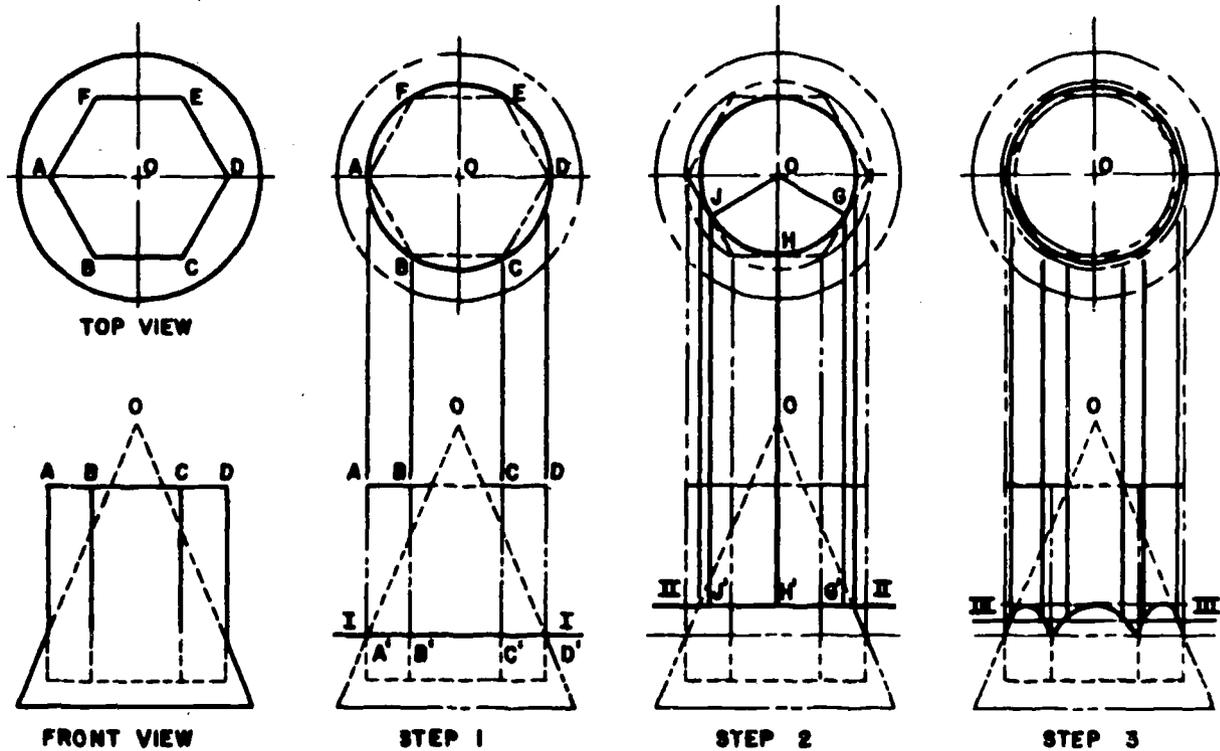


Figure 7-11. Intersection of a plane and a right cone (conic sections).

c. In the top view, draw a circle approximately halfway between the inscribed and circumscribed circles. Project this circle to the front view where it appears on edge as the cutting plane III-III. In

top view find points where the last circle drawn intersects the sides of the prism and project these points to the plane III-III thus locating two more points on each curve.



Bolthead and Hexagon Nut

Figure 7-12. Intersection of a prism and a cone.

d. Using a French curve, draw the hyperbolic curves through the points located in *a*, *b*, and *c* above. These curves are visible outlines, and take precedence over the identical curves formed by

the other three sides *DE*, *EF*, and *FA* of the prism. The chamfer of an ordinary hexagonal bolthead or nut is an example of the intersection of a prism and a cone (fig. 7-12).

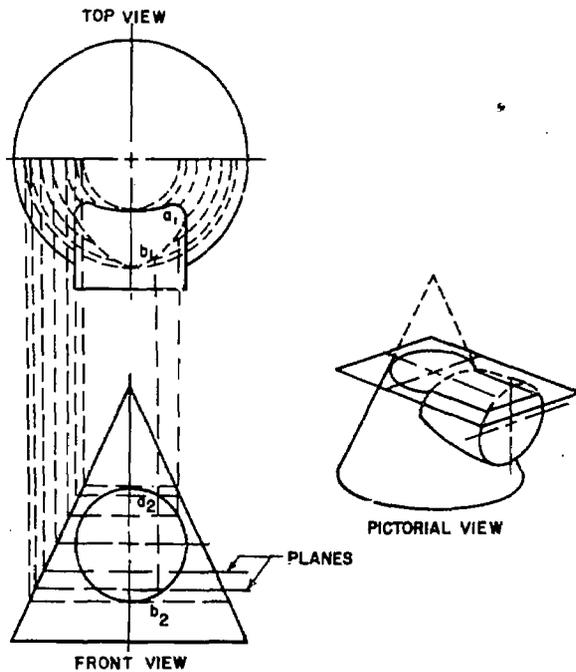


Figure 7-13. Intersection of a cone and a cylinder.

7-10. Intersection of a Cylinder and a Cone

To find the line of intersection of a cone and a cylinder, the cutting planes are passed perpendicularly to the axis of the right cone to cut circles from the cone (fig. 7-13). To obtain an accurate curve, be careful in selecting the number and location of cutting planes. Planes are passed through critical points and in areas where the line of intersection changes sharply in curvature. More points need to be found at these areas than elsewhere.

Section III. DEVELOPMENTS

7-11. Introduction

The *development* of a surface is that surface laid out on a plane. A *developable surface* is one which may be unfolded or unrolled so as to coincide with a plane. Surfaces composed of single-curved surfaces, or of planes, or of combinations of these types, are developable. Warped surfaces and double-curved surfaces are not developable. They may be developed approximately by dividing them into sections and substituting for each section a developable surface; that is, a plane or a single-curved surface. If the material used is sufficiently pliable, the flat sheets may be stretched, pressed, stamped, spun, or otherwise forced to assume the desired shape. Nondevelopable surfaces are often produced by a combination of developable surfaces which are then formed slightly to produce the required shape. Practical applications of developments are found in pattern making, and sheet-metal work. It is common practice to draw development layouts with the inside surfaces up. In this way all foldline and other markings are related directly to inside measurements, which are the important dimensions in all ducts, pipes, tanks, and other vessels; and in this position they are also convenient for use in the fabricating shop. Extra material must be provided for laps or seams. If the material is heavy, the thickness may be a factor, and the crowding of metal in bends must be considered. The draftsman must take stock sizes into account and should make his lay-

outs so as to economize in the use of material and labor. In preparing developments, it is best to put the seam at the shortest edge and to attach the bases at edges where they match, so as to economize in soldering, welding, or riveting.

7-12. To Develop a Right Cylinder

Cylinders and cones may be developed in their rolled-out-flat shape by constructing the position of the generatrix at regular intervals and connecting the end points with a straight-edge or French curve depending upon the object being developed. Figure 7-14 shows the steps in drawing the development of a right circular cylinder as follows:

a. Draw the stretchout line for a distance estimated to be slightly longer than the perimeter of the base.

b. The top view, showing the base of the cylinder, is subdivided into a number of equal parts. The number of subdivisions must be great enough (say 12, or 30° segments) that the length of the chord measured by the dividers is nearly equal to the length of the arc subtended by the chord.

c. With the dividers set to the length of one subdivision of the base (B), step off the same number of spaces in the stretchout line as stepped off on the perimeter of the base.

d. Erect perpendiculars at the end points (1 and 1), and mark height A on the development by projection from the front view.

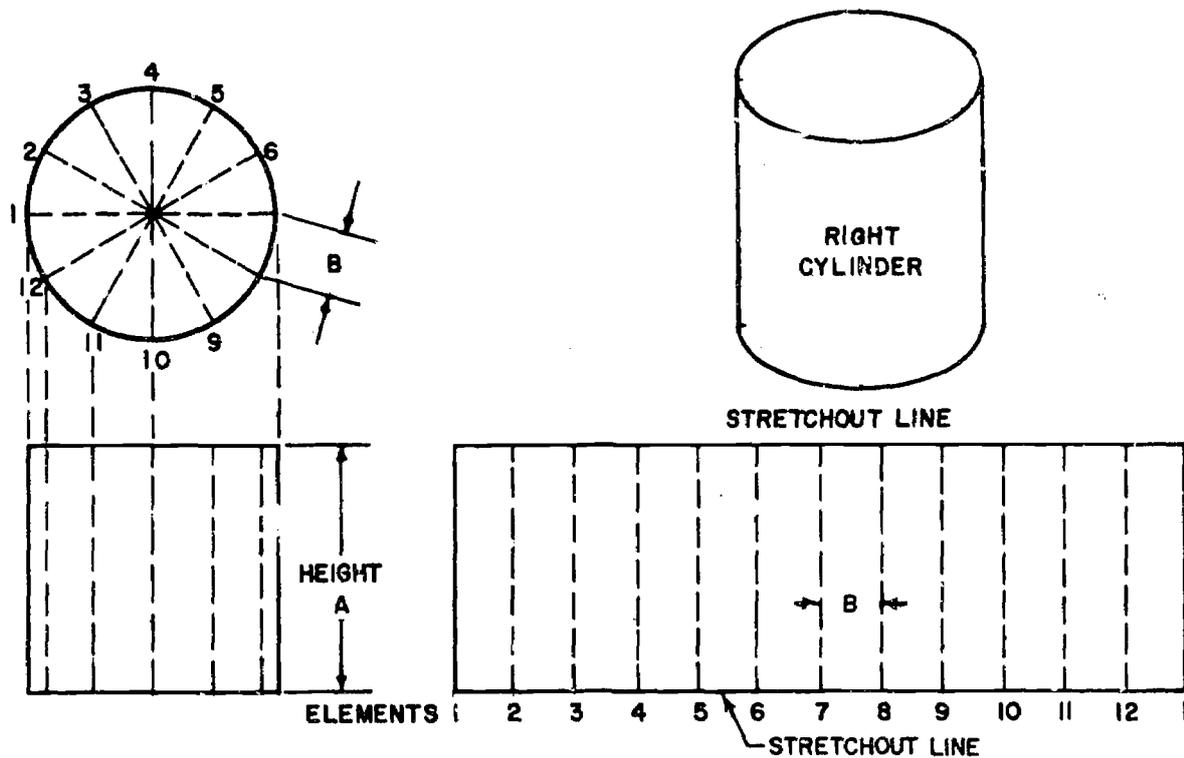


Figure 7-14. Developing a right cylinder.

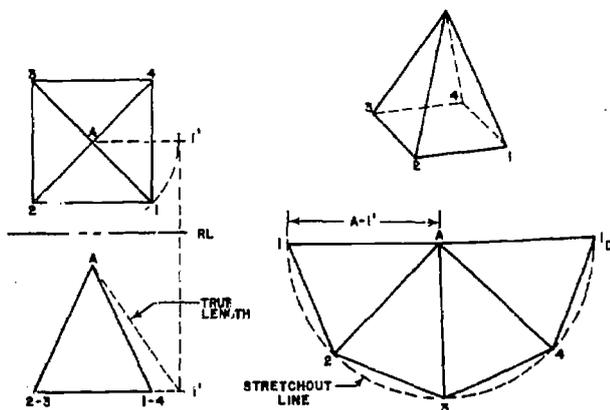


Figure 7-15. Developing a right pyramid.

7-13. To Develop a Right Pyramid

a. Right Pyramids. A right pyramid (fig. 7-15) is a solid bounded by plane surfaces. The sides are triangular and meet at a point called the apex. The base adjoining is a polygon. The axis is a straight line adjoining the apex with the midpoint of the base. The altitude is a perpendicular from the apex to the base. The altitude and axis coincide.

b. Views. Draw the front and top views. To develop a pyramid, it is necessary to draw the true shape of each side because all edges of a pyramid are equal in length; the true length of one edge and one side of the base will permit

drawing the developed view. As stated previously, any line parallel to a reference line will project in its true length in the related view. If line A1 is revolved, pivoting at A, so that it is parallel to the reference line between the top and front views, it will project in its true length in the front view. The edge of the base, 1-2, is parallel to the reference line and projects in its true length in the front view.

c. Development. Establish any point A and swing an arc with a radius equal to the true length of a side as shown in the front view (A-1, fig. 7-15). From any starting point on the arc, step off four distances on the arc equal to the edge of the base, 1-2, and to each other. Connect the points so established to each other with successive straight lines to establish the bend lines along which the developed shape is folded to form the lateral surface of the pyramid.

7-14. To Develop a Truncated Pentagonal Prism

When a solid has all of its surface areas made up of plane figures, the development is made by constructing the surface areas in the same sequence in which they must be when the development is unfolded. It is necessary to select which edges will be cut for opening, and which edges will be fold or bend lines when the development is unfolded. Usually the cut lines are taken as the shortest

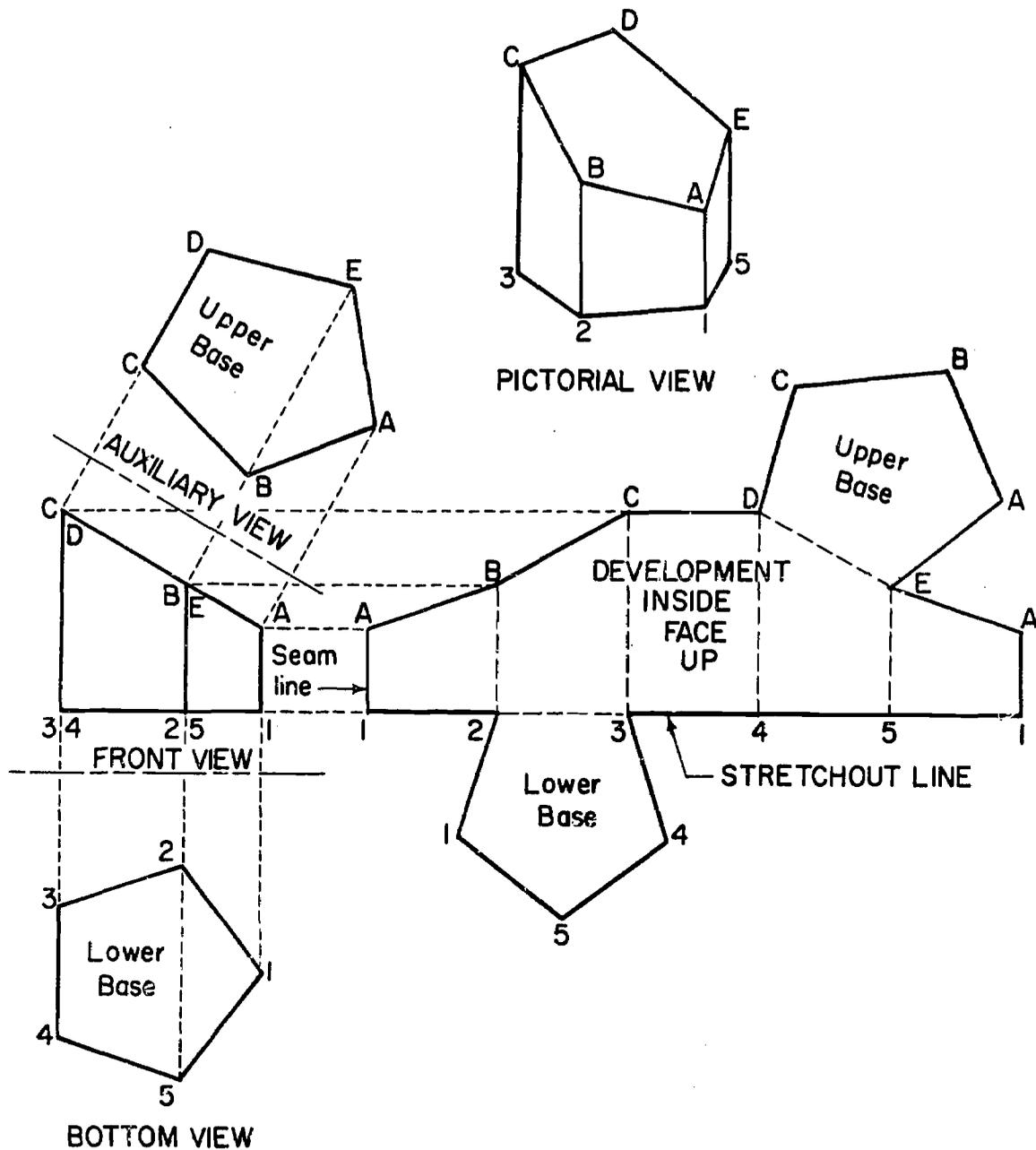


Figure 7-16. Developing a pentagonal prism.

lines in order to save time and material in making seams. Figure 7-16 shows the development of a regular pentagonal prism, cut by a plane $ABCDE$ not parallel to the base making it a truncated prism. The procedures are:

- Draw a stretchout line or baseline and measure off five equal spaces, equal to the edges of the base pentagon.
- Draw vertical construction lines at each point (1, 2, 3, 4, 5, and 1) measured off in step 1 along the stretchout line.
- Locate points lettered $A_1, B, C, D, E,$ and A by projection from the front view to the vertical con-

struction lines drawn in step 2, and join these points using a straightedge.

d. Draw auxiliary view, to find true size and shape of the upper base (top), and draw bottom view (lower base) of the prism.

e. Draw upper and lower bases by construction in their proper position on the development.

7-15. True-Length Diagrams

When developing a surface having many oblique lines, it is often more convenient to construct a true-length diagram than to draw double auxiliary views. The true length of many lines may

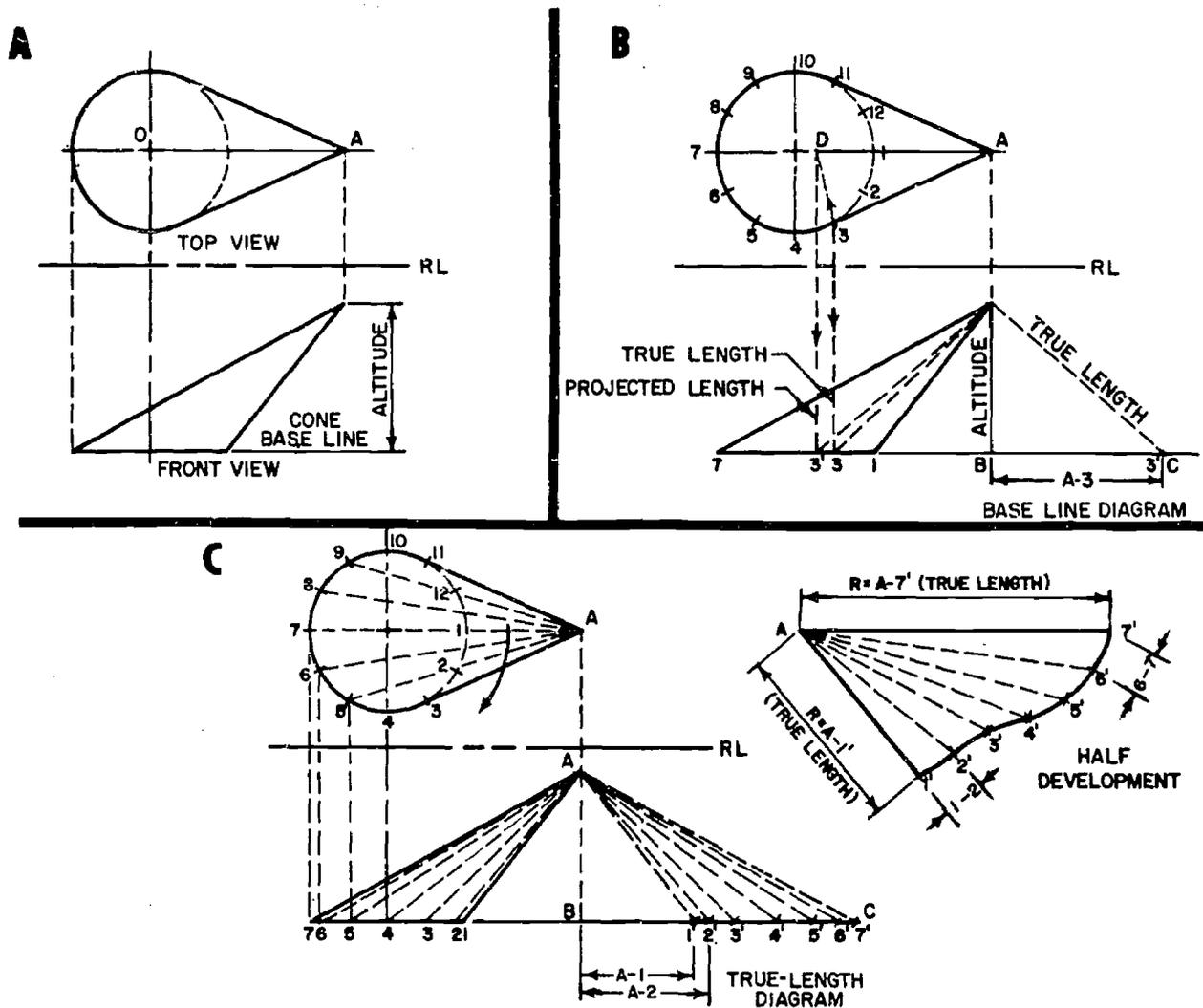


Figure 7-17. True-length diagram.

then be measured and transferred to the development with dividers. Figure 7-17 illustrates the construction of a true length diagram for the development of an oblique cone. Given the top and front views in block A, to draw the true length diagram and the development, proceed as follows:

a. Divide the base circle in the top view into a number of equal parts (12 parts are used in block B, figure 7-17). The point numbered 3 will be used to illustrate how to find the true length of an element such as the oblique line A-3.

b. Set dividers on the end points of the oblique line, A and 3, in the top view of block B and then with A as a center, swing or rotate the line A3 until it is parallel to the reference line RL in position AD. The line AD will project to the front view in its true length A3'.

c. The same result is obtained in the diagram to the right of the front view as follows. Extend the baseline of the front view a convenient length to

C, and drop a perpendicular from vertex A to the baseline at B. With dividers, transfer the distance A3 from the top view to the baseline of the diagram, measuring from B to locate the point 3'. Then the distance A3' in the diagram is the true length of the element A3.

a. Block C (fig. 7-17) shows how this diagram is used to find the true lengths of the oblique elements of the cone as numbered in the top view. The development consists of constructing a series of adjacent triangles with the true lengths of the elements being taken from the true length diagram, and distances between points 1-2, 2-3, 3-4, and so on, being taken from the base circle in the top view. The points 1', 2', 3' and so on, are joined by using a French curve. Only half of the development is shown in block C, figure 7-17. Carefully observe that the true length of a line can be found by rotating it into a position parallel to a projection plane, and then projecting its true length on that plane.

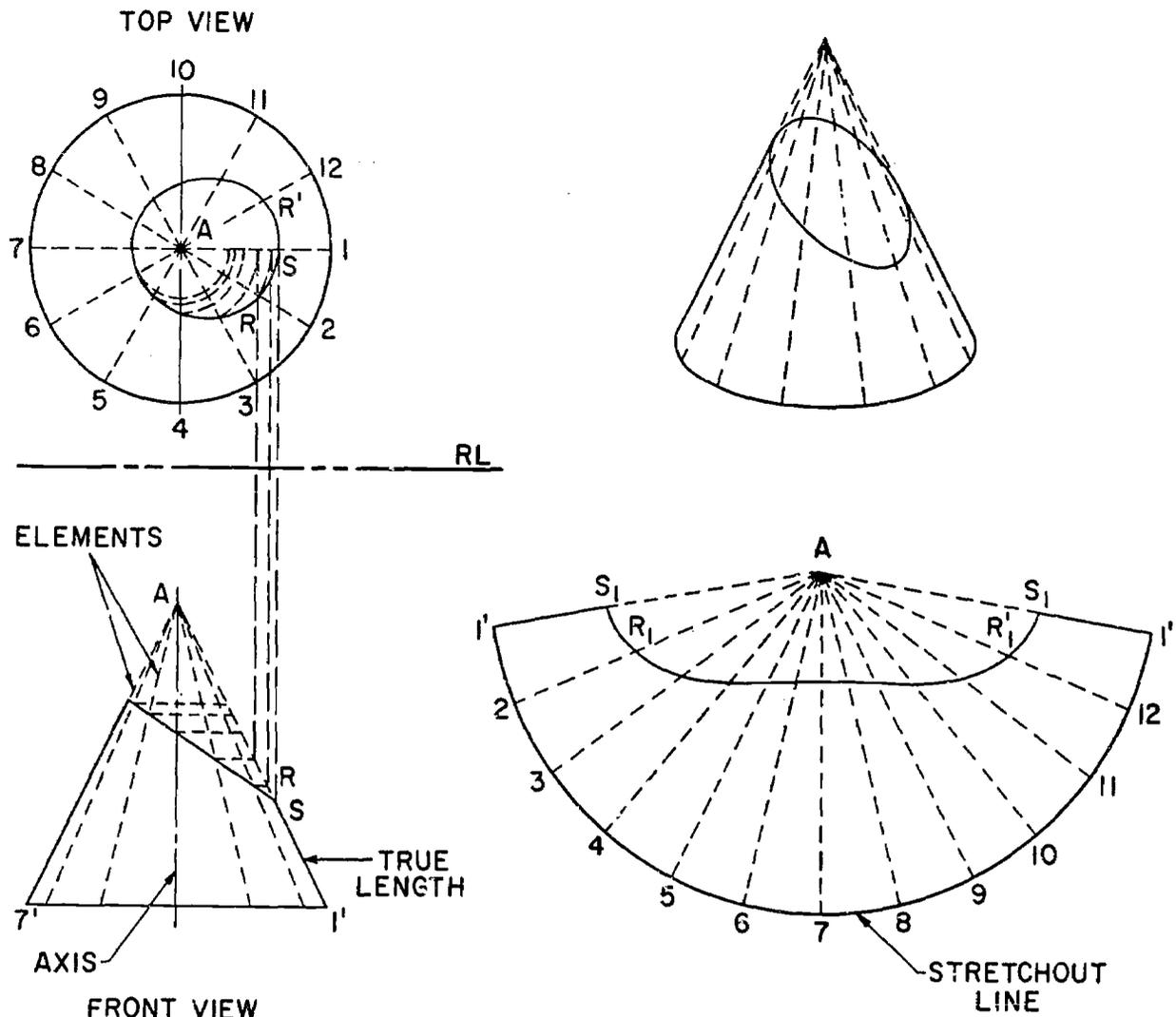


Figure 7-18. Developing a truncated cone.

7-16. To Develop a Truncated Cone

a. Cones. A cone is a solid bounded by a single-curved surface. The surface is generated by a straight line, one point of which is fixed, moving along the path fixed by the curved base. Each position of the generating line is an element of the surface. The axis of a cone is a straight line connecting the apex with the center point of the base. The altitude is a perpendicular from the apex to the base. When the altitude and axis coincide, a right cone results; when they do not coincide, the cone is oblique.

b. Views. Draw the top and front views as shown in figure 7-18. Divide the top view into any convenient number of equal segments. Note that the front view shows the cut surface, or frustum is revolved to line A-1, which projects in its true length in the front view. The true-length projection established the slant height of the cone. The points of the frustum are projected to line A-1 in the front view.

c. Development. Use line A-1' in the front view as a radius and swing an arc from any point A. The extent of the stretchout line may be computed from the formula

$$\frac{r}{s} \times 360^\circ$$

where

r = radius of the base
 s = the slant height of the cone

or it may be established by transferring measurements from the perimeter of the top view to the stretchout line. Number all the points and draw element lines to them from A. Establish the perimeter of the top face by measuring along line A-1' in the front view from A to the points projected from the top view. Transfer these measurements to the appropriate element in the development and connect the points with an irregular curve.

7-17. To Develop an Oblique Cone

a. Views. Draw the top and front views as

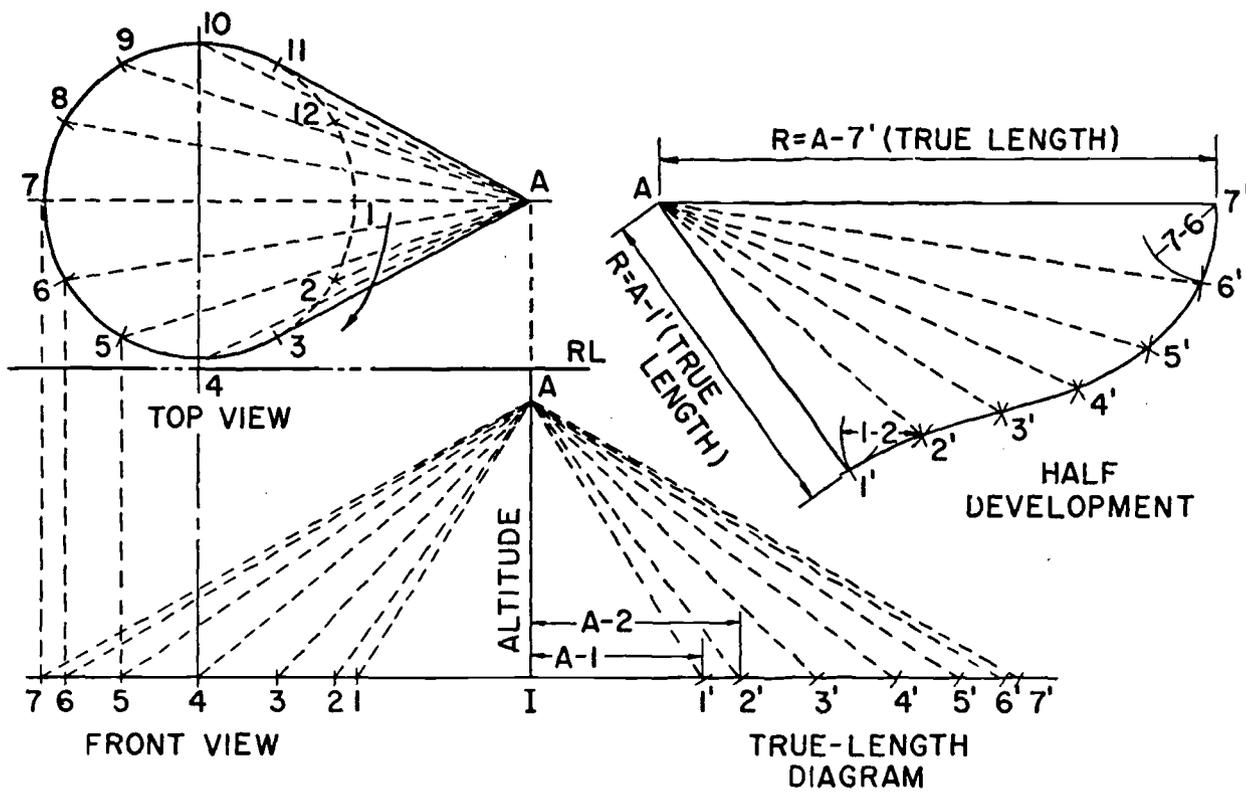


Figure 7-19. Developing an oblique cone.

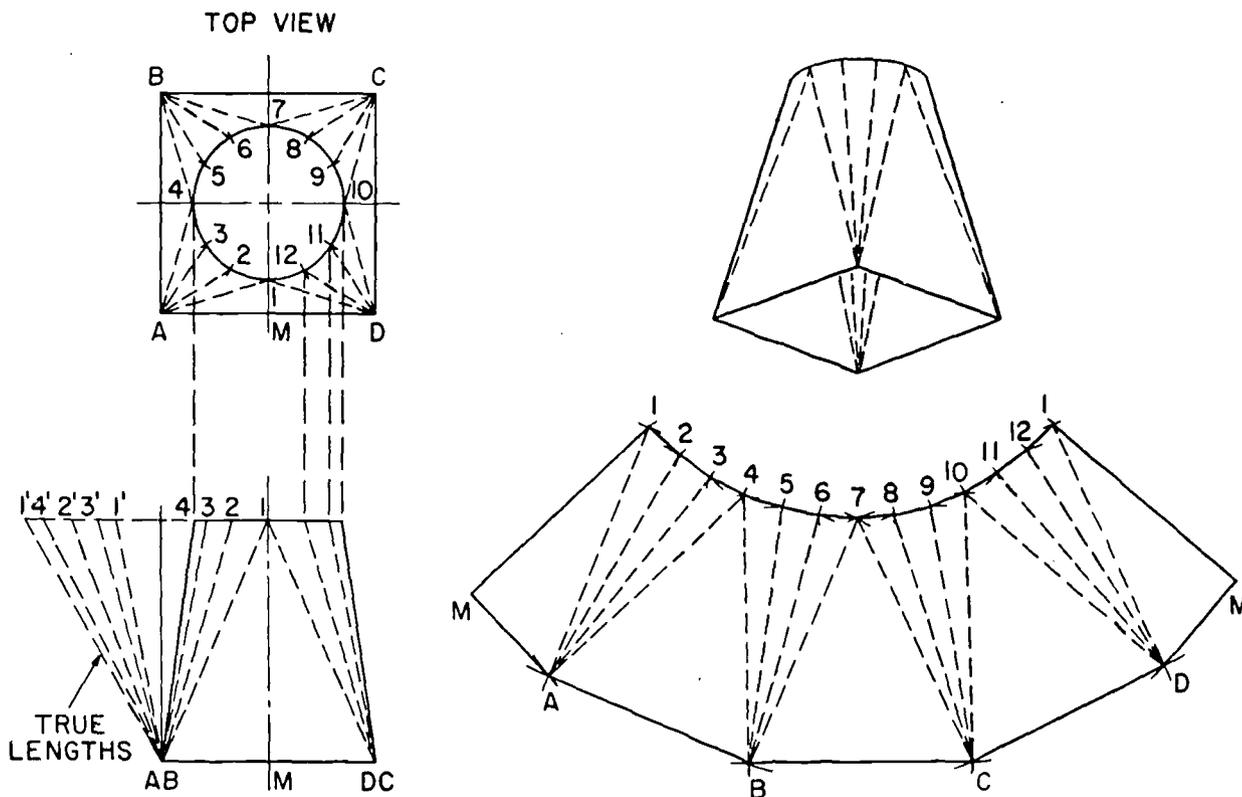


Figure 7-20. Developing a transition piece.

shown in figure 7-19. Extend the base line drawn in the front view and establish an altitude $A-I$ perpendicular to it. The vertical height of the altitude is projected from the front view. Construct the true-length diagram by the right-triangle method as described previously.

b. Development by Triangulation. Nondevelopable surfaces can be developed by approximate methods. The most common method is to divide the surface into small developable surfaces, in this case, triangles. The triangles constructed in the true-length diagram of figure 7-19 are laid out consecutively in their true shapes. Establish A at any convenient point and draw a line from A equal in length to $A-7'$ in the true-length diagram. To establish the point 6 in the development swing an arc, with A as center, with a radius equal to line $A-6'$ in the true-length diagram; intersect the arc with a second swing with point 7 as center and equal in length to the true distance $7-6$ taken from the top view. Establish the necessary points of the half development with intersecting arcs swing from point A and successive points along the perimeter of the base. Distances of the long arcs are obtained from the true-length diagrams, and the distances of the short arcs are obtained from the top view. When all points in the half development have been established, draw the element (or bend) lines and connect the points with the aid of an irregular curve. The development, although only approximate, is accurate enough for most practical purposes.

7-18. To Develop a Transition Piece

a. Transition Pieces. Transition pieces are used

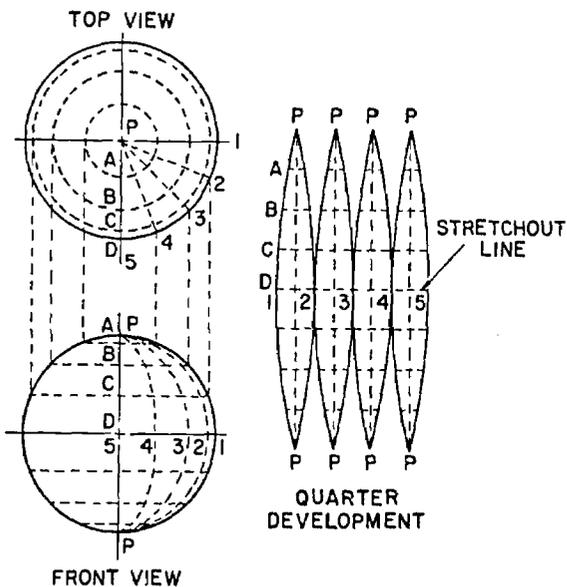


Figure 7-21. Developing the surface of a sphere, gore method.

frequently when fabricating ducts or other sheet metal constructions to connect openings of different shapes or sizes. The transition piece shown in figure 7-20 connects a rectangular duct with a circular pipe. An analysis of the pictorial view reveals that the surface may be broken down into four isosceles triangles the bases of which form the square base connecting the piece to the duct, and four conical surfaces the upper edges of which form the circular opening connecting the piece to the round pipe. The development is achieved by taking the component surfaces separately and developing each in succession, proceeding around the entire piece until the complete surface has been developed.

b. Views. Draw the front and top views as shown. The conic surfaces are triangulated and the true lengths of their elements are obtained by constructing a true-length diagram adjacent to the front view. The true lengths of the edges of the rectangular base and the segments of the circular opening are shown in the top view.

c. Development. Establish point M at any convenient location and draw line $M-1$ as it appears in its true length in the front view. Next establish point A by swinging a short arc from point M equal in radius to the distance $M-A$ in the top or front view and intersecting this with a long arc swung from point 1 and equal in radius to line $A-1'$ in the true-length diagram (fig. 7-20). Draw lines $M-A$ and $M-1$ in the development. Establish successive points by triangulation, using the true lengths of the lines or segments as the radii of the arcs. When all the points along the perimeter of the circular opening have been established, they may be connected with an irregular curve. The remaining points are connected with a straight-edge.

7-19. To Develop the Surface of a Sphere

a. Spheres. The surface of a sphere is a double curved surface generated by a curved line and containing no straight-line elements. Double-curved surfaces can be developed only by approximate methods. As stated previously, development by approximate methods requires dividing the complete surface into small segments that are developable.

b. Views. Draw the top and front views as shown in figure 7-21. The sphere is considered cut by a series of planes passed perpendicularly to the axis in the front view. Their projection in the top views shows them as circles. A quarter section of the sphere is cut by vertical planes. Their projec-

tion in the top view represents them as edges. Although the development of only one quarter is described here, the remaining quarters are developed in the same way.

c. Development. The development of one longitudinal section provides the pattern for the re-

maining sections. Line *D* is the stretchout line. The height of each section, *PP*, and the vertical spacing between the horizontal cutting planes are taken from the front view. The widths of successive segments are taken from the top view. Each section is symmetrical about *PP* and the stretchout line. A full development requires 16 sections.

CHAPTER 8

MULTIVIEW PROJECTIONS

Section I. PROJECTIONS

8-1. Orthographic Projection

The purpose of any mechanical or construction drawing is to illustrate and describe an object in sufficient detail and clarity so that the correct interpretation is made by any manufacturing or producing agency. To achieve this purpose, a drawing must be made in strict accordance with accepted practices. The accepted method of representing the accurate shape of an object is based on a system known as orthographic projection. This system is comprised of a series of separate views which are interrelated and dependent upon

each other. The proper drawing procedure for constructing these views will be described in this chapter.

8-2. Military Purpose

In the military, orthographic projection is used primarily because of its concise and complete descriptive information and is the accepted method of engineering drawing. It is necessary that any one connected with construction or fabrication be familiar with orthographic theory and be able to apply it in the form of multiview projections.

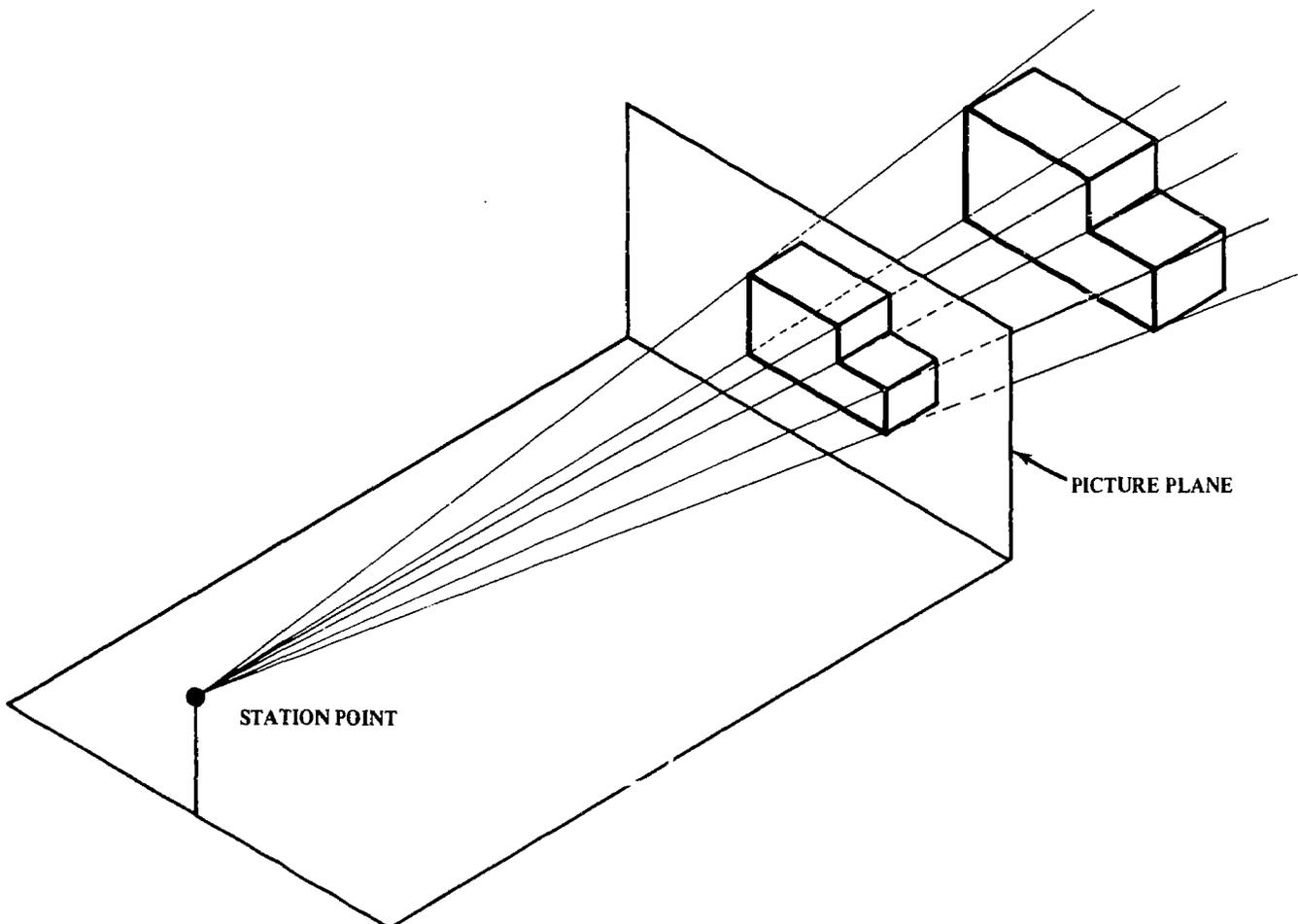


Figure 8-1. Perspective projection.

8-3. Theory of Orthographic Projection

Military draftsmen use the orthographic system of projection to describe the shape of machine parts and structures. The task which confronts him is to record the shapes and sizes of three dimensional objects on one plane. This plane is represented by a sheet of drawing paper. The other systems, axonometric and oblique, are also used, and are discussed in chapter 9. All are based on some form of projection. The theory governing a method should be clearly understood before it is used to prepare a drawing.

a. Perspective Projection. In order to better understand orthographic projection, an understanding of the principals of perspective projection are necessary. In this form of projection, the projecting lines (visual rays) all converge on a point set at a definite distance. Imagine an observer standing in one position and viewing an object from a fixed distance. Now imagine that a transparent plane is placed between the object and the observer's eye. If we mark every point where the projecting lines intersect the plane and connect them we form an outline of the viewed object. This outline is a *projection drawing*. The projecting lines are aptly called *projectors*; the eye is called the center of projection; and the transparent plane is referred to as the plane of projection (fig. 8-1). In perspective projection, objects closer to

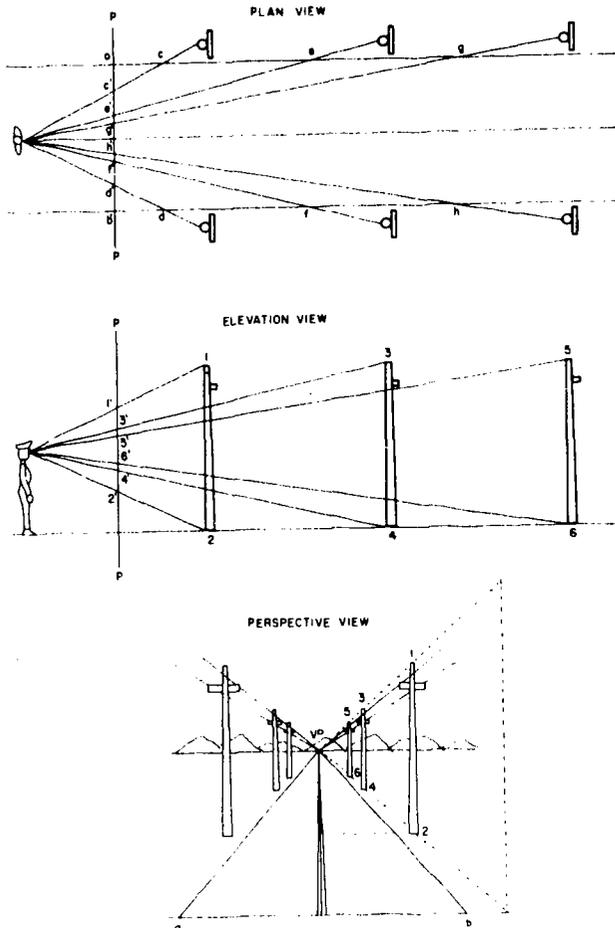


Figure 8-2. Theory of perspective projection.



Figure 8-3. A perspective drawing.

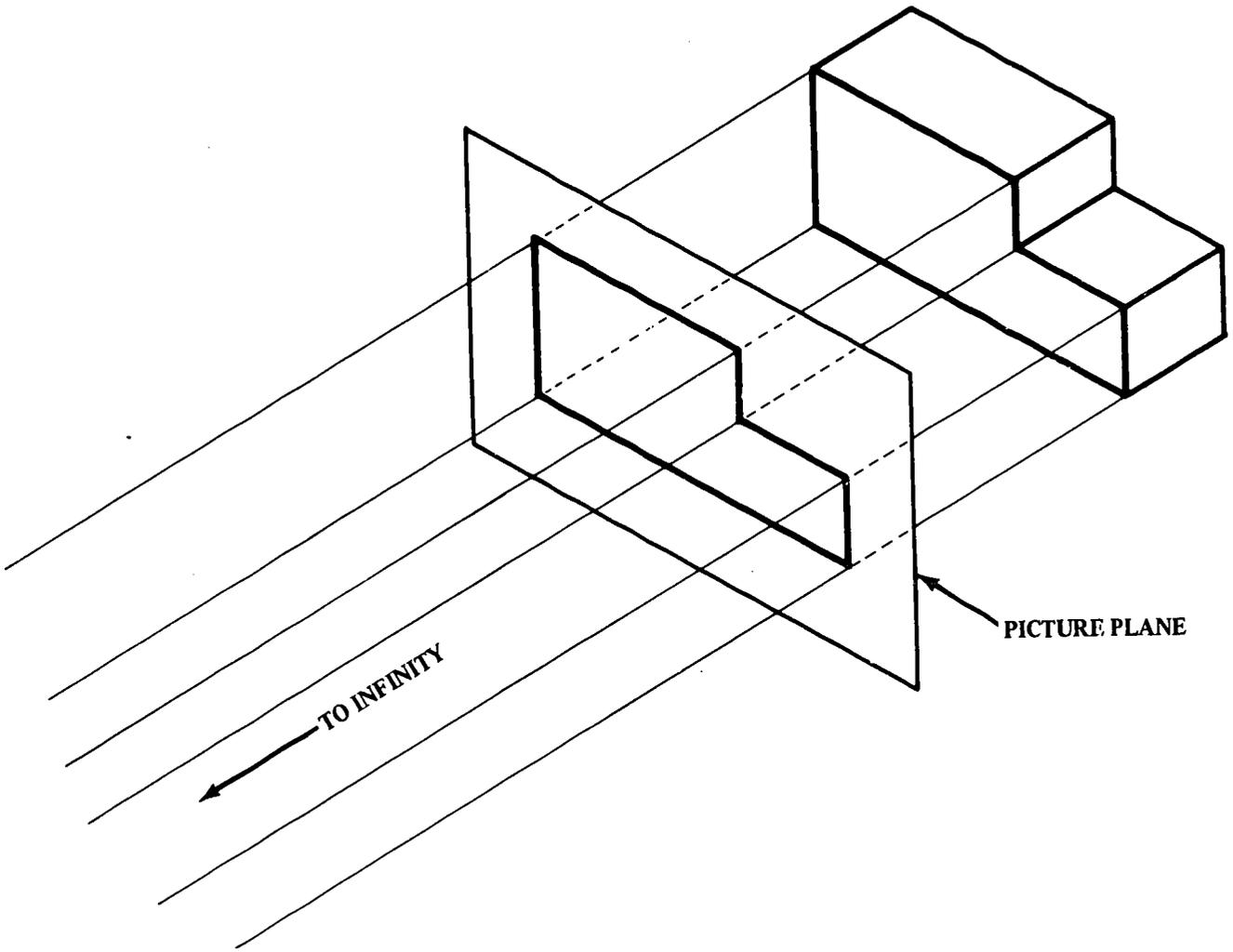


Figure 8-4. Orthographic projection.

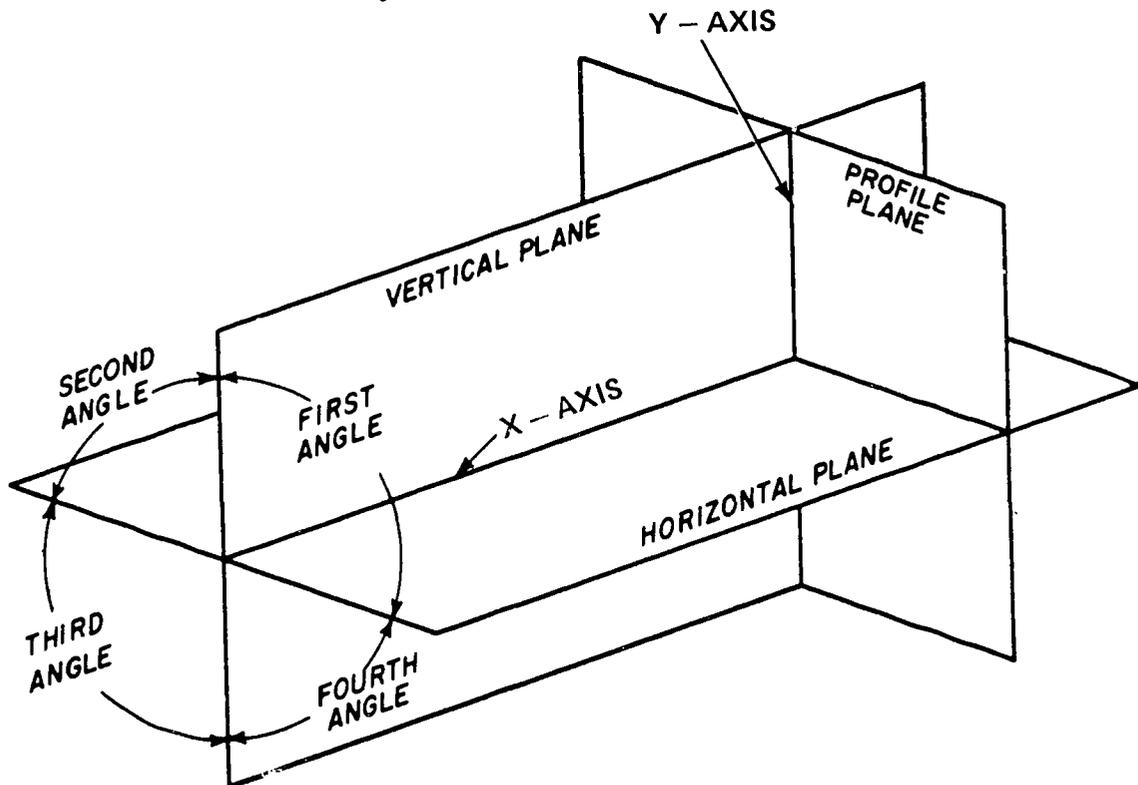


Figure 8-5. Angles of projection.

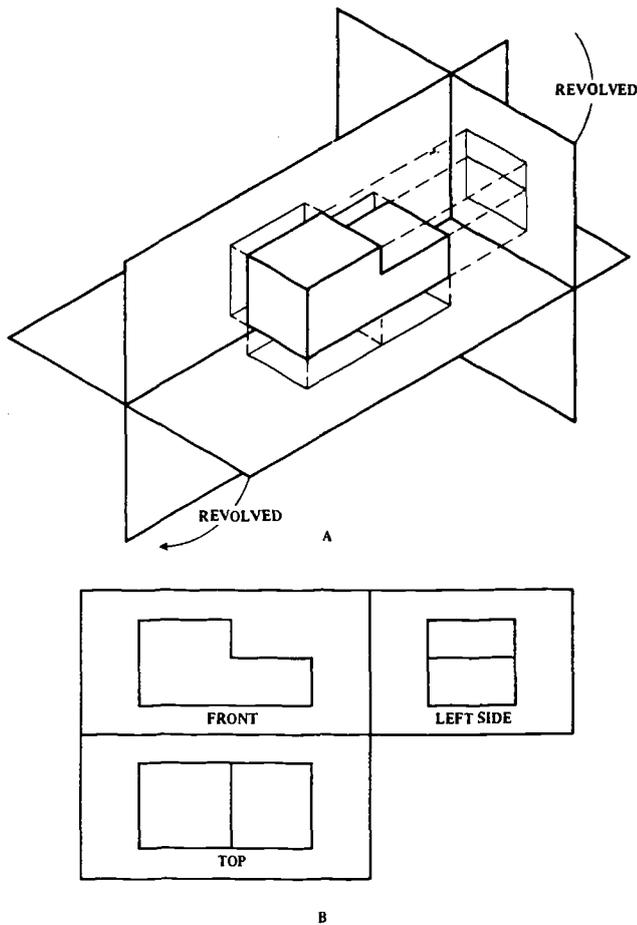


Figure 8-6. First angle of projection.

us appear large and seem to diminish the farther away they get. This is due to the projecting lines (visual rays) converging on one point (fig. 8-2). Because of this, perspective drawings do not show true size and shape and are not suitable for working drawings. Perspective drawings, however, are used for technical illustrations, preliminary sketches, and display drawings for proposed buildings (fig. 8-3).

b. Orthographic Projection. Referring again to the object and the viewer, should we move the observer straight back until he is at an infinite distance from the object and the plane of projection, the projection lines instead of converging are now parallel to one another and perpendicular to the projection or picture plane (fig. 8-4). The resulting image projected to the picture plane will be the same shape and overall size as the object. This view is called an *orthographic projection*.

c. Angles of Projection. The principal planes of projection are considered the vertical plane, profile plane, and the horizontal plane. These planes are assumed to revolve about a certain axes or hinge as was noted earlier. The horizontal plane

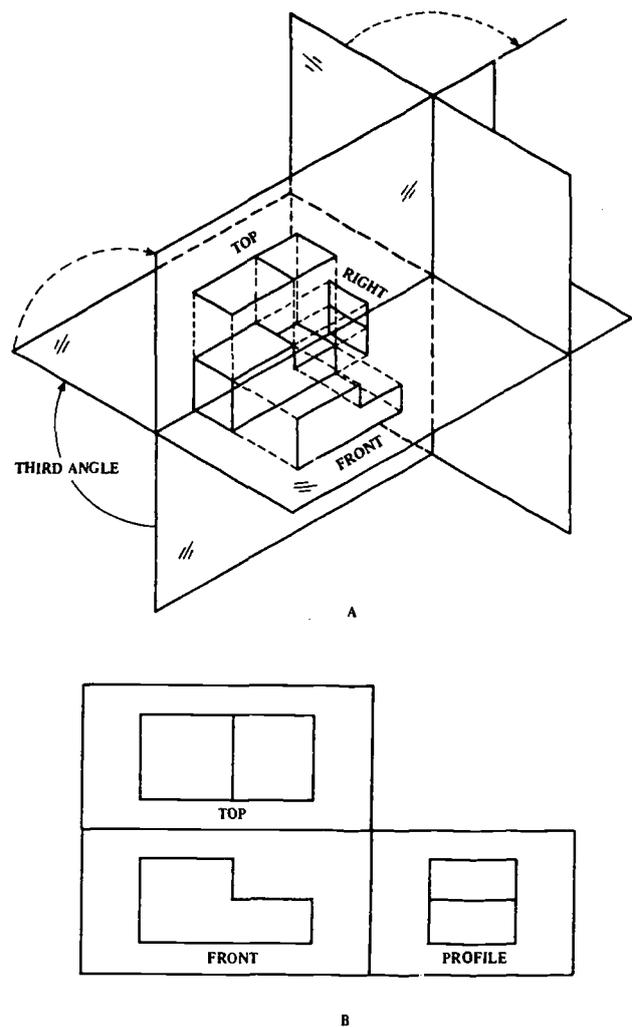


Figure 8-7. Third angle of projection.

revolves into position with the vertical plane using the X-axis. The profile plane assumes its position by way of the Y-axis. The intersection formed by the horizontal and vertical planes form four quadrants; each quadrant is considered an angle of projection and is titled as follows: first, second, third and fourth angles of projection. By placing an object in any one of the four quadrants, its surfaces can be projected to its respective plane (fig. 8-5).

(1) *First angle of projection.* If an object is placed in the first quadrant (A, fig. 8-6) and its surfaces projected to their respective planes, and the horizontal and profile planes revolved to the vertical plane, the views assume the following positions (B, fig. 8-6): top (horizontal) view is below the front (vertical) view, and the left side (profile) view is directly to the right of the front view. This system is used in most European countries for working drawings. However, it has been abandoned by draftsmen in this country for some-

time, although it is used occasionally by architects and structural designers.

(2) *Second and fourth angle of projection.*

When an object is placed in either the second or fourth quadrant and the profile and horizontal planes revolved into the vertical plane, the top view is superimposed on the front view. This overlapping impairs the clean visibility of either view and is ineffective in producing an accurate working drawing. Consequently, second and

fourth angle of projections are seldom, if ever, used for working drawings.

(3) *Third angle of projection.* In the United States and Canada, the third angle projection system is used. When an object is placed in the third quadrant (A, fig. 8-7) and projectors extended to their respective planes, the front view is on the vertical plane, the top view is projected on the horizontal plane and the side view is on the profile plane. When the planes, horizontal and profile, are revolved into position (B, fig. 8-7), the top (vertical) view appears *above* the front (horizontal) view, its natural position, and the *right* (profile) view falls to the *right* of the front view (fig. 8-7).

d. *Application of Third Angle Projection.* In order to better visualize the position of the object in the third angle projection, it is best to imagine the object as being suspended within a transparent glass box (fig. 8-8). All panels are hinged to the vertical panel, with the exception of the back panel which may be considered to be hinged to either the right or left panel (fig. 8-9). All panels swing away from the object to come on an equal line with the front panel. There exists six planes of projection (fig. 8-10): vertical or frontal, where the object is viewed from the front; profile, left and right, the object being viewed from the side; horizontal plane, the object as seen from above or below; and some instances when there

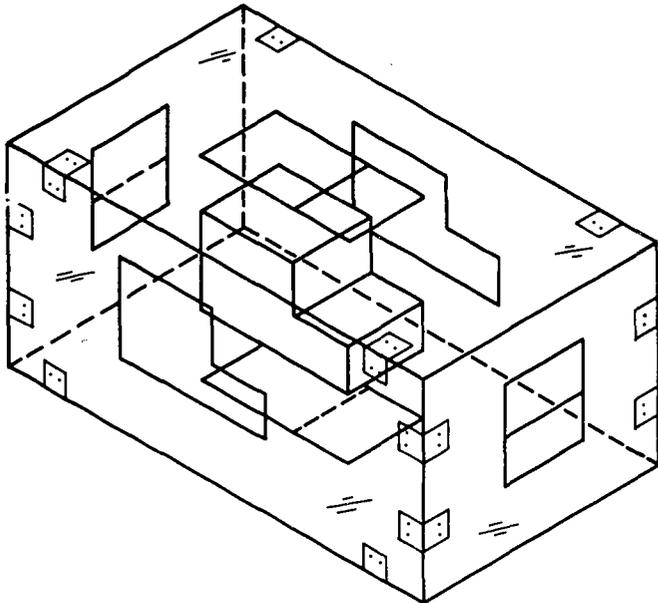


Figure 8-8. Suspended object in a glass box.

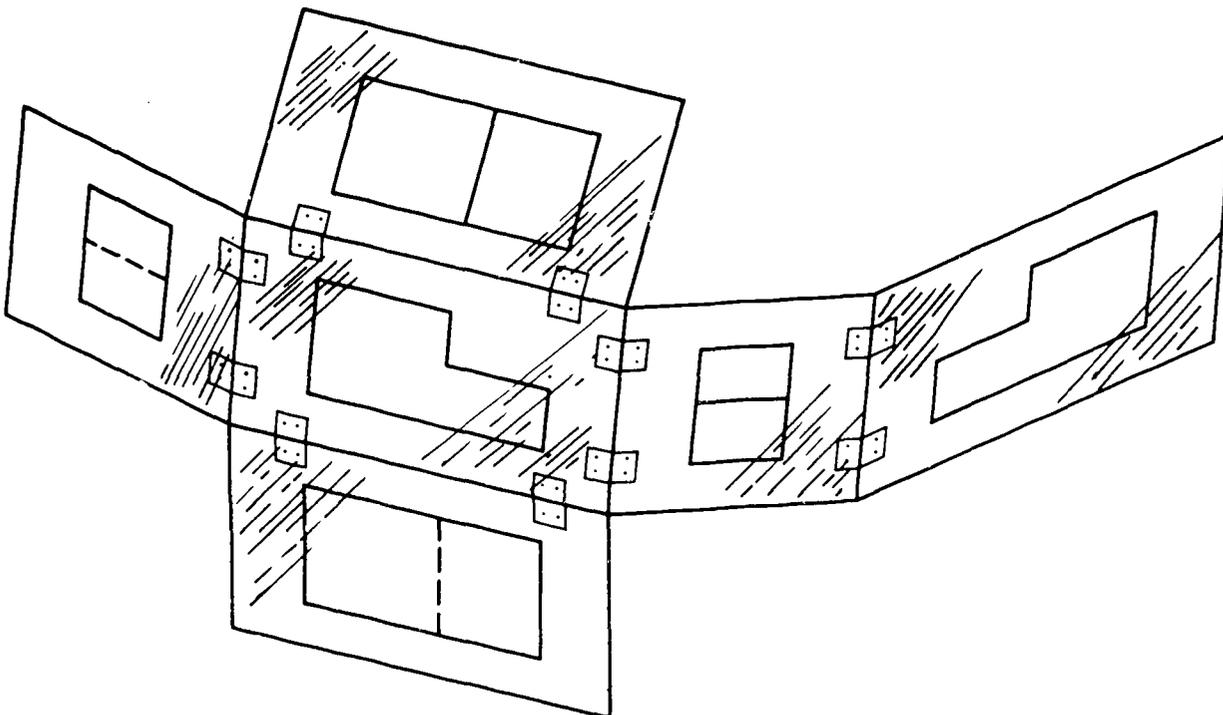


Figure 8-9. Unfolding glass box.

are distinct features on the rear or back of the object, a rear plane is used.

8-4. Selection and Spacing Views

Careful consideration should be given to the general outline of an object before final views are

selected. A few basic principles should be observed and understood before attempting to make an orthographic drawing. Only views which provide clear and complete description should be used. Views which repeat information tend to be confusing, and are a waste of time and effort.

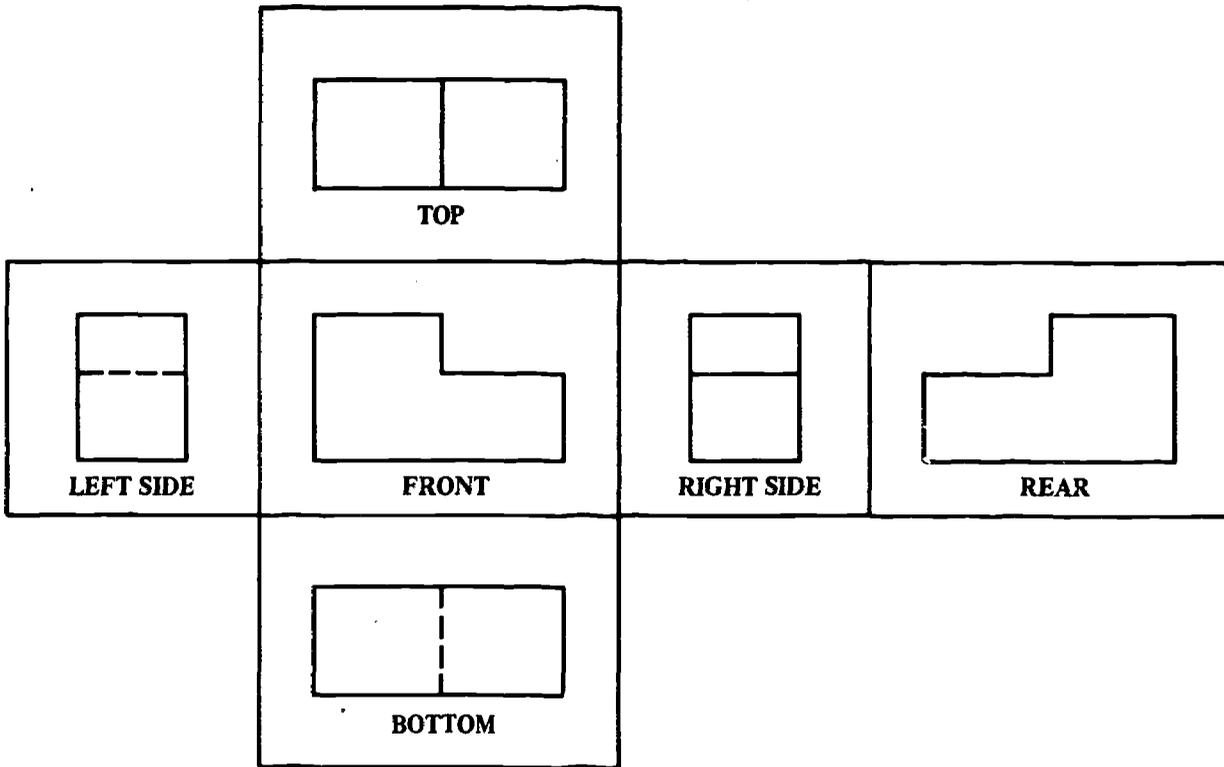


Figure 8-10. Flattening box to paper plane.

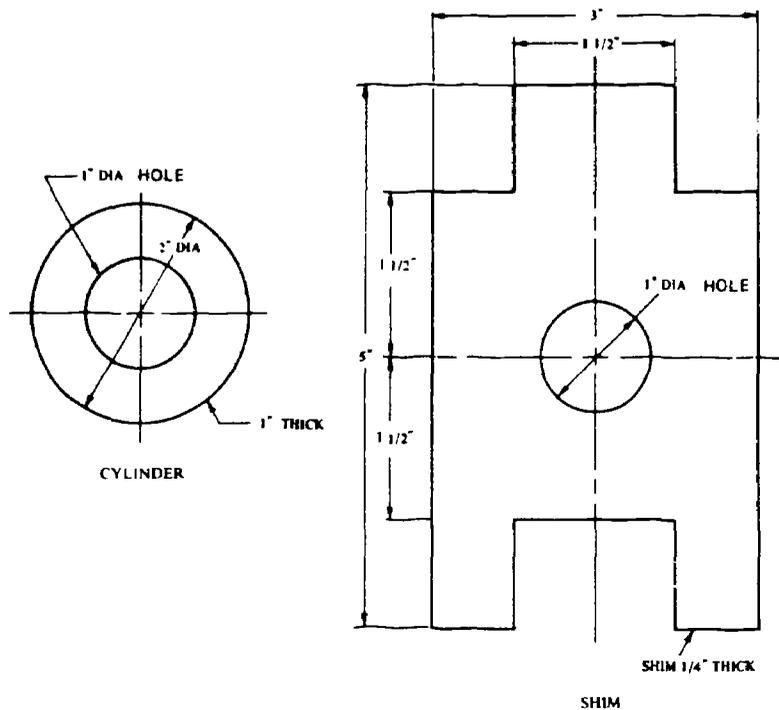


Figure 8-11. One view drawings.

Since one view reveals only two dimensions, for example height and length, one or more additional projections may be needed to complete the description. It is very important that the view selected to represent the front shows the most characteristic shape of the object. What may normally be considered as the front surface of an object should not be selected as the front view if this surface fails to show the most characteristic contour shape. Position the object so that the least amount of hidden lines appear in the views. When a choice arises between two equally important views, as between a top and bottom view or right

and left side view, the rule is to use the top view in preference to the bottom view, and a right side view in preference to a left side view.

a. One View Projection. In such cases as a cylinder or shim (fig. 8-11), it may be possible to use only one view. When describing the profile view of a cylinder, giving the height accompanied by a note giving the diameter, it may not be necessary to show an additional view of a circle. In the case of a shim where one view shows the general outline and cutouts with a note stating that it is $\frac{1}{4}$ inch thick, it is not necessary to show other views of $\frac{1}{4}$ -inch-thick strips.

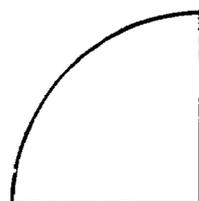
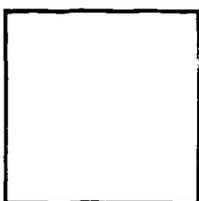
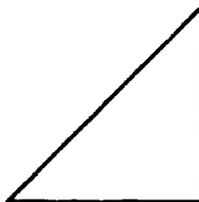
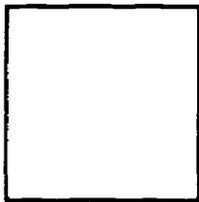


Figure 8-12. Two view drawings.

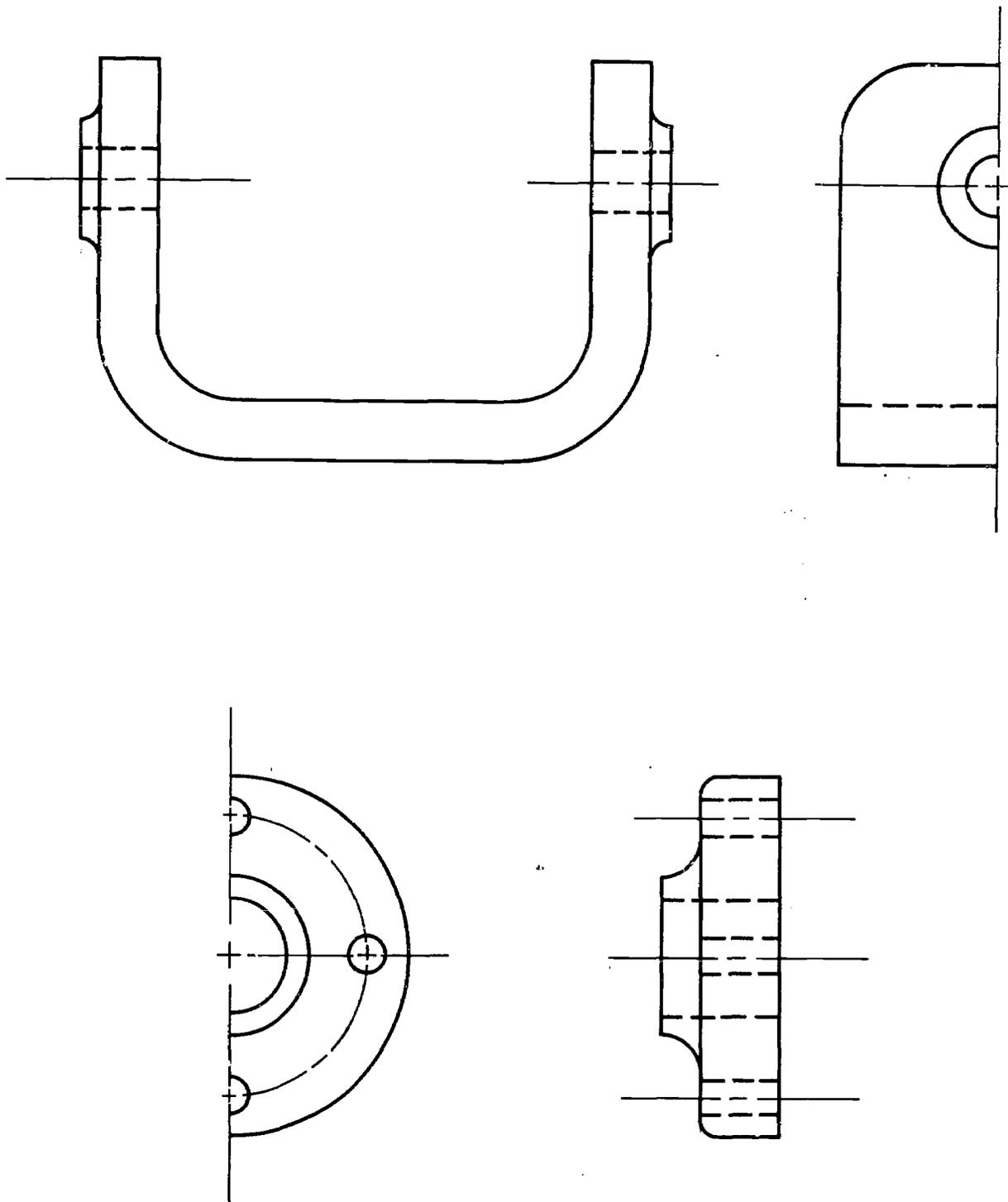


Figure 8-13. Partial views.

b. Two View Projection. Sometimes two views (fig. 8-12) are sufficient for an object presuming that the contour in the third view is of the shape that would naturally be expected. In such familiar objects such as bushings and bolts or simple objects, two views may provide enough information to completely describe the object.

c. Partial Views. Symmetrical objects may be

represented by partial (fig. 8-13) views when space is critical on a drawing. The partial view should always be nearest to the full view except when the full view is a section view. Remember how the different planes are revolved. It is permissible to use the front, top or side views as partial views.

d. Three or More Views. Normally three views

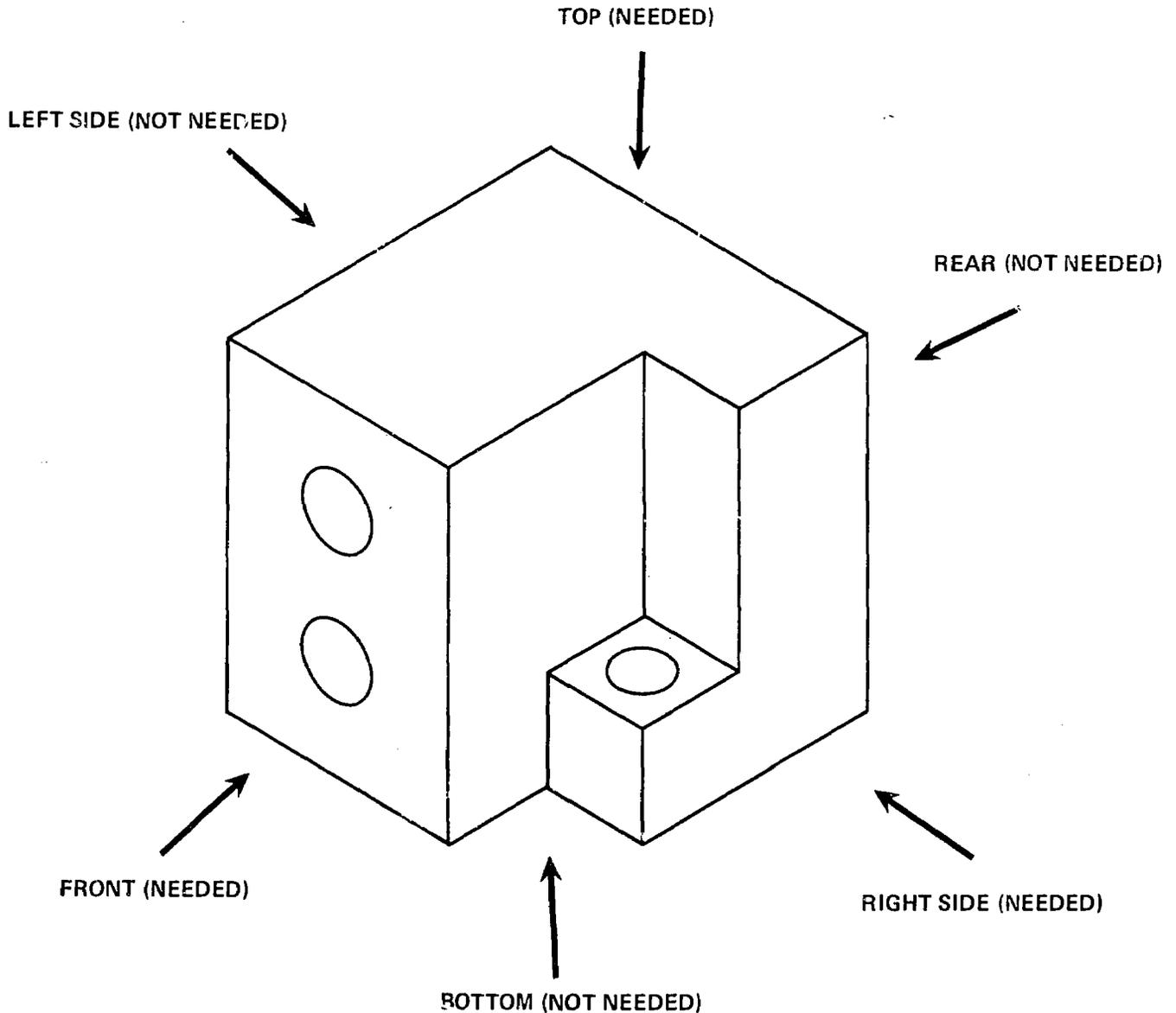


Figure 8-14. Three-view selection.

(fig. 8-14) of an object are shown in its functioning position, with its principal surfaces parallel to the planes of the projection. More views are required for complex objects with special features. Refer to sections II and III for views of complex objects.

8-5. Special Surfaces

a. Inclined Surfaces. When a surface recedes at an angle to the observer's viewpoint, the surface will not appear in its true length in that particular plane. Its appearance will be a foreshortened view of its actual size. In adjacent planes, its true length will appear as a line because the surface is perpendicular to these planes. Such surfaces are called inclined surfaces. These surfaces may be easily constructed by projection (fig. 8-15).

b. Oblique Surfaces. Should a surface be at an angle to all the principal planes or projection, it is an oblique surface (fig. 8-16). Such a surface will not appear in its true size and shape in any normal plane. Unlike the inclined surface, an oblique surface is not perpendicular to any regular plane of projection and therefore it will not appear as a line. Oblique surfaces require another type of projection known as a secondary auxiliary view (para 8-13 and 8-14).

c. Curved Surfaces. Curved surfaces (fig. 8-17) assume different appearances on various planes of projections. When a curved line, or a circle, is parallel to a plane of projection, it will appear as a curve, or circle, on that plane. On adjacent planes, it will appear as straight lines. The tangency points on a continuous curved line whose centers are perpendicular will appear as a line in

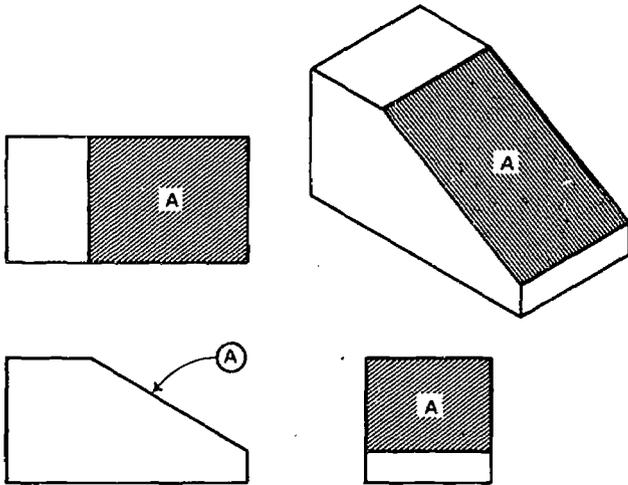


Figure 8-15. Inclined surfaces.

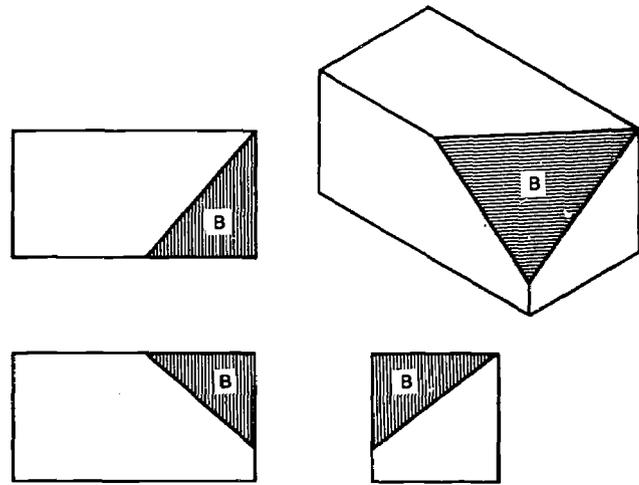


Figure 8-16. Oblique surfaces.

the plane of projection. If the centers are at an angle, no line is shown.

8-6. Rounds, Fillets and Runouts

Rounded corners are made from specially constructed molds. In making these castings, extra care is taken to eliminate sharp corners. Rounded corners give greater strength and permit an object to be handled with more ease. Smoother intersections will generally improve the appearance.

a. *Rounds.* When a rounded intersection occurs on an outside edge it is called a round (fig. 8-18).

b. *Fillets.* Fillets are rounded intersections on inside corners (fig. 8-18).

c. *Runouts.* When rounds and fillets intersect, they are referred to as runouts. They are represented by an arc or curve having the same radius as the fillet or round. Whether the arc turns inward or outward is determined by the shape and thickness of the filleted area (*d* below).

d. *Drawing Procedure.* Curves representing runouts, fillets and rounds may be drawn freehand, with a compass, or with a French curve. The curve should be kept smaller than a quarter of a circle. Fillets and rounds are not dimensioned. A note is used near the principal view or is included in the general notes. Example: "All fillets and rounds to be $\frac{1}{8}$ -inch radius unless otherwise noted." Typical filleted intersections are shown in figures 8-19, 8-20, and 8-21. The runouts shown in figure 8-19 differ because of the different shapes of the horizontal intersecting members. In figure 8-20, the runouts differ because the top surface of the web at (A) is flat, with only slight

rounds along the edge, while the top surface of the web at (B) is considerably rounded. The correct method of representing fillets in connection with plane surfaces tangent to cylinders is shown in figure 8-21. These small curves are called runouts; note that they terminate at the point of tangency.

8-7. Precedence of Lines

In some instances, visible lines, hidden lines and center lines will fall on each other. Since a true description of the object is paramount, visible lines take precedence over all other lines. Hidden lines have precedence over center lines. In many instances center lines will coincide with a cutting plane symbol. The line that contributes most to the clarity of the object should take precedence. Care should be exercised in placing dimension and extension lines so that they do not coincide with other important lines on the drawings (chap 3).

8-8. Drawing Procedure

The first step in laying out a three-view drawing is to first carefully examine the object to be drawn. After selecting the appropriate views and scale to be used, block in the views in light construction lines. Wherever possible, views should be symmetrical and well balanced. Large open or empty spaces should be avoided and in most instances can be eliminated by changing the object's position. Ample space must be left between views for the additional information such as notes, dimensions, and titles. Rarely can one view be completely constructed without reference to the other views. It is good practice to complete as much of the front view as possible and then, transferring points to the top and profile views, construct the

latter. Points may be transferred by actual measurement or with dividers (fig. 8-22). A simple method used in projection of points to adjacent views is accomplished with T-square and triangle. Points may be directly projected to the top view and side view with the T-square and triangle alone (fig. 8-23). By constructing a 45° miter line to the front view, points may be projected from the

top view to the side view (fig. 8-24). Points are first extended with the T-square to the miter line and then projected down to the side view. In this manner, all three views may be completed.

8-9. Representing Hidden Features

a. *Use of Hidden Lines.* The prime purpose of

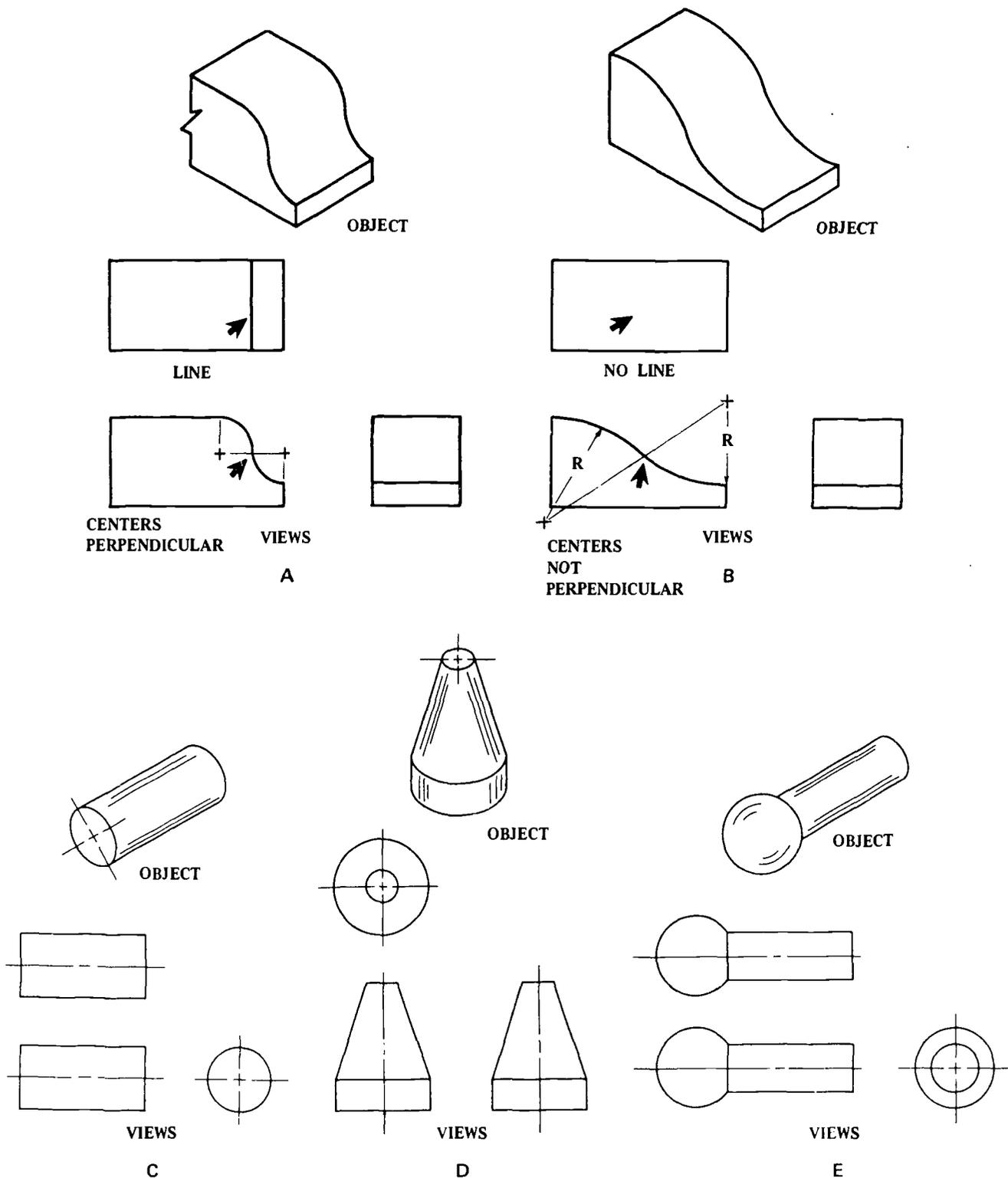


Figure 8-17. Curved surfaces.

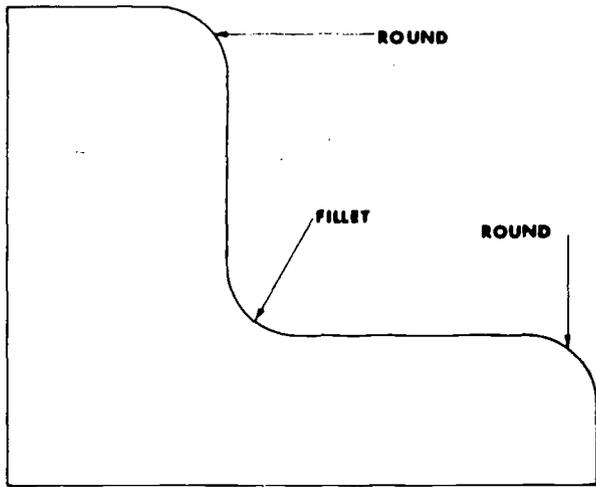
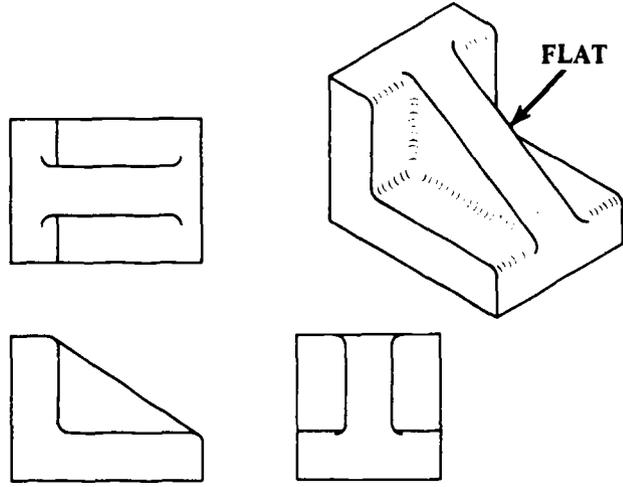


Figure 8-18. Rounds and fillets.



A

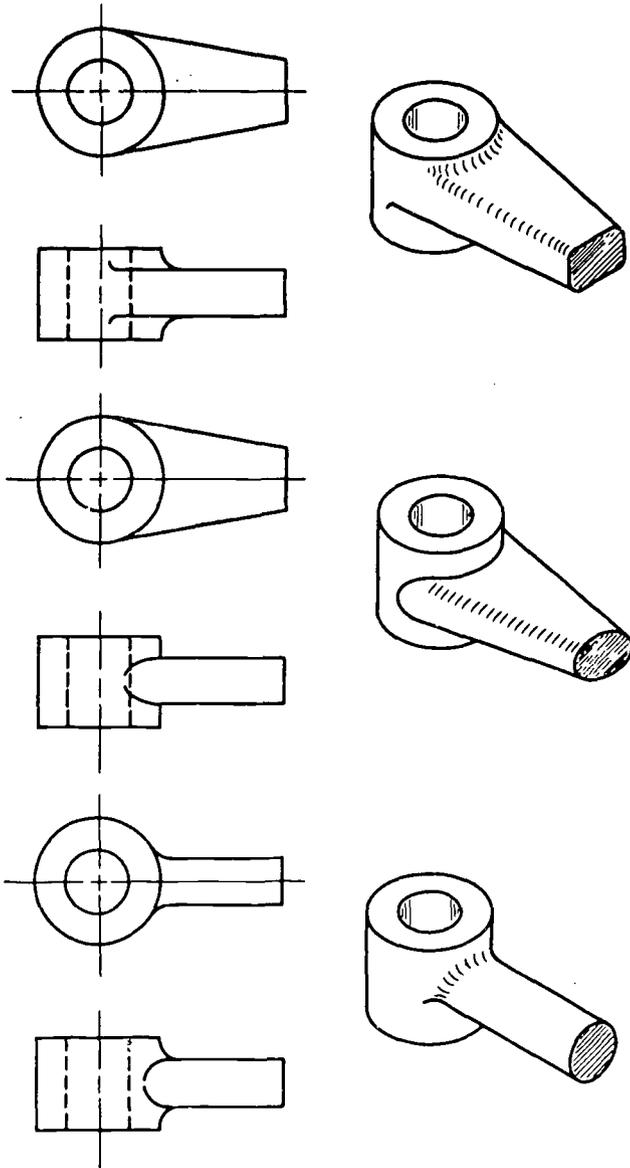
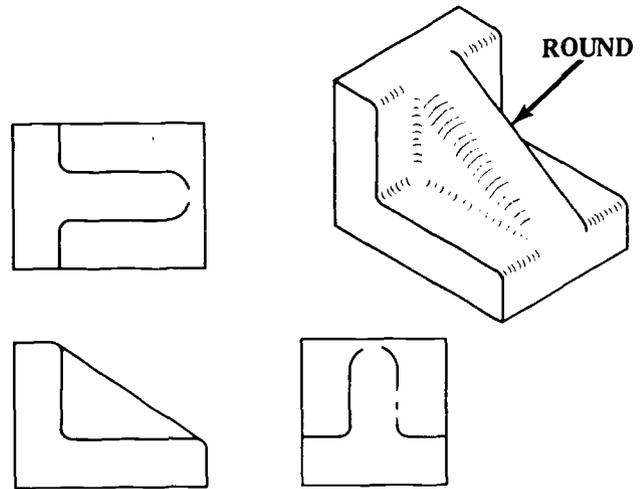


Figure 8-19. Runouts with different shape intersecting members.



B

Figure 8-20. Runouts with different shape intersecting webs.

an orthographic working drawing is to provide accurate and complete information. In many cases all features of an object cannot be seen by an observer. Certain surfaces or edges which may appear on one plane as a visible line becomes hidden or invisible on another. Hidden lines are drawn on an external surface to represent surfaces and intersections which are not visible from the point from which the view is taken. Hidden lines are drawn with evenly spaced dashes that are approximately $\frac{1}{8}$ inch long and of medium line weight. The length of the dashes may vary slightly according to the size of the drawing. The space between dashes should approximately equal $\frac{1}{4}$ the length of the dash. Hidden lines are always begun with a dash touching the line from which it

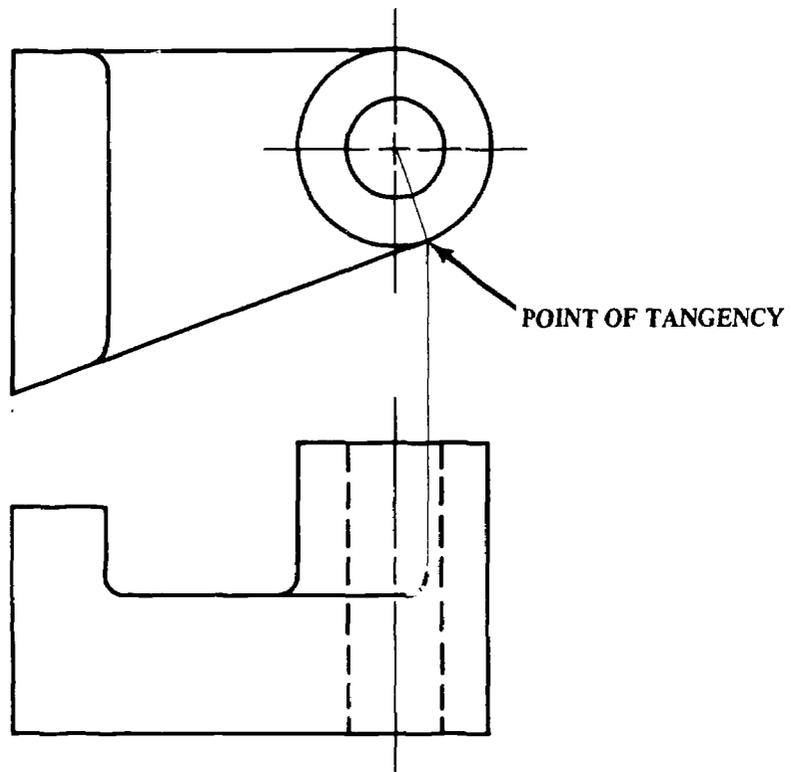
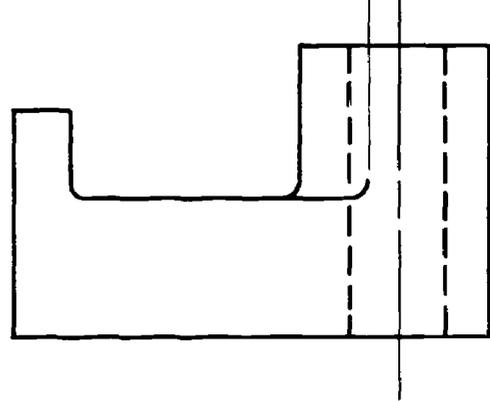
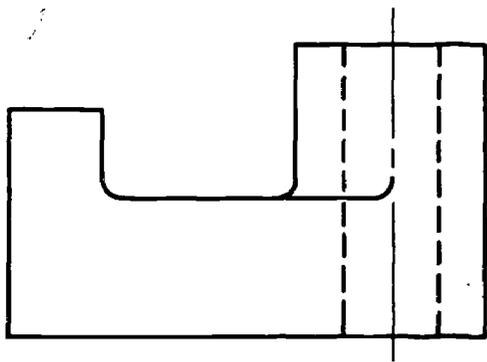
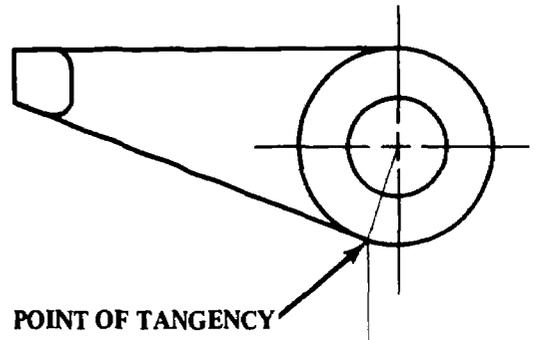
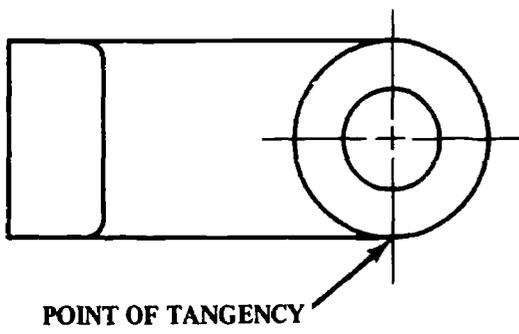


Figure 8-21. Runouts terminating at points of tangency.

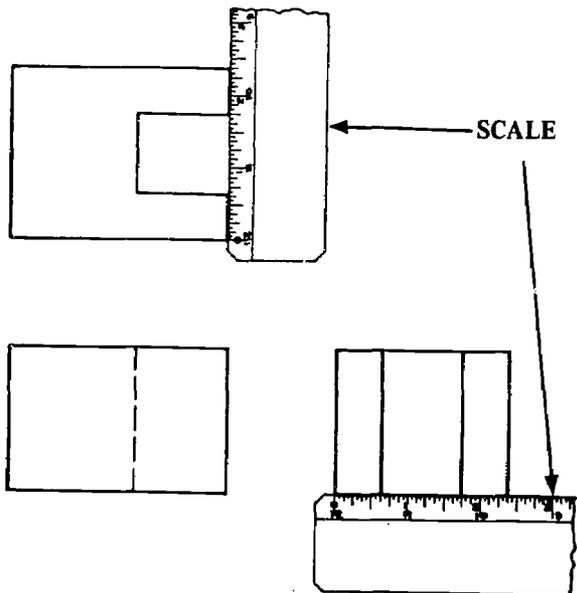
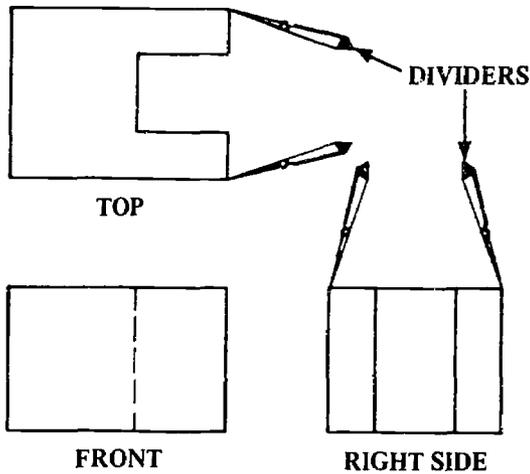


Figure 8-22. Transfer by measurement.

starts, the only exception being when a dash would indicate the continuation of a full line. Dashes will touch at corners, and arcs should start with dashes at the point of tangency. This practice will enable the reader to see the end points of the arc (fig. 8-25).

b. *Omission of Hidden Lines.* Normally, as many hidden lines as necessary will be shown. However, when too many hidden lines are employed they tend to confuse, rather than clarify. Hidden lines may also be eliminated when a feature is clearly illustrated in another view. Should hidden features present too great a problem in complexity, a section view may be warranted. Beginning draftsmen should include all hidden lines until considerable experience is gained or a supervisor indicates otherwise.

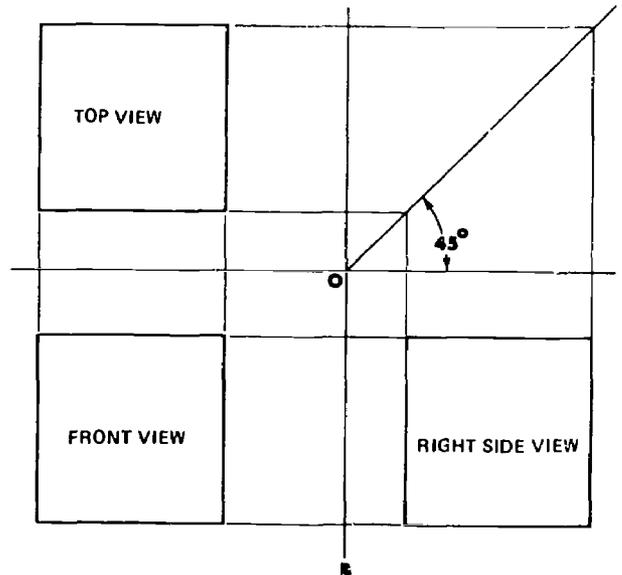
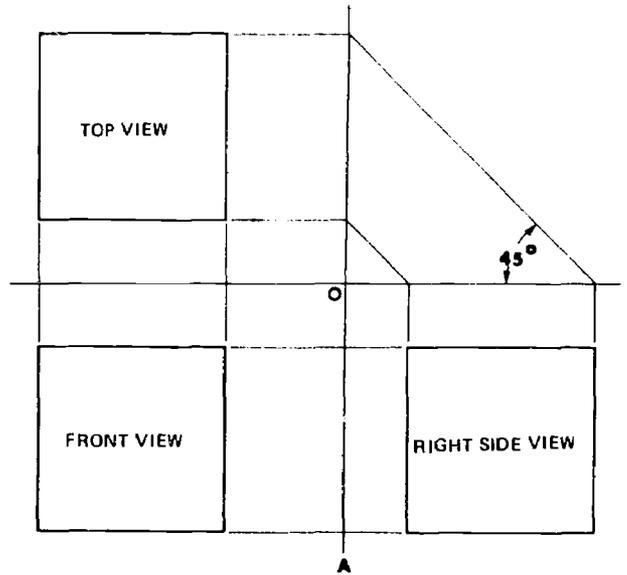


Figure 8-23. Transfer with T-square and triangle.

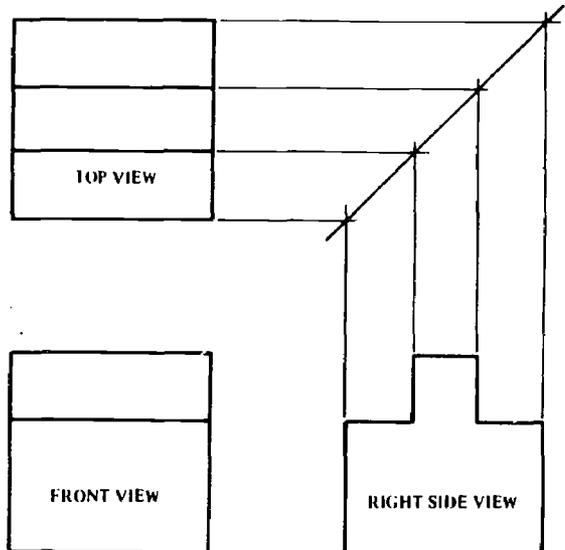


Figure 8-24. Transfer with miter line.

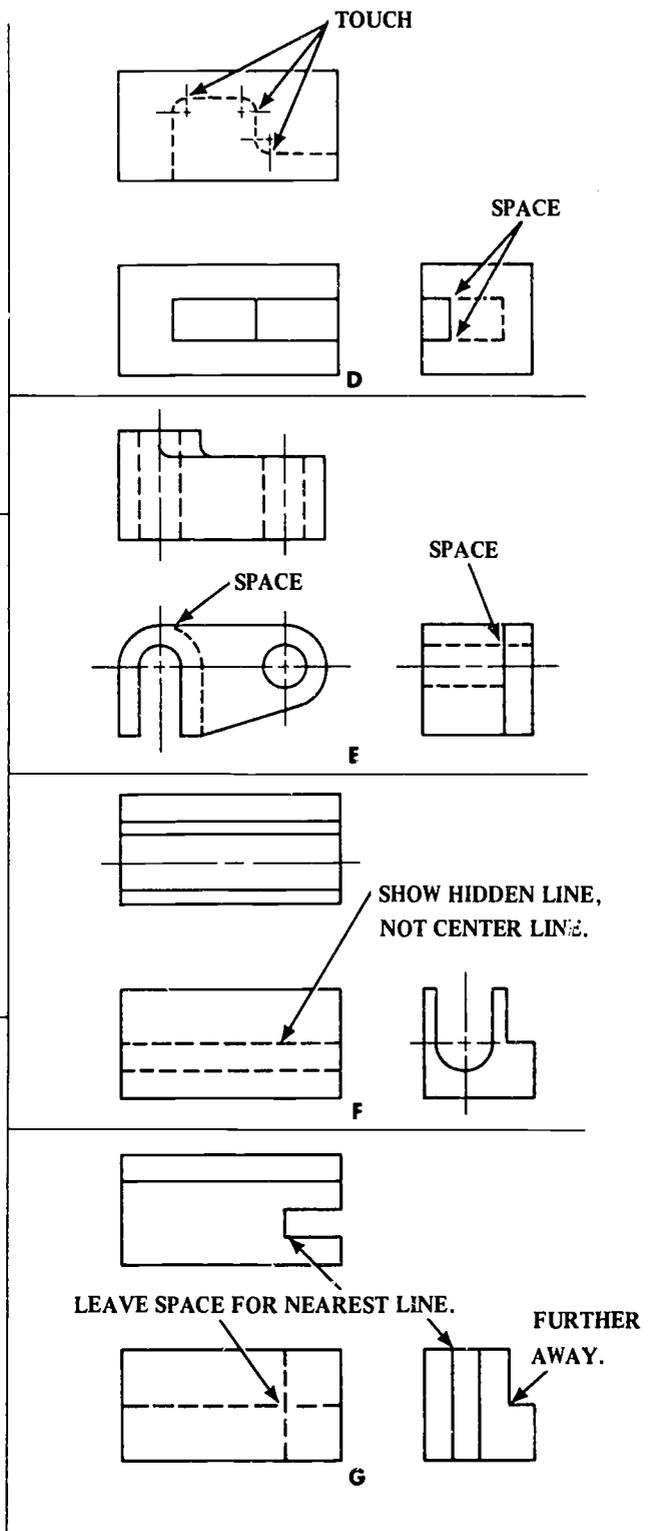
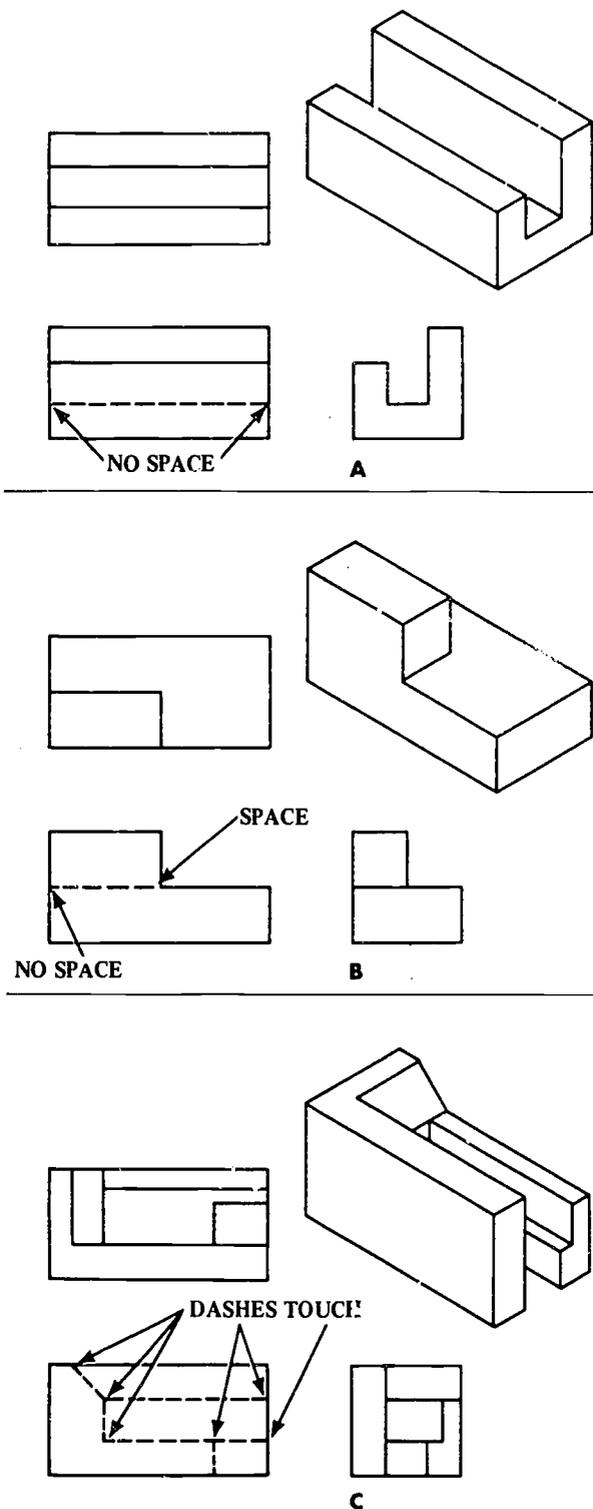


Figure 8-25. Hidden lines.

Section II. SECTIONS

8-10. General Purpose and Methods

a. Purpose. For many objects which are fairly simple in design, the job of providing accurate construction details may be accomplished by the

usual methods of orthographic projects. For objects whose internal construction is so complex as to render the use of hidden lines too confusing, another means must be used for clarification. This is done by drawing a sectional view of the object.

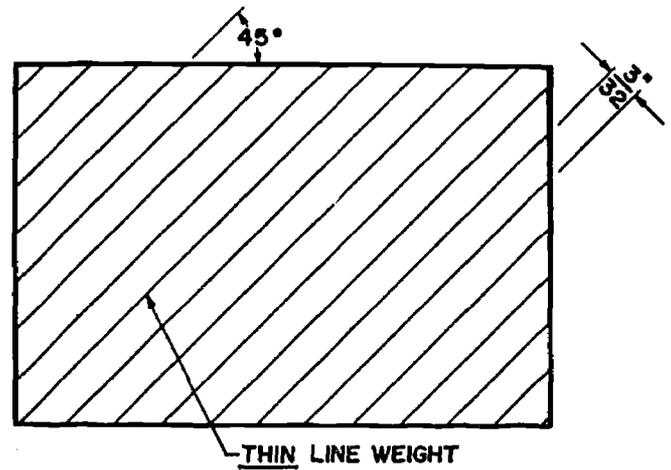
In this manner, the internal shape may be shown while still maintaining the exterior shape.

b. Sectional Views. There are many types of sectional views and careful consideration should be given prior to selection to insure that the type chosen meets the demands of the problem at hand. In a sectional view, an imaginary cutting plane is assumed to be passed through the object. The cutting plane symbol describes where the cut is made and through what portion.

c. Cutting Plane Symbol. The cutting plane symbol (fig. 8-26) is shown on the principal view and indicates where the section is being taken. There are two forms of symbol used. The first form consists of alternating a long and two short dashes. The approximate lengths of the long dashes may vary from $\frac{3}{4}$ inch up to $1\frac{1}{2}$ inches (determined by the size of the drawing). On the same sheet, do not vary the dash lengths. The short dashes should be about $\frac{1}{8}$ inch long and the spaces $\frac{1}{16}$ inch long. The second form is made up of equally spaced dashes approximately $\frac{1}{4}$ inch long. On some objects where the cutting plane line is evident, it is not necessary and not recommended to draw the symbol completely through the object. Where the cutting plane symbol is staggered or bent, as in an offset section, it is good practice at all times to construct the complete symbol. When it is clear that the cutting plane falls along a center line, the practice is to omit the symbol and use the center line. Cutting line symbols should be heavier than the object line and should be easily recognizable. The ends of the cutting plane line are bent at a 90° angle and end with a bold arrowhead. No part of the cutting

plane symbol should touch the object outline. The arrowheads will point in the direction in which the section is being viewed. This means that the arrows will then point away from where the section view is drawn.

d. Identifying Letters. To identify the section,



COMMON FAULTS

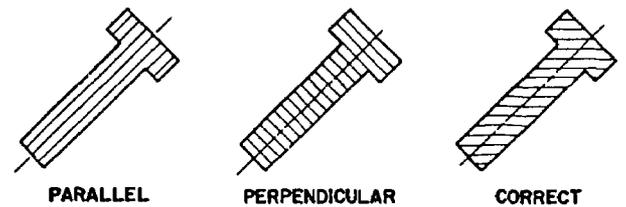
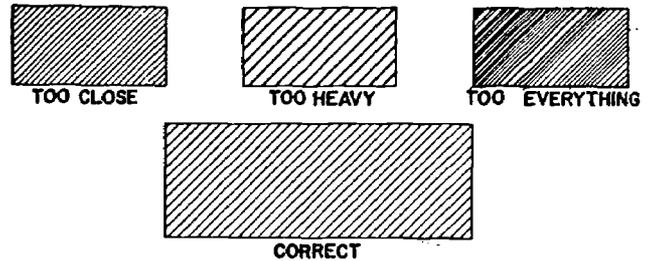


Figure 8-27. Section lines.

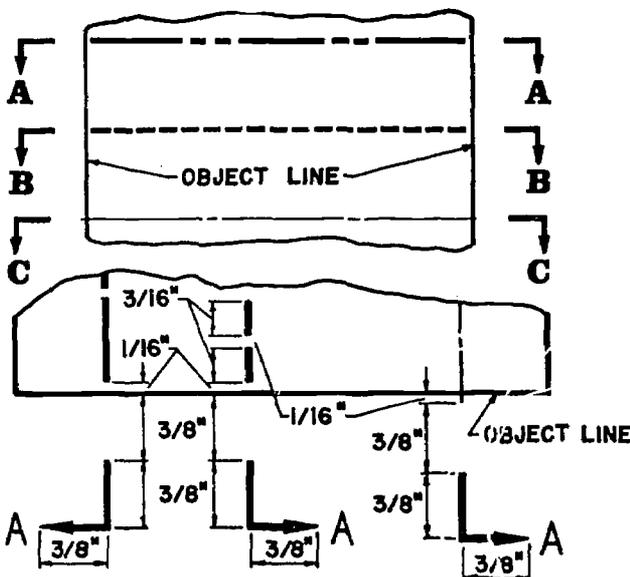


Figure 8-26. Cutting plane symbol.

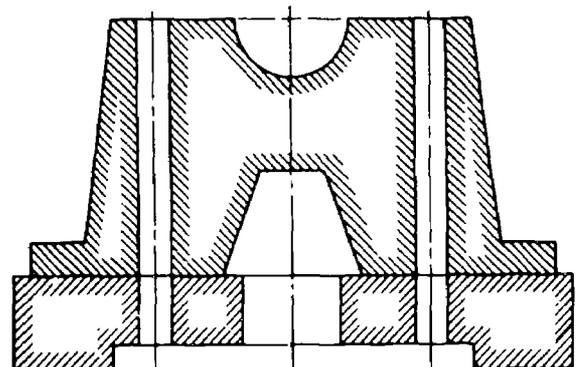
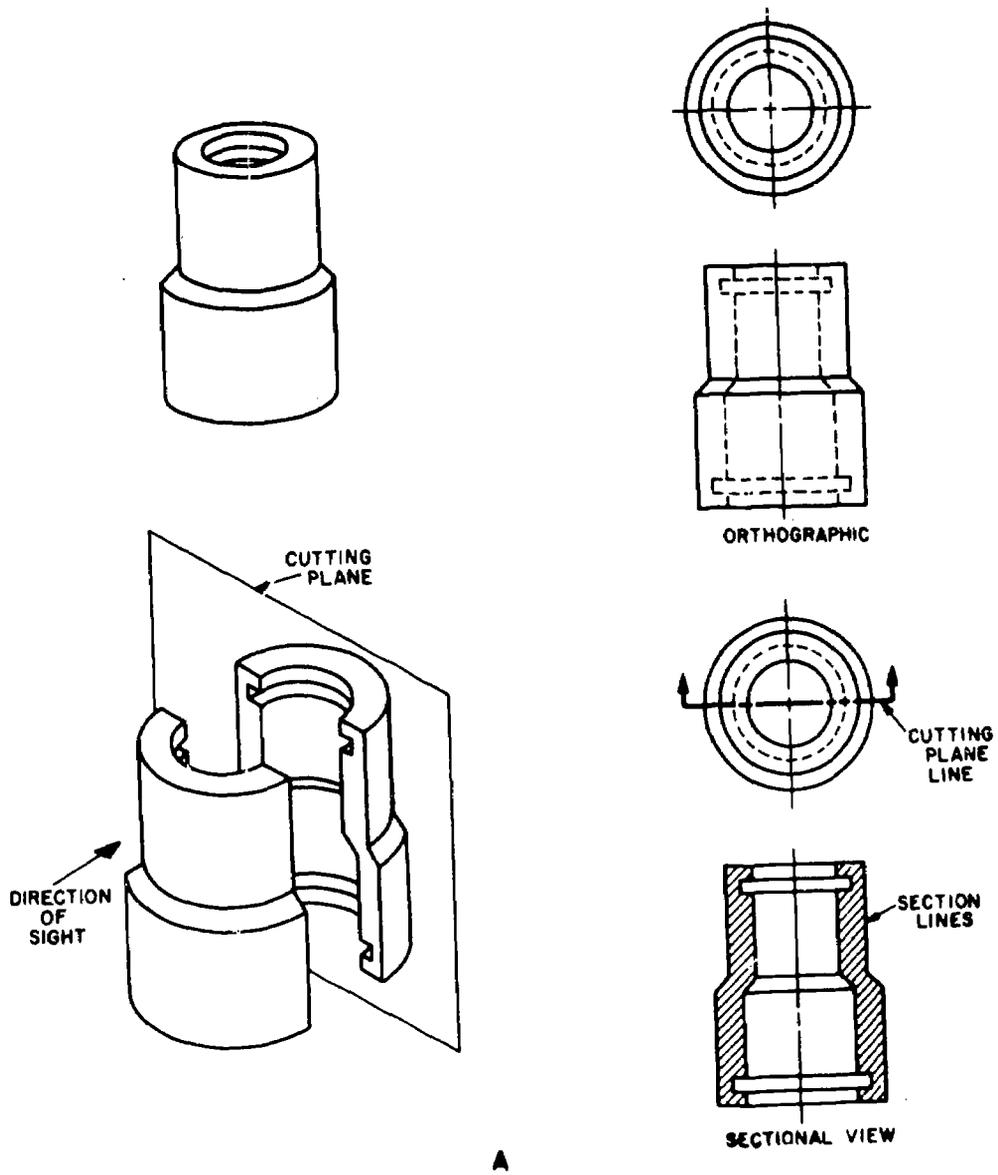
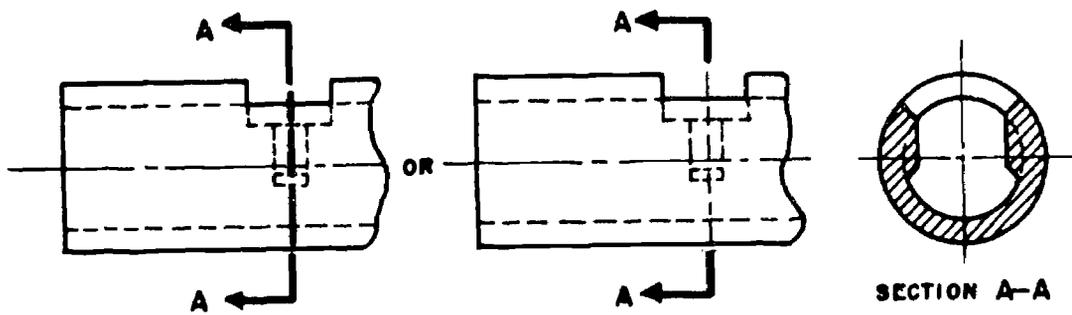


Figure 8-28. Outline sectioning.



A



B

Figure 8-29. Full sectioning.

capital letters (A-A, B-D, C-C etc.) are placed at the tips of the arrowheads to be read horizontally. Letter size should be $\frac{1}{4}$ inch to $\frac{3}{8}$ inch (fig. 8-26). A note such as "Section A-A" is always placed under the sectional view.

e. Section Lines. To distinguish the exposed surface and to emphasize the interior contours, section lines are used. Section lines are normal light continuous lines drawn at a 45° angle (fig. 8-27), except when two or more adjacent parts are shown together. In this instance, to provide a distinct contrast, section lines should be drawn in an opposite direction. In the event a third part is together with the first two, the recommended angle for the third part is 30° or 60° . Any suitable angle may be used if there are still additional parts to be sectioned. To general purpose symbol (cast iron) is used for most purposes; however, sectioning symbols are used to indicate different materials as shown in appendixes C through H.

f. Spacing of Section Lines. Although there is no set rule governing their spacing, common sense will dictate that the size of the drawing will deter-

mine the desirable spacing. For normal size views a space of $\frac{1}{32}$ inch to $\frac{1}{8}$ inch may be used. For larger views, increase the spacing accordingly. The space should not be measured but spaced by eye. Beginners have a tendency to place section lines too close together. This is not only time consuming, it also makes slight variations more noticeable. When drawing section lines, maintain even line weights and check frequently for gradual increase or decrease in the spacing.

8-11. Types of Sectioning

a. Outline Sectioning. For large areas, section lines may be drawn around only their outlines in order to save time (fig. 8-28).

b. Full Sectioning. A full section occurs when the cutting plane passes completely through the object. A, figure 8-29 shows an object before and after being cut by a plane. Normally hidden lines are omitted and are only added when absolutely necessary for further clarification. B, figure 8-29 shows another object in full sectional view.

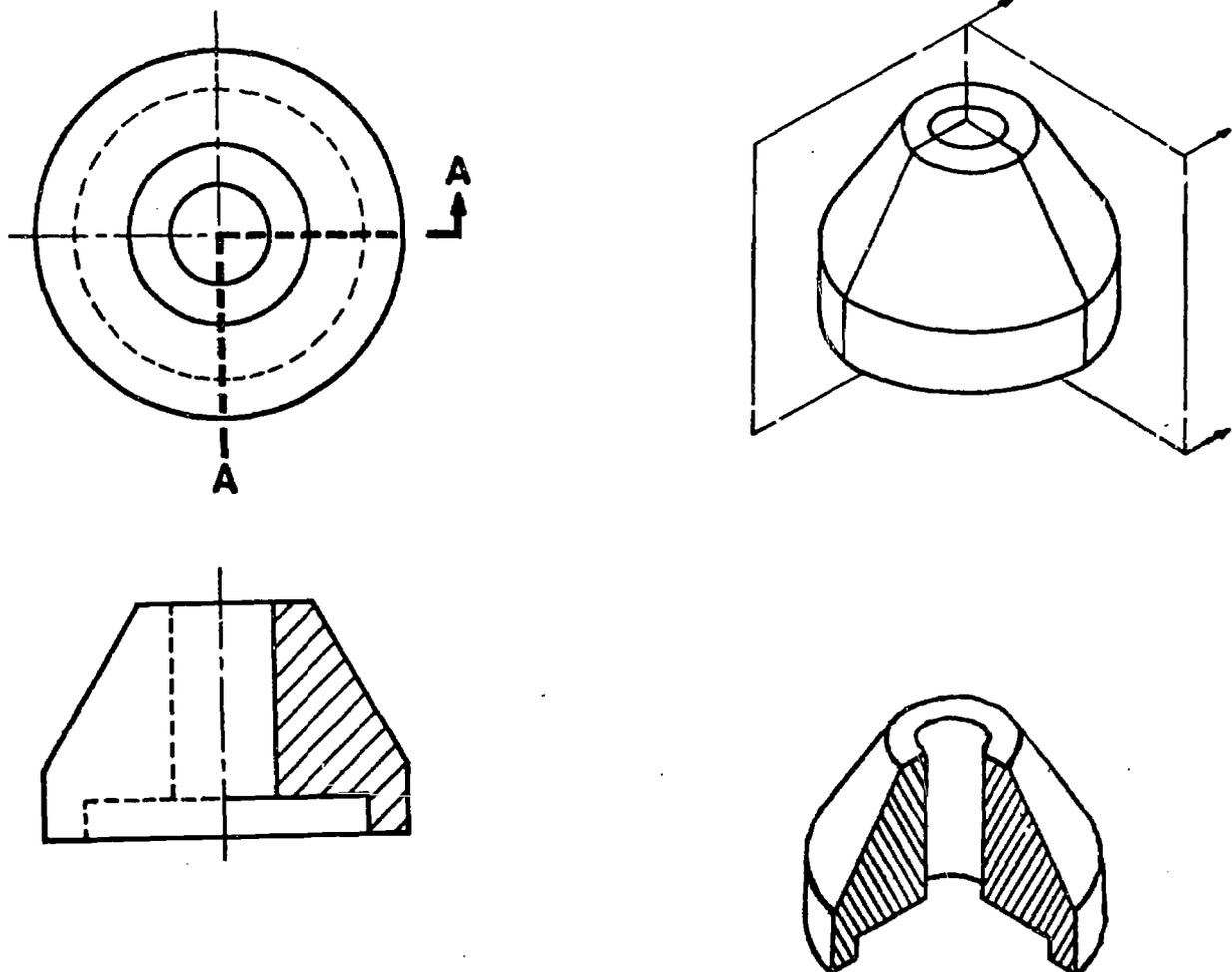


Figure 8-30. Half sectioning.

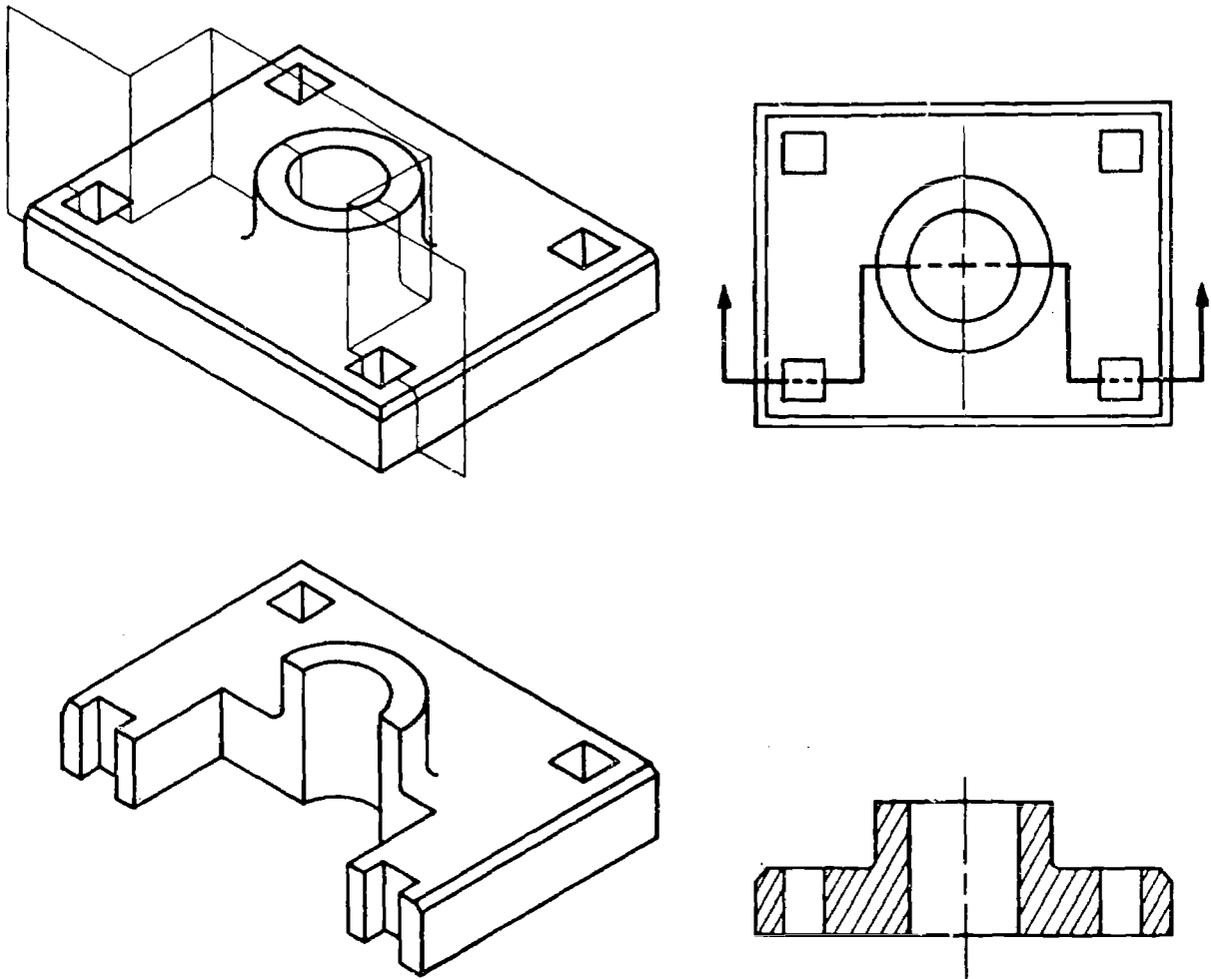


Figure 8-31. Offset sectioning.

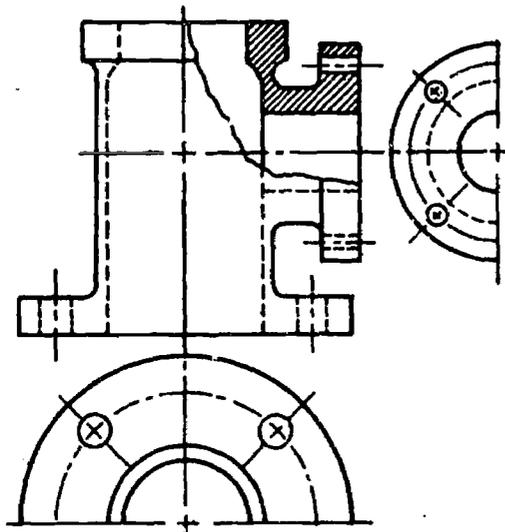


Figure 8-32. Broken-out sectioning.

c. Half Sectioning. In a half section (fig. 8-30), the cutting plane symbol extends only half way through the object and makes a turn of 90°. Thus, one quarter of the object is removed. Half sec-

tions are used when it is an advantage to show interior construction as well as the shape of the outer surface. If it is necessary to show hidden lines, they should be restricted to the unsectioned portion. A center line is preferred over the cutting plane symbol or visible line in the sectional view. In making any sectional view, the procedure is the same as orthographic projection

d. Offset Sectioning. When all important features do not fall on the main axis of the cutting plane or when the omission of some features would detract from a clear interpretation of the object, the cutting plane may be staggered or offset. It will be offset in such a manner as to pass through these features. The cutting plane is bent or "offset" (usually at 90°) as shown in figure 8-31. This type of sectioning is referred to as an offset section.

e. Broken-out Sectioning. In cases where only a small portion of the object is necessary to show interior construction, a broken-out section (fig. 8-32) is used. In this instance, the cutting plane symbol appears as an irregular wavy line on the

principal view. The area scribed by the irregular line is broken away to reveal the described features. No reference letters or titles are necessary.

f. Revolved Sectioning. A revolved section (fig. 8-33) is made by passing the cutting plane perpendicular to the center line or axis of the part. The resulting section is then revolved 90° on its axis onto the plane of the paper. A, figure 8-33 shows the plane, which is perpendicular to the center line, cutting the part crosswise. B, figure 8-33 shows the plane revolved 90° around the

vertical axis until the cross section is parallel with the center line. Notice, in C, figure 8-33, the revolved section is superimposed on external view. The visible continuing lines on each side of the section are omitted and broken lines used so as to leave the sectioned part prominent as shown in D, figure 8-33). As is the case with a broken-out section, no cutting plane symbol or section title is used. A revolved section is always drawn to its true shape regardless of the direction of the contour lines of the object. Revolved sections are a convenient method of showing cross sectional

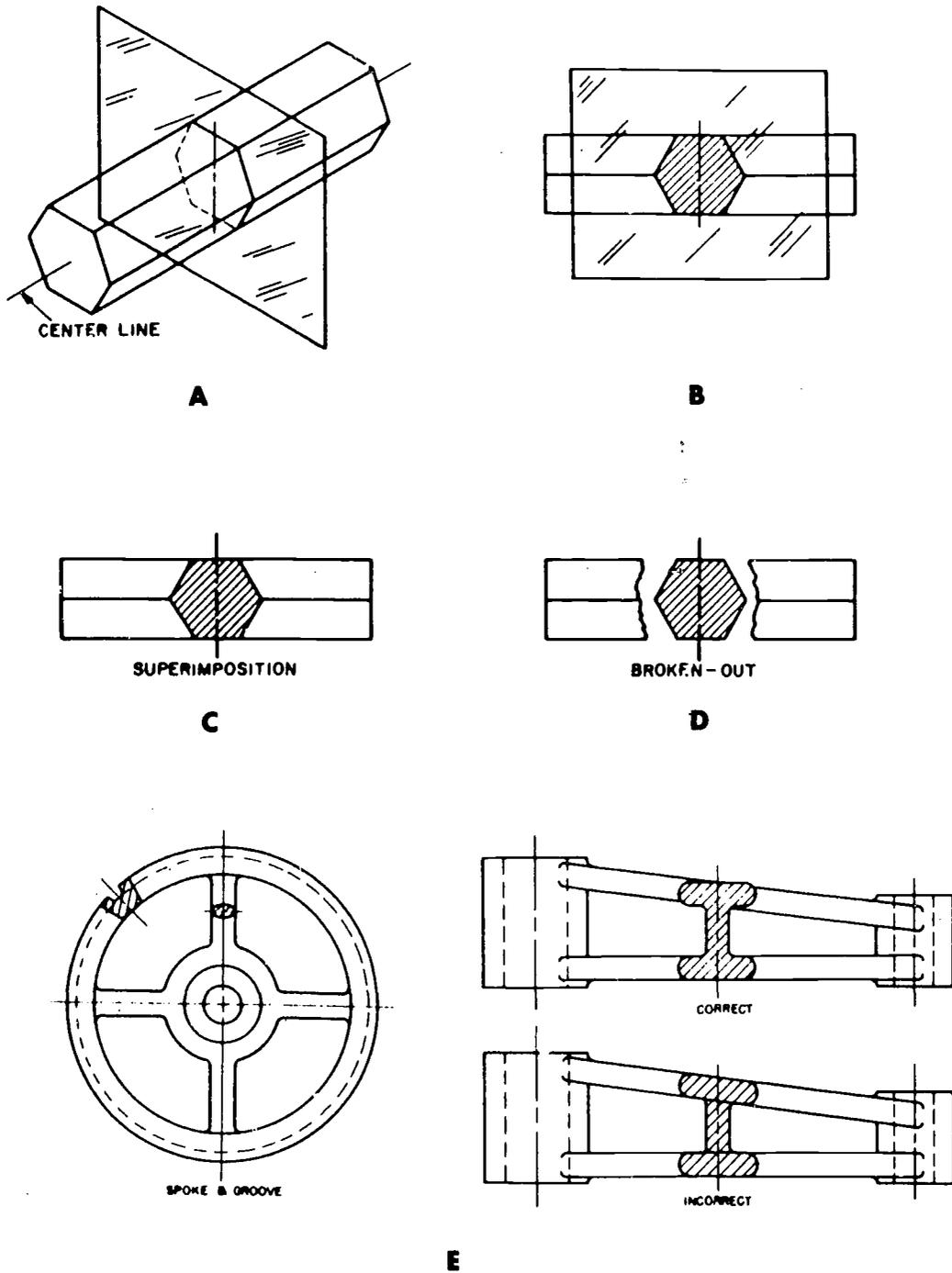


Figure 8-33. Revolved sectioning.

shape of such objects as spokes, ribs, or elongated parts as shown in E, figure 8-33.

g. Removed Sectioning. A removed section has at least two distinct advantages over the revolved section. First, the principal view is not cluttered with revolved sections (A, fig. 8-34); secondly, the removed section may be drawn to a larger scale for dimension purposes and clarity (B, fig. 8-34). Removed sections are used much the same as revolved sections, but are removed from the principal view and placed elsewhere on the drawing sheet. The cutting plane symbol, properly identified, must be placed on the principal view. The removed section should always be clearly identified such as section A-A, or in some cases just "A-A" is sufficient. It is good practice and sometimes advantageous to draw removed sections to a larger scale than the principal view.

h. Thin Sectioning. Very thin materials such as gaskets, washers, sheet metal, and others too small for section lining may be shown as solid black lines (fig. 8-35). When two or more thin materials appear together, the practice is to leave a white space between parts.

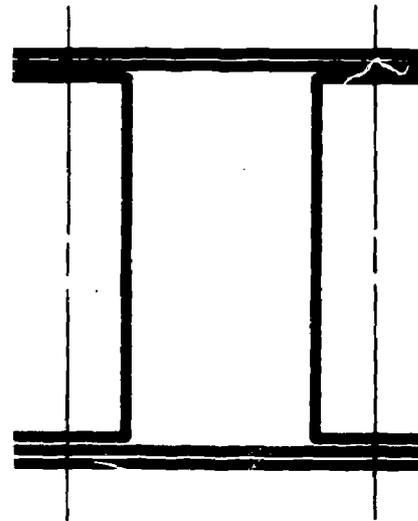


Figure 8-35. Thin sectioning.

8-12. Sectioning Conventions

a. Sections Through Ribs, Webs, and Similar Features. When a cutting plane passes through a rib parallel to the flat side of a rib or web, the sectioning of the rib or web is omitted. A true section would give the idea of a very heavy, solid piece, which would not be a true description (fig. 8-36).

b. Alternate Sectioning. When a rib does not show clearly in a sectional view, indicate the rib by leaving out every other section line on the rib (fig. 8-37).

c. Sections Through Shafts, Bolts, and Rivets. When a cutting plane passes lengthwise through the axis of shafts, bolts, pins, rivets, or similar elements, they are left in full and sectioning is not used (fig. 8-38).

d. Alined Ribs, Lugs, Spokes, and Holes. When ribs, lugs, spokes and holes occur in odd number, it is preferable that they be alined (fig. 8-39). Note how the true projection of the ribs show the pair on the left foreshortened (A, fig. 8-39), suggesting in the sectional view that they do not extend to the outer edge of the base. B, figure 8-39 shows the preferred method of sectioning. This holds true also for spokes (fig. 8-40).

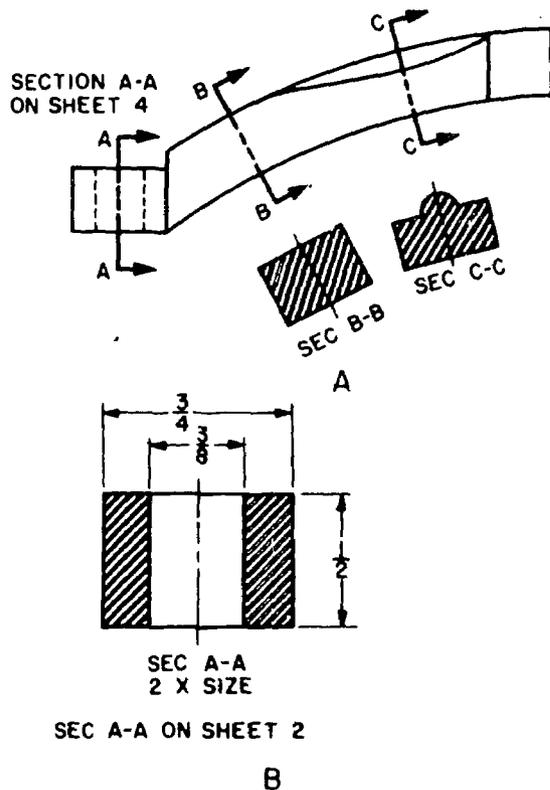


Figure 8-34. Removed sectioning.

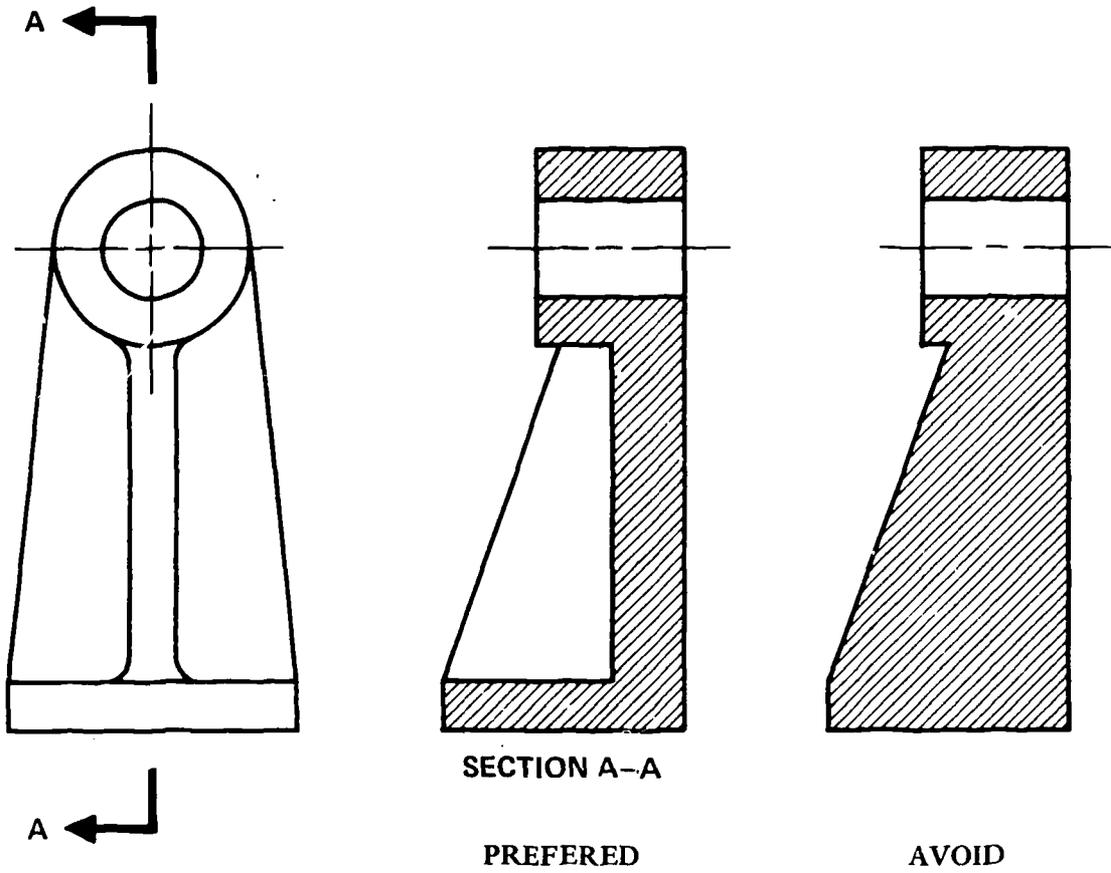


Figure 8-36. Section through a rib.

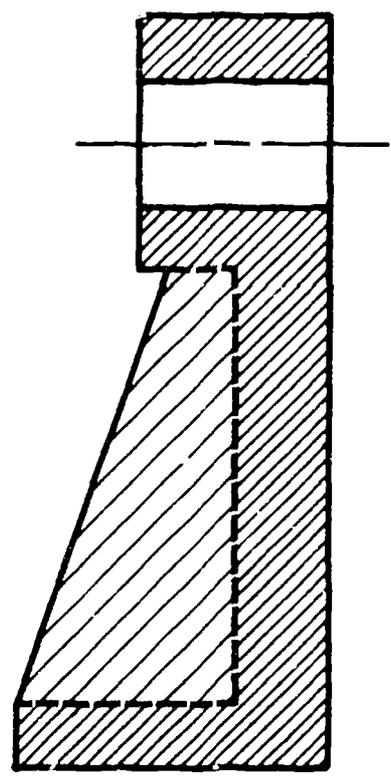


Figure 8-37. Alternate sectioning.

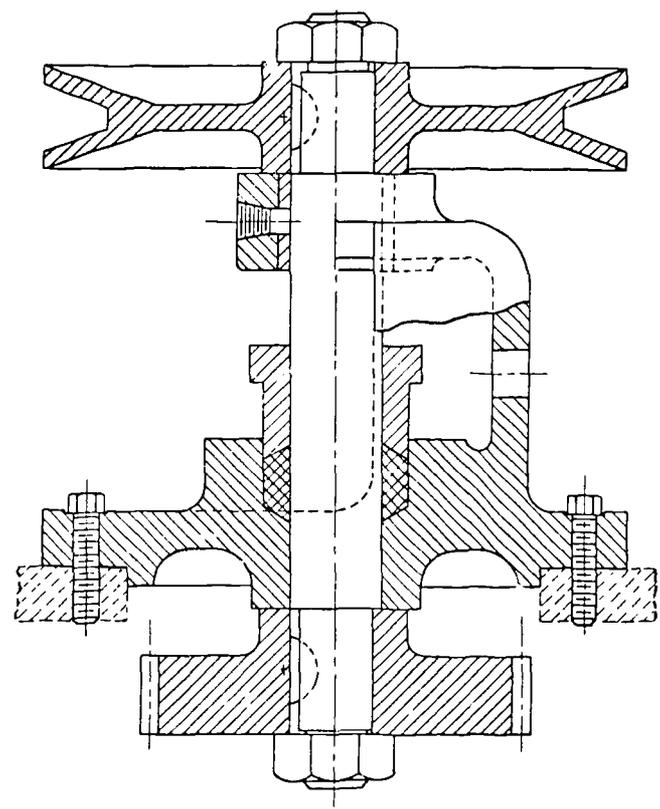


Figure 8-38. Assembly sectioning.

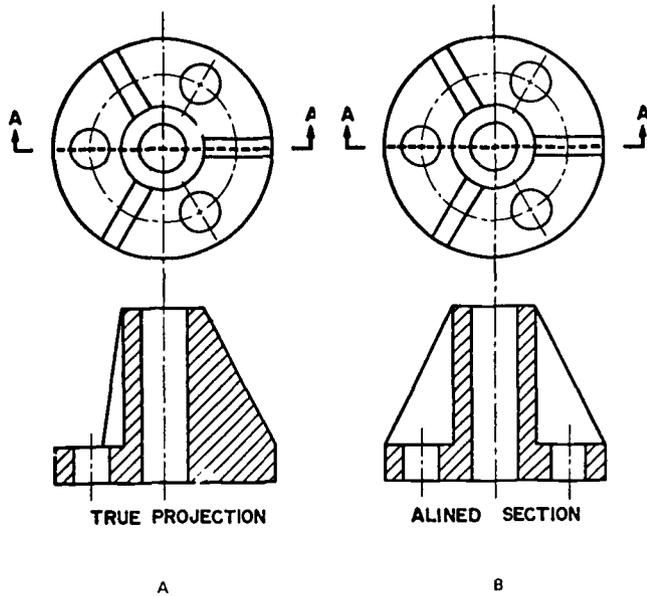


Figure 8-39. Alined holes and ribs.

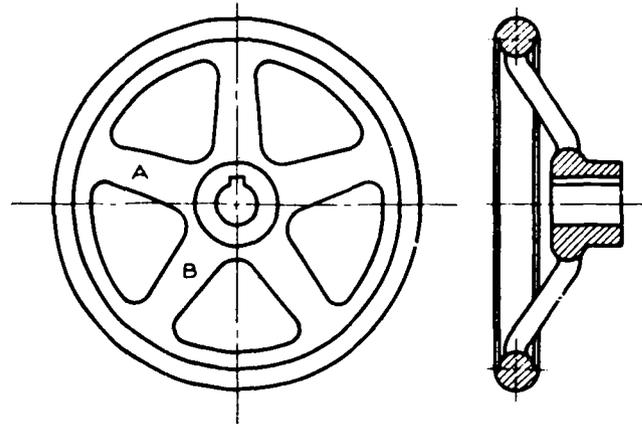


Figure 8-40. Alined spokes.

Section III. AUXILIARY AND EXPLODED VIEWS

8-13. Types of Auxiliary Views

a. Introduction. For a drawing to provide accurate and complete object description, all surfaces must be represented in their true shape. It has been mentioned in a previous section (orthographic projection) that some objects will have surfaces which are not parallel to regular planes of projection. These surfaces are called inclined or oblique. Since these surfaces will appear foreshortened or not in their true shape, another means of projection becomes necessary to describe them. The views used in such instances are known as primary (or single) and secondary (or double) auxiliary views. The construction of these views is described in this section.

(1) *Groups.* Normally, primary auxiliary views may be categorized into three distinct groups: front, top and side auxiliary. These are dependent upon which plane the auxiliary plane is hinged, as follows:

(a) A front auxiliary shows a surface perpendicular to the front plane and inclined to the profile plane.

(b) A top auxiliary view is hinged to the top view and the inclined surface is perpendicular to the top plane.

(c) A side auxiliary view is one where the slanted surface is perpendicular and hinged to the side (profile) plane.

(2) *View characteristics.* An interesting point to remember is that the inclined surface is always perpendicular to the plane from which the

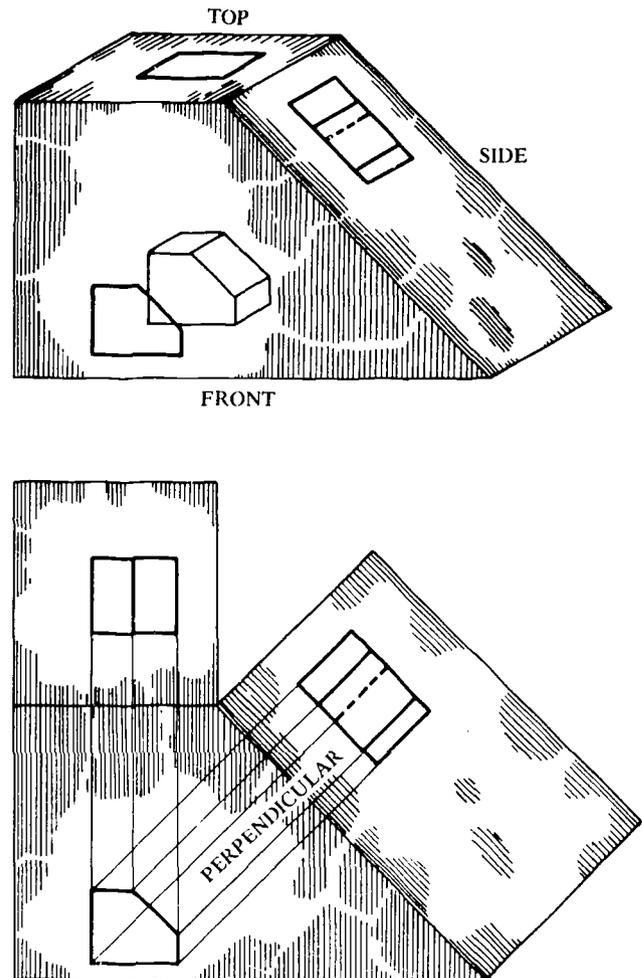


Figure 8-41. Primary auxiliary view.

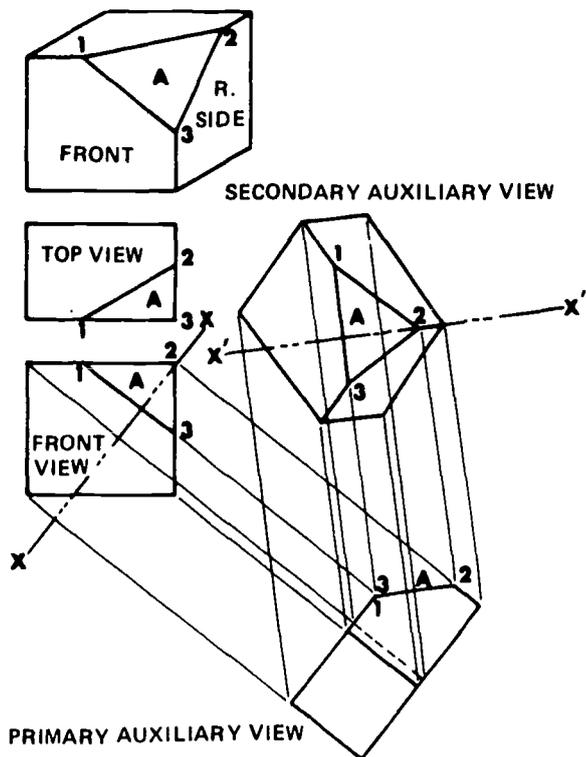


Figure 8-42. Secondary auxiliary view.

view name is derived. In a front auxiliary, the inclined surface is perpendicular and hinged to the vertical plane, and generally shows surfaces which lie more on the profile side of the object. In a top auxiliary view, the inclined surface is also on the profile plane but is considered hinged to the top plane. A side profile will normally show a surface that may be seen from the vertical plane but not in its true shape, the inclined surface being hinged to the profile or side plane.

b. Primary Auxiliary View. When a surface is slanted or inclined to two planes of projection and perpendicular to another, a primary auxiliary view (fig. 8-41) is used. The true shape of the slanted surface must be projected to a plane that is parallel to it. This parallel plane is assumed to be hinged to the plane to which it is perpendicular and rotated into the frontal plane.

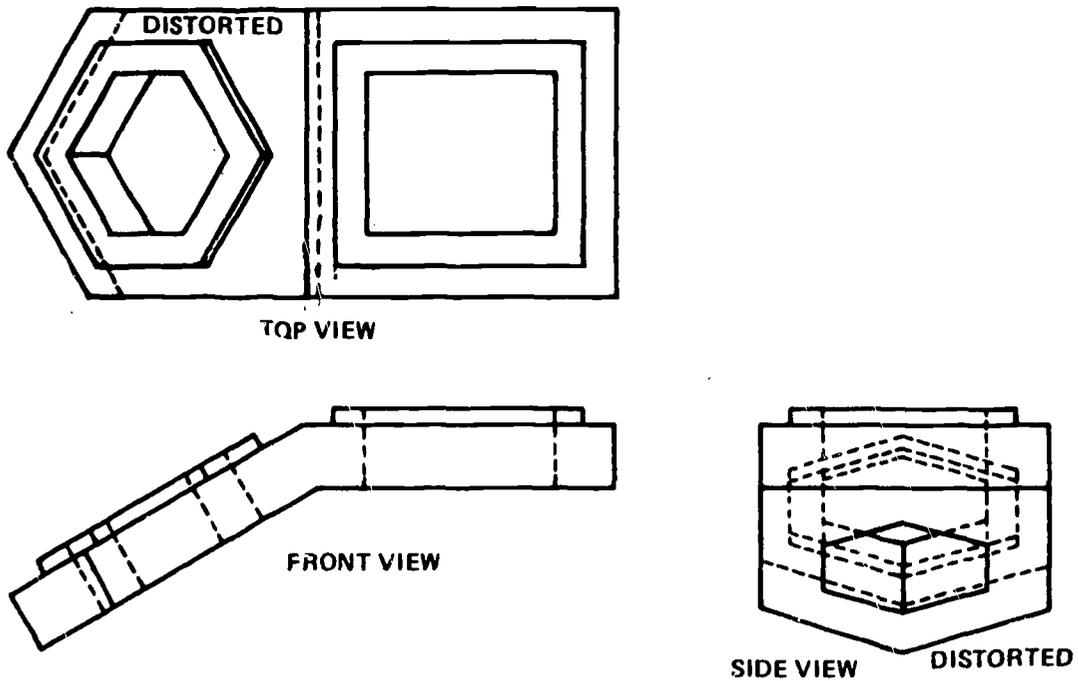
c. Secondary Auxiliary View. When a surface is inclined or oblique to all the ordinary views of its true shape, a secondary auxiliary view (fig. 8-42) is projected from the primary auxiliary view. A secondary auxiliary may be projected from a front, top, or side auxiliary view.

d. Partial Auxiliary View. When an auxiliary view represents the shape and details of an inclined surface only, and omits the foreshortened details from the auxiliary view because they are

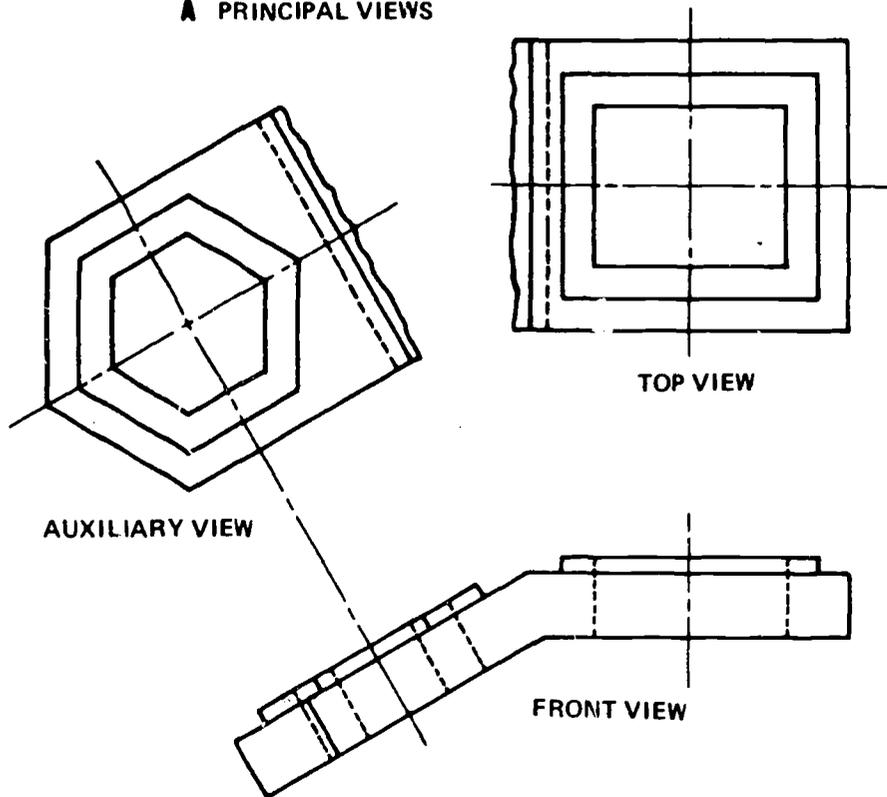
shown in their true shape and size in the principal views, it is called a partial auxiliary view. By using a partial auxiliary view, much drawing time and space can be saved and greater clarity achieved. In A, figure 8-43, the drawing of a "Holder" in the normal procedure, front view, top view, and right side view, with a complete auxiliary view shows several surfaces distorted. In B, figure 8-43, the distorted portions and the right side view are eliminated, leaving only the front view and partial views of the auxiliary view and top view. Notice how the broken line is used in the partial views to show where the foreshortened details are omitted.

e. Construction of Primary Auxiliary Views. Normal procedure for drawing auxiliary views is to first construct two principal views of the object (fig. 8-44). Make sure that one of the views shows the inclined surface as a straight line, perpendicular to the viewing plane. Next construct a line perpendicular to the true edge of the inclined surface. Then construct a reference line parallel to the true edge of the inclined surface. By projecting points from the inclined surface and through the reference line, the true length of the inclined surface may be plotted. Transfer depth dimensions with dividers or scale. Hidden lines need not be shown unless needed for additional clarity.

f. Construction of Secondary Auxiliary Views. In order for the true size of the surface to appear in the secondary auxiliary view (fig. 8-45), the reference line "y'-y" must be parallel to the edge view of that surface. Therefore, it is necessary to obtain a primary auxiliary view showing the edge view of the incline surface. In order to do this, it is necessary that the reference lines RL_1 and RL_2 be perpendicular to a line in surface ABC that appears in true length. Line AB in the front view is a true length that appears as a point in the primary auxiliary view, and surface ABC must therefore appear edgewise in that view. After the projection lines perpendicular to reference lines RL_1 and RL_2 are constructed, from the front view to the primary auxiliary view, transfer all depth measurements with dividers from the top view with respect to reference line RL_1 . For the secondary auxiliary view, reference line RL_2 is used in transferring measurements. All measurements perpendicular to RL_2 in the secondary auxiliary view are the same as between the reference line and the corresponding points in the front view. Note that corresponding measurements must be inside (toward the central view in the sequence of three views) or outside (away from the central view). For example, dimension "a" is



A PRINCIPAL VIEWS



B PARTIAL VIEWS

Figure 8-48. Partial auxiliary view.

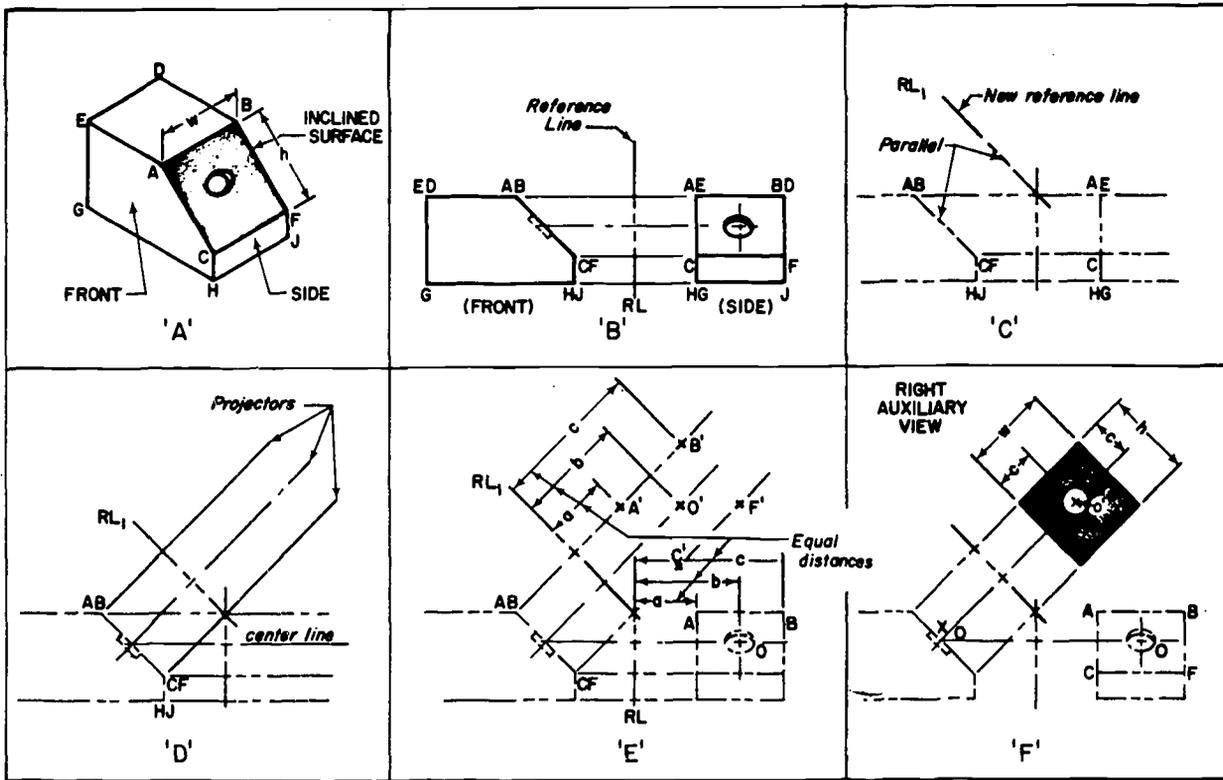


Figure 8-44. Constructing primary auxiliary views.

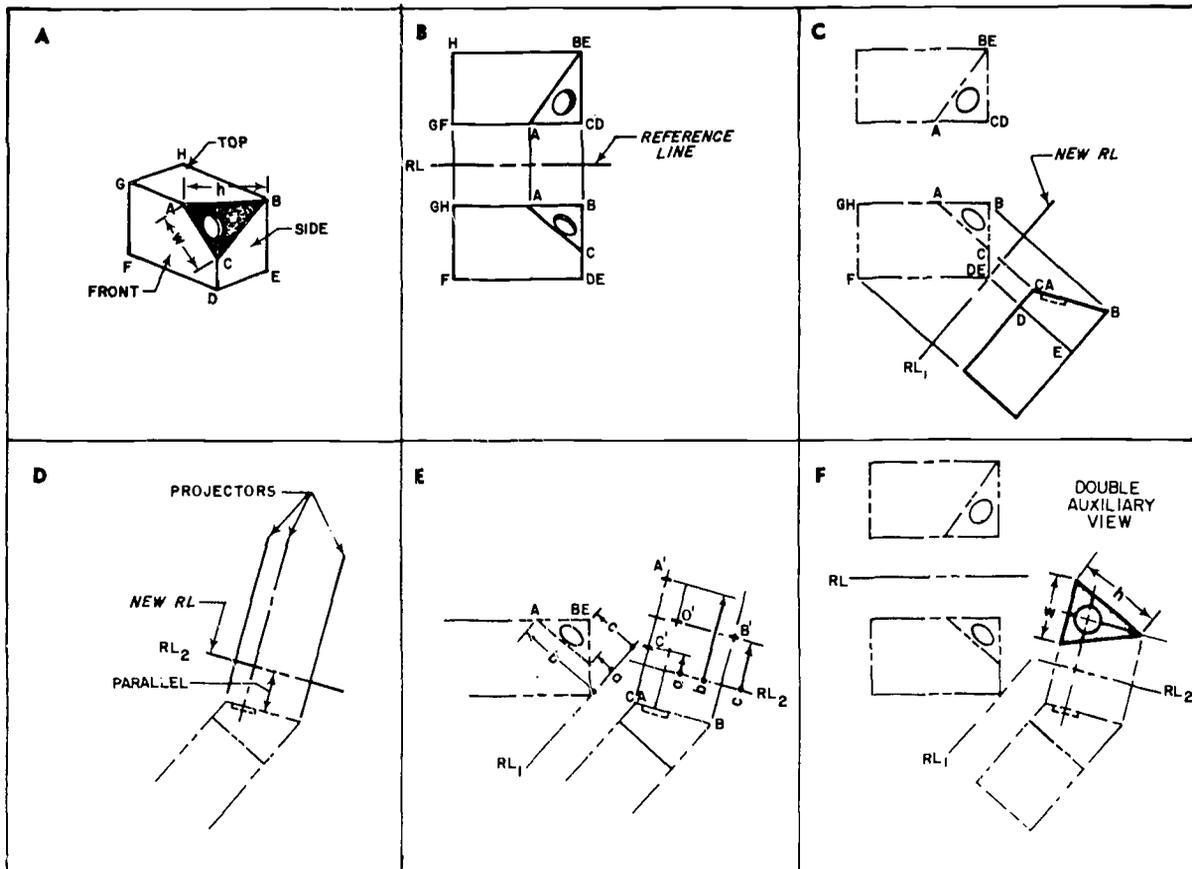
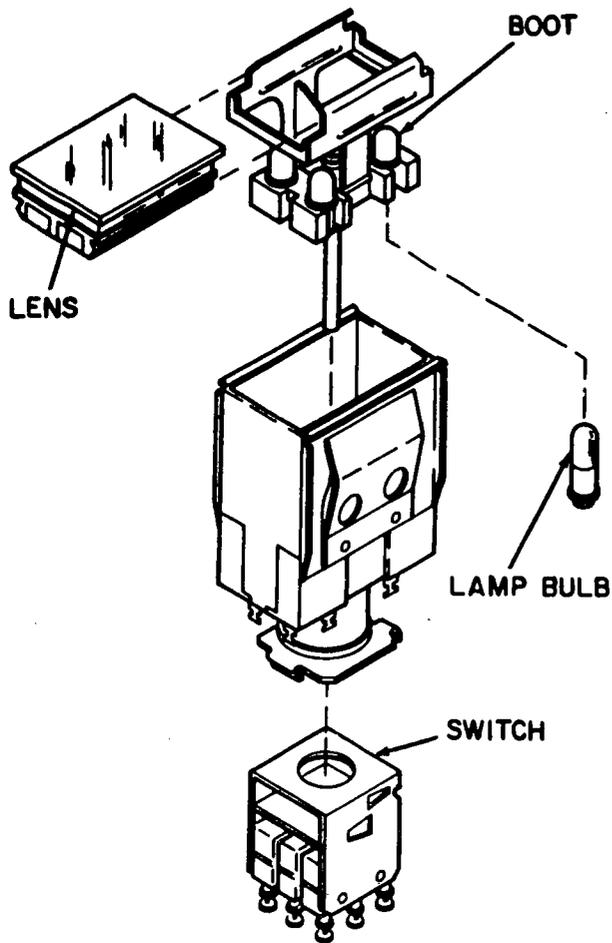


Figure 8-45. Constructing secondary auxiliary views.



on the side of the reference line RL_2 away from the primary auxiliary view in both places.

8-14. Exploded Views

Exploded views are used to illustrate the assembly or disassembly of a unit which has several removable parts. It is basically a pictorial view of each of the parts to the same scale, with the parts arranged in a relationship which corresponds to their relationship when assembled (fig. 8-46).

Figure 8-46. Exploded views.

CHAPTER 9

PICTORIAL DRAWING AND SKETCHING

Section I. INTRODUCTION

9-1. General

It is possible to represent accurately the most complex forms by means of multiview drawings showing a series of exterior views and sections. This type of representation has, however, some limitations: its execution requires a thorough understanding of the principles of multiview projection, and its reading requires a definite exercise of the constructive imagination.

9-2. Pictorial Drawing

Pictorial drawing enables the person without technical training to visualize the object represented. The perspective drawing gives the most

natural look and is particularly useful in the designing state as it gives immediately a clear image of the end product, such as perspective view of architectural construction. However, it is not useful for detailed information of construction, as most of the lines, arcs, and angles are distorted and not measurable. The isometric drawing is most often used as a pictorial drawing, all the lines on the oblique axis are true and measurable, all angles and circles on the frontal plane are true, measurable, and not distorted, but those not on the frontal plane are distorted. Since the depth axis is flexible in the oblique drawing, it has an advantage over the isometric which has all its axes fixed.

Section II. AXONOMETRIC PROJECTION

9-3. Description

a. Axonometric single-plane projection is a method of showing an object in all three dimensions in a single view. Axonometric projection may be closely compared to orthographic projection because in both cases the projectors are perpendicular to the plane of projection. It is the object itself, rather than the projectors, that is inclined to the plane of projection.

b. Axonometric projection includes isometric, dimetric and trimetric projections.

9-4. Isometric Projection

a. In isometric projection, all surfaces of an object are inclined to the same angle ($35^{\circ} 16'$) with the planes of projection. As a result of this inclination, the length of each edge of the object projects slightly shorter than its true length. This foreshortening amounts to the ratio of 1 to the cosine of $35^{\circ} 16'$, or $1/0.8165$. This means that if an edge of an object measures one inch in length the projected line will measure 0.8165 (para 9-5). Since all surfaces form the same angle, all lines will be foreshortened to the same ratio. There-

fore, one scale may be used for the entire layout. Hence the term "isometric", which literally translated means "one-scale".

b. To form an isometric axis, assume that an object, such as a cube with the dimension equaling 1 x 1 x 1 inches (1, fig. 9-1), is rotated about its vertical axis 45° (2, fig. 9-1). In this position two surfaces are visible. To obtain the third surface the object is tilted forward (3, fig. 9-1) until all edges are equal in length (4, fig. 9-1). The meeting of these three mutually perpendicular lines form equal angles of 120° to each other. This forms what is termed the isometric axes (fig. 9-2). All lines parallel to these lines are called isometric lines and may be projected from the object to the isometric planes and remain respectively parallel to the axes. The isometric axes may be easily constructed with a 30-60° triangle and the T-square.

9-5. Isometric Drawing

a. In isometric projection an inch equals 0.8165. If you made an inch actually equal an inch, the drawn figure would be slightly larger. However, there would be no perceptible difference in the

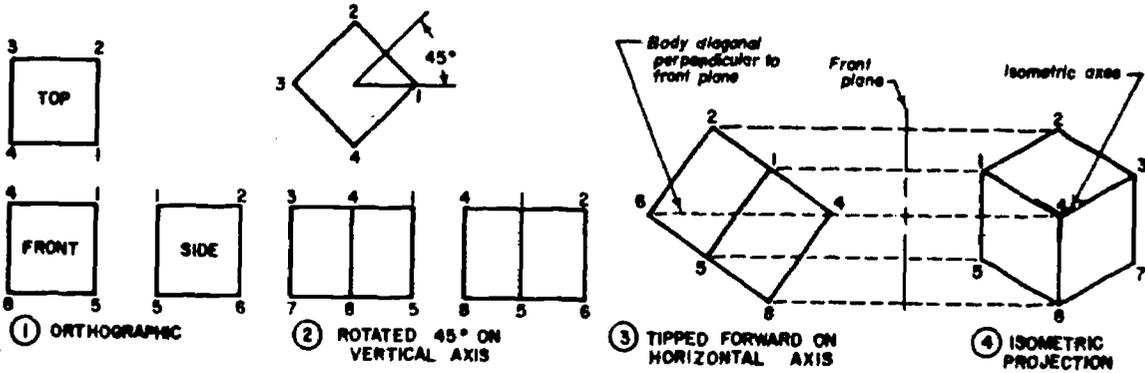


Figure 9-1. From orthographic to isometric projection.

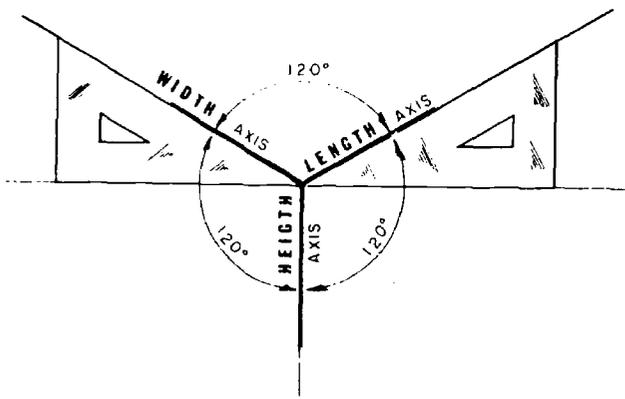


Figure 9-2. Isometric axes.

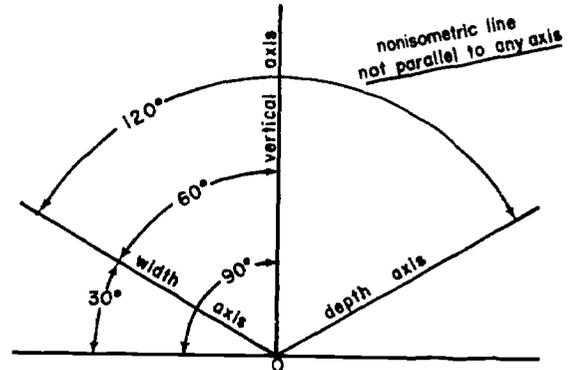


Figure 9-4. Various isometric positions.

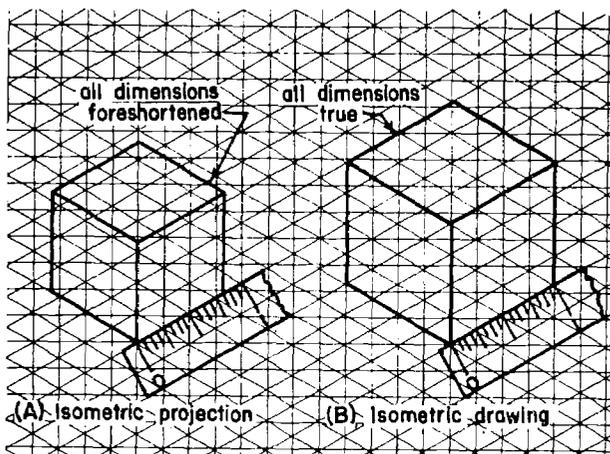


Figure 9-3. From isometric projection to isometric drawing.

appearance of an object. Since all lines are equally foreshortened, they would all be proportionately enlarged (fig. 9-3).

b. By using this method, no special scale is needed and a regular scale may be used. The dimensions on the object are the same as those on the drawing—except of course, when drawings are drawn at a selected scale, smaller or larger. Since this method is more convenient, isometric drawing is used rather than an isometric projection.

c. If an object is rectangular in shape and all surfaces mutually perpendicular, its drawing is made simpler by constructing an isometric box and drawing the height, width and depth of the object along the isometric axes. Refer to figure 9-4 for the various positions a rectangular box can be drawn using the isometric axes.

9-6. Nonisometric Lines

a. It has been previously stated that an isometric line is one that is parallel to one of the legs of the isometric axis. It is also true that a normal line on a normal multiview projection will be an isometric line on an isometric drawing. It may be gathered from this that a line which is not normal in an orthographic view (inclined or oblique), will not be parallel to any leg of the isometric axis. A nonisometric line would be one which forms an angle other than $35^{\circ} 16'$ with the plane of projection. Such a line will not appear in its true length on an isometric drawing.

b. In figure 9-5, surface A is perpendicular to the horizontal plane but oblique to the frontal

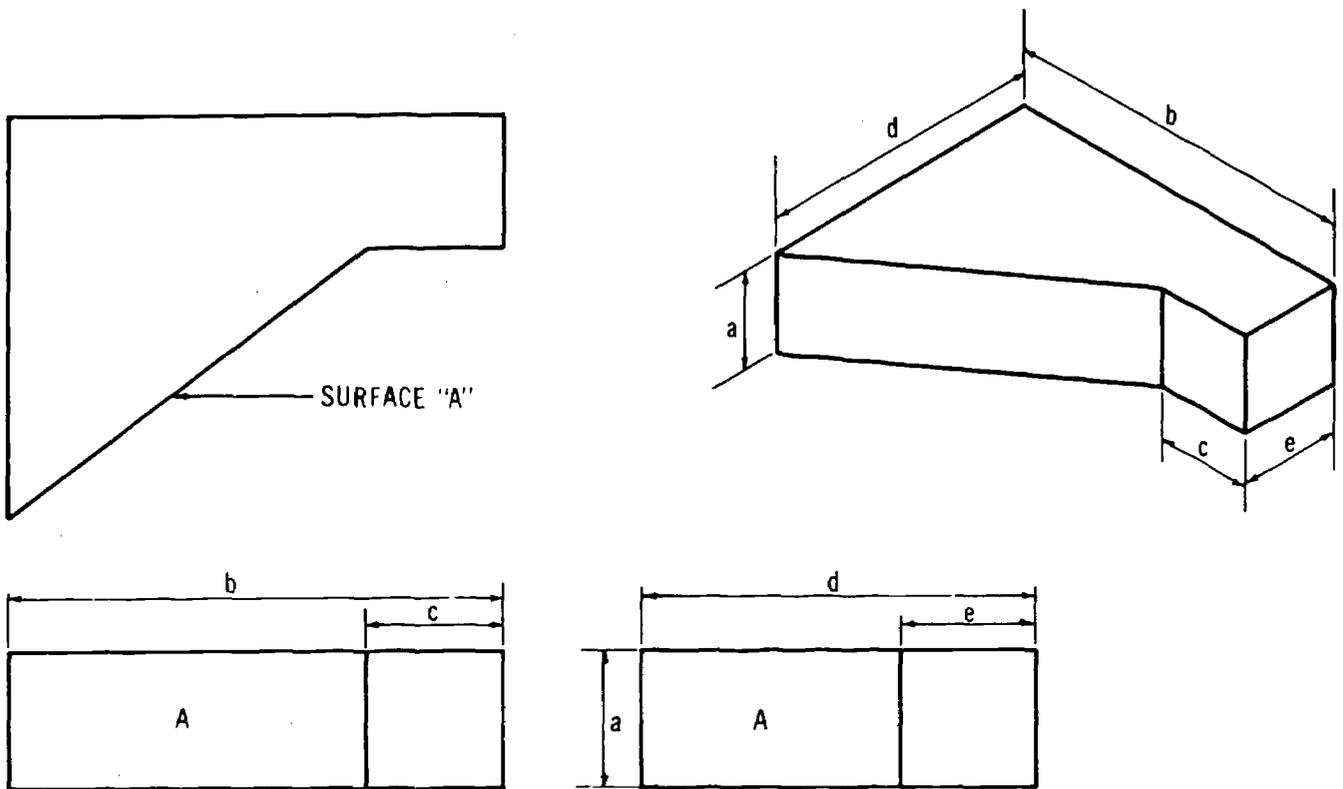


Figure 9-5. Incline surface.

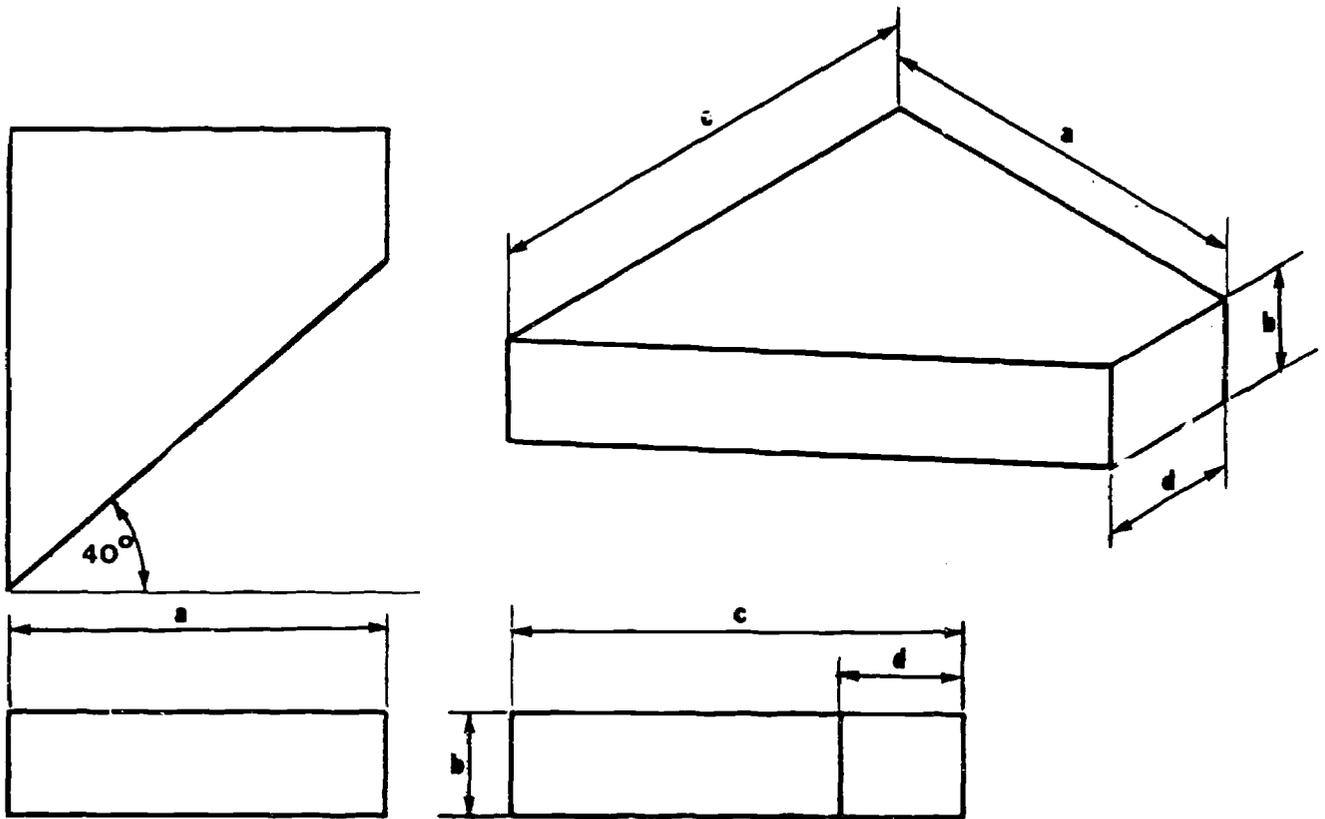


Figure 9-6. Isometric drawing of specific angles.

plane resulting in a foreshortening of the surface. Its true length is shown in the top view, but will appear as a nonisometric line, and therefore not

in its true length, in an isometric drawing. Surface A can be located however by first constructing all normal lines from the orthographic views

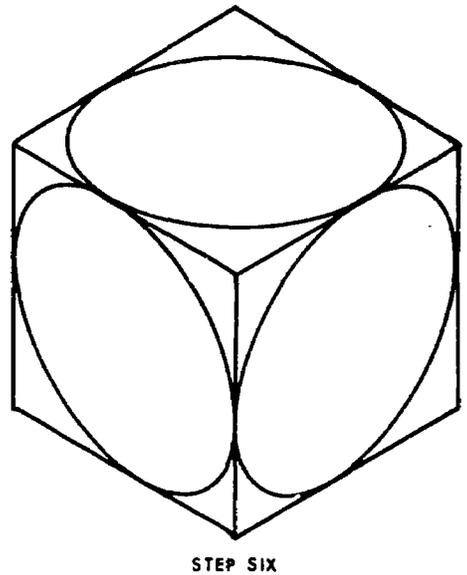
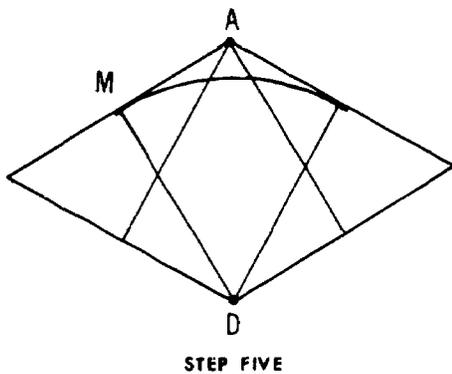
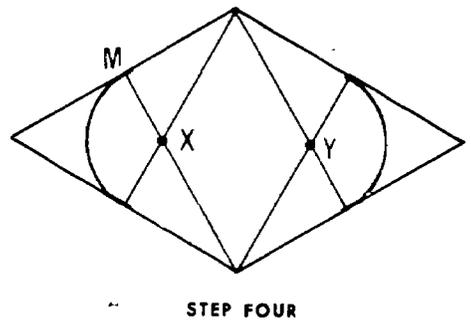
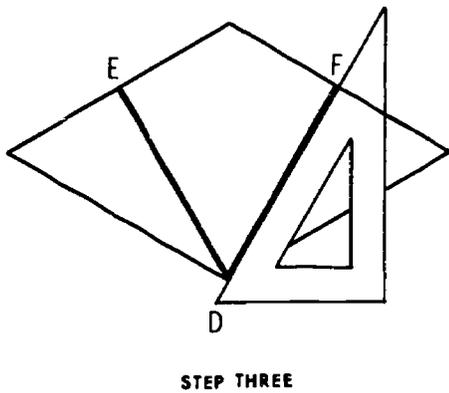
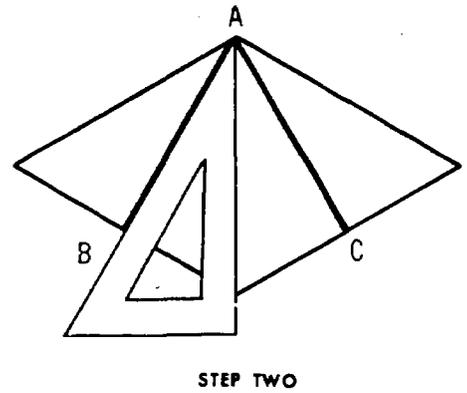
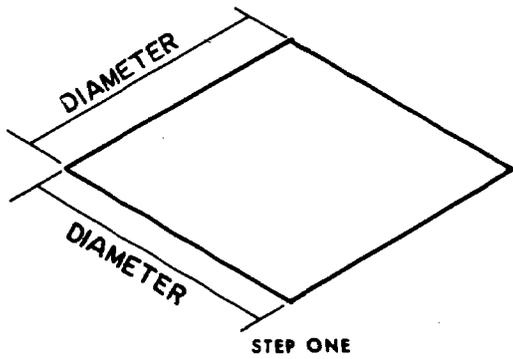


Figure 9-7. Isometric circles.

to the isometric drawing. This completes construction of the entire isometric drawing, exclusive of the lines which form the surface A. The end points of this surface can be located at the ends of the normal lines and surfaces bounding surface A. All that remains is to connect these points with straight lines.

9-7. Angles in Isometric

Should a specific angle be given in an orthographic view, the same principles as in nonisomet-

ric lines are used in transferring it to the isometric drawing. Locate the end points of the angle along the normal lines on the orthographic view by distances. Construct the corresponding isometric lines on the isometric drawing and lay off the distances taken from the normal view (fig. 9-6).

9-8. Circles in Isometric

a. A circle which appears in a normal multiview projection will appear as an ellipse in an isometric drawing. An isometric circle may be easily

constructed by the four center method. This method is usually accurate enough for most drawings. First, construct an isometric square that equals the diameter of the circle, step one, figure

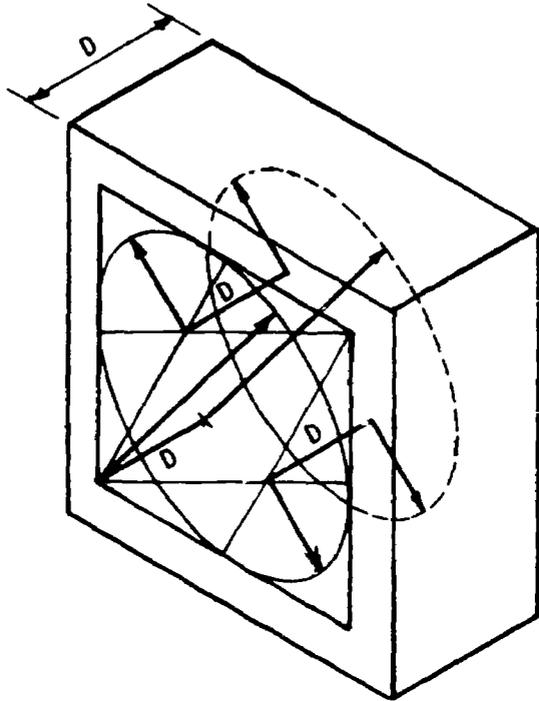


Figure 9-8. Isometric circle in the rear.

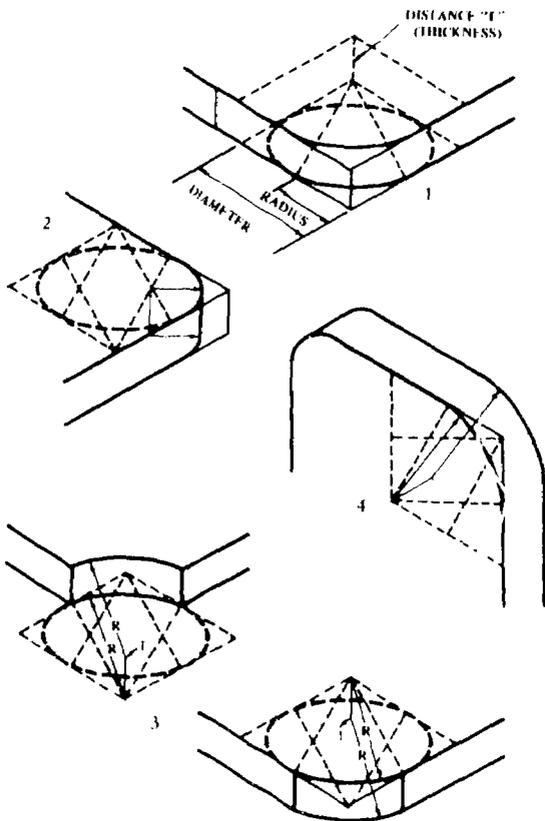
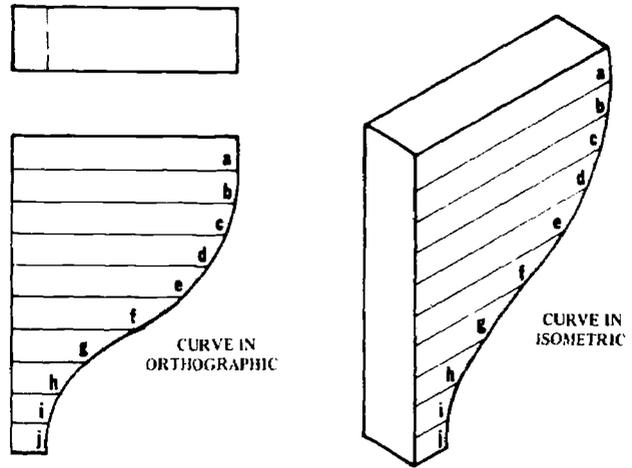


Figure 9-9. Isometric arcs.



9-7. Next with the 60° side of the triangle, draw lines AB and AC from corner A, step two. Draw lines DE and DF from corner D, step three. Draw two arcs with radius = xM , with centers x and y, step four. Draw two arcs with radius DM with centers D and A, step five. Step six shows the isometric circles for the front, top, and right side views.

b. To show portions of a circle on the rear of an object (fig. 9-8), lay off the thickness of the object or the depth of the hole. Then by projecting the centers of the radii used on the front of the object, back a distance equal to the thickness of the object, draw as much of the circle that is visible.

9-9. Isometric Arcs

The same principles may be employed to draw an arc on an isometric drawing (fig. 9-9). However, it is not necessary to construct the entire square. Only the radius of the arc need be laid out.

9-10. Isometric Curves

Should an object contain an irregular curve, a drawing of this curve's true shape should be made on an orthographic view. The view and the isometric drawing must be to the same scale. The true shape of the curve (fig. 9-10) can be plotted on the isometric view by a series of reference lines and distances taken from the orthographic view.

9-11. Isometric in Reverse Axis

The depth axis of an isometric drawing can be reversed to give special details on the bottom (fig. 9-11).

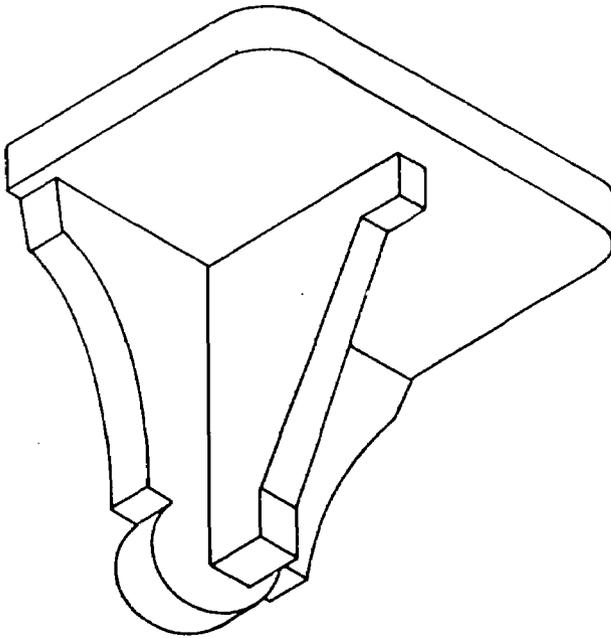


Figure 9-11. Isometric reversed axis.

9-12. Isometric Sections

Isometric sectional view (fig. 9-12) is used to good advantage to show a detail of shape or interior construction. The cutting planes are taken as isometric planes and the section lining is done in the direction that gives the best effect. In almost all cases, it is the direction of the long diagonal of a square drawn on the surface. For a full section the cut face is drawn first and then the part of the object behind it is added, 1, figure 9-12. A half section is made by outlining the figure in full and then cutting out the front quarter, as in 2, figure 9-12.

9-13. Isometric Paper

The isometric paper is like graph paper in that the lines are equally spaced but are drawn at an angle of 120° , i.e. on the isometric axes. As shown in figure 9-13, first sketch in the isometric of surface A, counting off the isometric grid spaces to equal the corresponding squares on the given view. Then sketch in the additional surfaces, B, C, D, E, and the small ellipse, to complete the sketch.

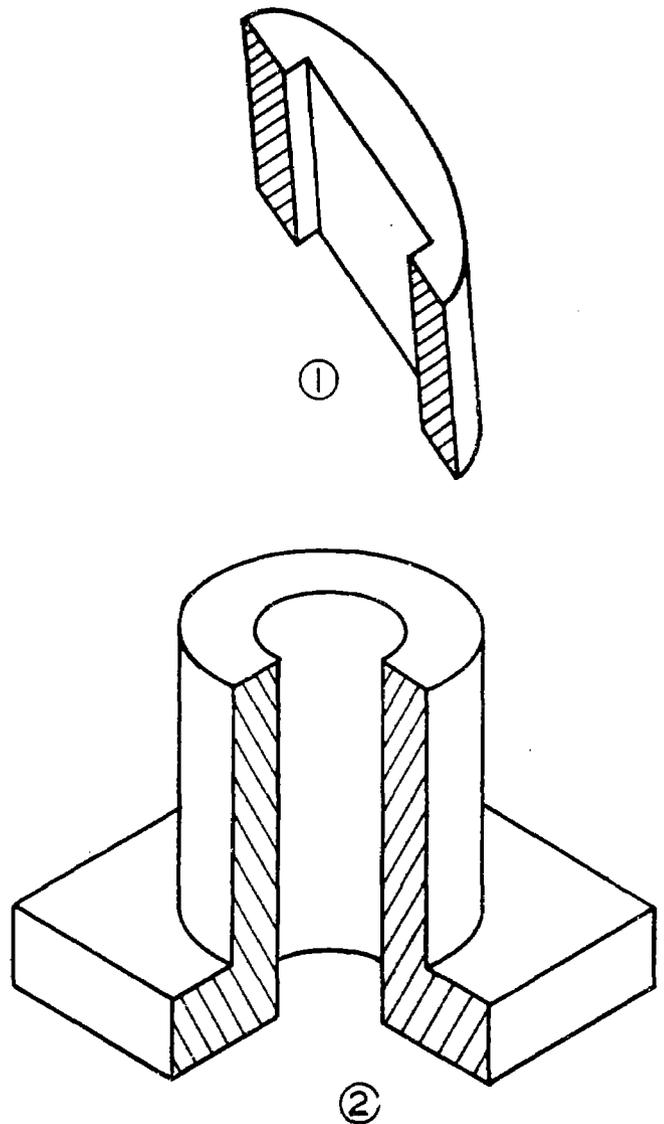


Figure 9-12. Isometric sections.

9-14. Dimensioning Isometric Views

Special consideration must be given to dimensioning an isometric drawing. Generally the same rules are observed that are used for other multi-view drawings. It is highly desirable to keep dimensions off the view. The most distinctive feature of isometric dimensioning is that dimensions are perpendicular to the dimension line and parallel to the plane with their respective extension and dimension lines (fig. 9-14).

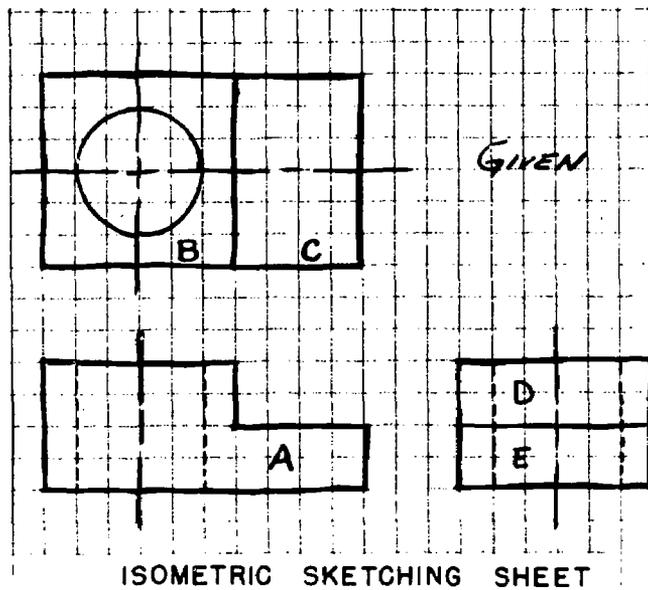


Figure 9-13. Sketching on isometric graph paper.

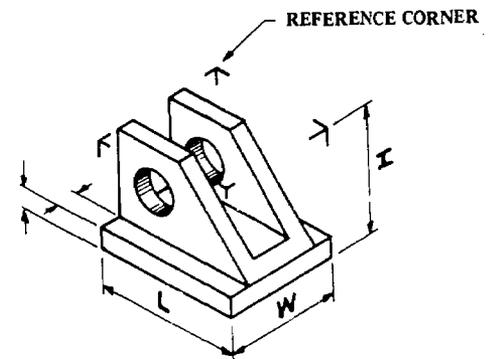
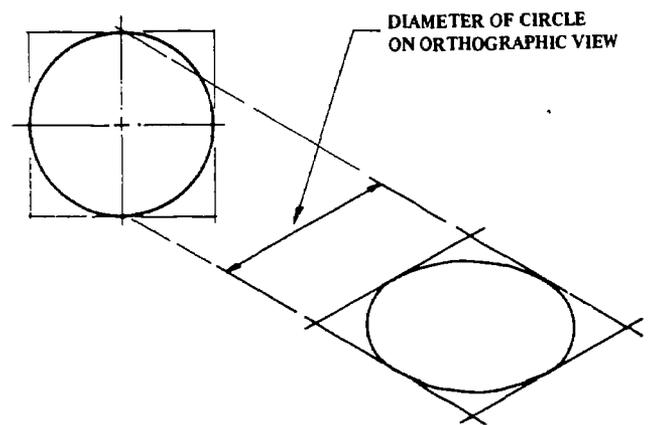
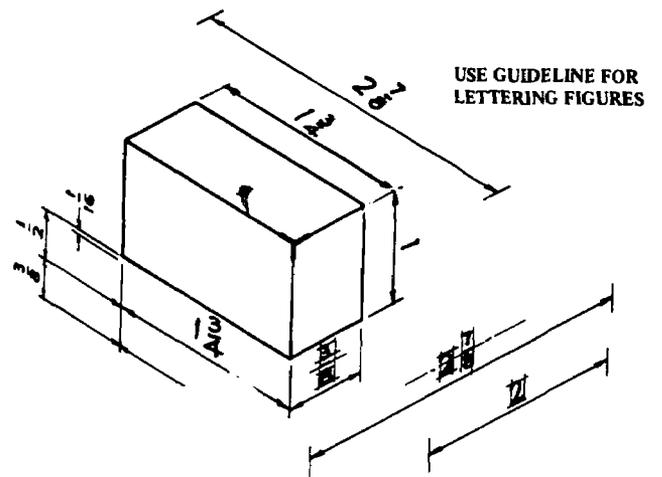


Figure 9-14. Dimensioning isometric drawings.

Section III. OBLIQUE DRAWING

9-15. General

a. Whenever one view has most of the important details, the use of the oblique drawing is advantageous. For instance, such objects as shims (a major outline with holes or cutouts and only a thickness) or cylinders (a series of concentric circles with various thicknesses), the oblique method of pictorial drawing is very easy to draft.

The main view (the outline and holes of the shim or the concentric circles of the cylinder) can be drafted without distortion. Only the necessary lines showing depth need be added to complete the drawing. All lines, angles, arcs, and circles that are parallel to the picture plane on the main view are measurable and true, as in orthographic projection but not so on an isometric drawing.

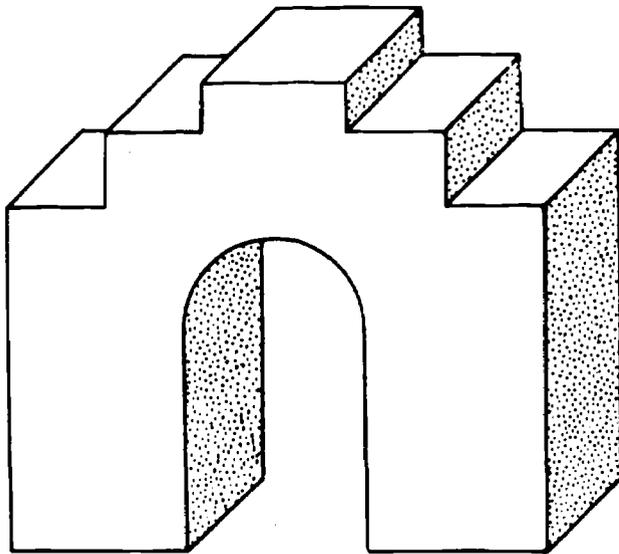
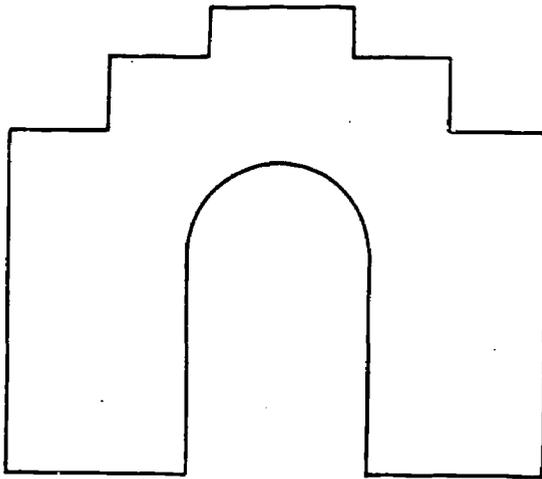
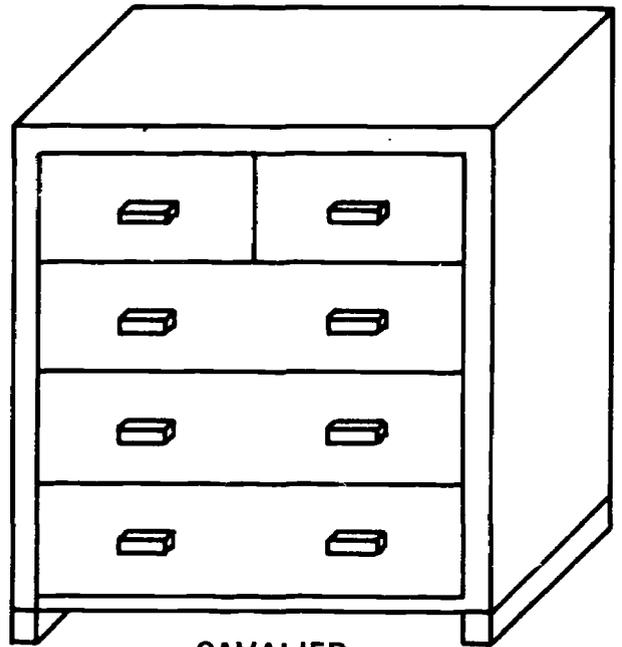


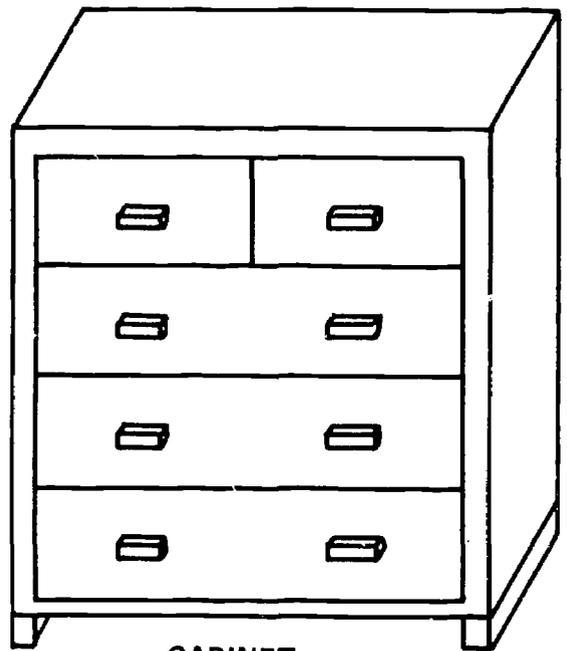
Figure 9-15. Oblique drawing.

Also all lines on the oblique axis (depth) are measurable as those on the isometric axis in an isometric drawing. Another advantage is that the angle of the oblique axis can be selected to bring out the shape or significant features of the object, which might be hidden in an isometric drawing. In an isometric drawing, the isometric axes can not be changed. In figure 9-15, note how the front view and the frontal plane of the oblique drawing are identical and not distorted, and the oblique axis is drawn at any convenient angle.

b. One of the disadvantages of an oblique drawing is that the oblique axis which is inclined more



CAVALIER



CABINET

Figure 9-16. Cavalier and cabinet projections.

than 30° seems to have an exaggerated perspective. However, this can be avoided by keeping the angle to 30° or less. Another disadvantage is when the length of the receding lines are long, the drawing gives a reversed perspective. That is to say, when compared with a perspective drawing (lines becoming small as they recede), in the oblique drawing the lines seem to get larger as they recede. The appearance of this distortion may be materially lessened by decreasing the length of the receding lines. The gain in doing this is a more natural look, but the loss is that these

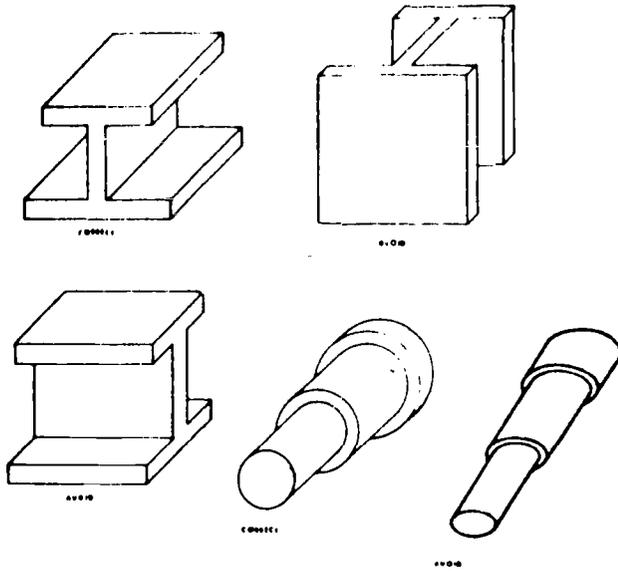


Figure 9-17. To avoid distortion.

lines are no longer true, but are still measurable. When the receding lines are true length and the oblique (depth) axis is 45° , the oblique drawing (fig. 9-16) is called a *cavalier projection*. When the receding lines are drawn to half size, the drawing is known as a *cabinet projection*. If the effect of a cabinet projection is too thin, then instead of $1/2$ reduction of the receding lines, a ratio such as 2 to 3, or 3 to 4, may be used to get a better effect.

9-16. Choice of Position

The essential contours of an object should be placed parallel to the plane of projection to avoid

distortion (fig. 9-17). Also the longest dimension of an object should generally be placed parallel to the plane of projection.

9-17. Drafting an Oblique Drawing

The oblique drawing has three axes that represent three mutually perpendicular edges and upon which measurements can be made. Two of the axes are always at right angles to each other as they are in a plane parallel to the picture plane. The third (depth) axis may be at any angle to the horizontal, 30° or 45° being generally used (fig. 9-18). The depth axis may also be reversed to show special features on the bottom of an object. Note that as long as the front of the object is in one plane parallel to the plane of projection, the front face of the oblique projection is exactly the same as in the orthographic front view.

9-18. Drafting Oblique Circles

To draft circles that are on the oblique faces, a principle similar to the four-center isometric approximation can be used. Construct four perpendiculars from the middle points of the square inscribing the oblique circle. In isometric it happens that two of the four intersections of the perpendiculars from the middle points of the containing square fall at the corner of the square. However, in the oblique, the position of the corresponding points depends on the angle of the depth axis. Figure 9-19 shows three squares in oblique positions at different angles and the construction of their inscribed circles.

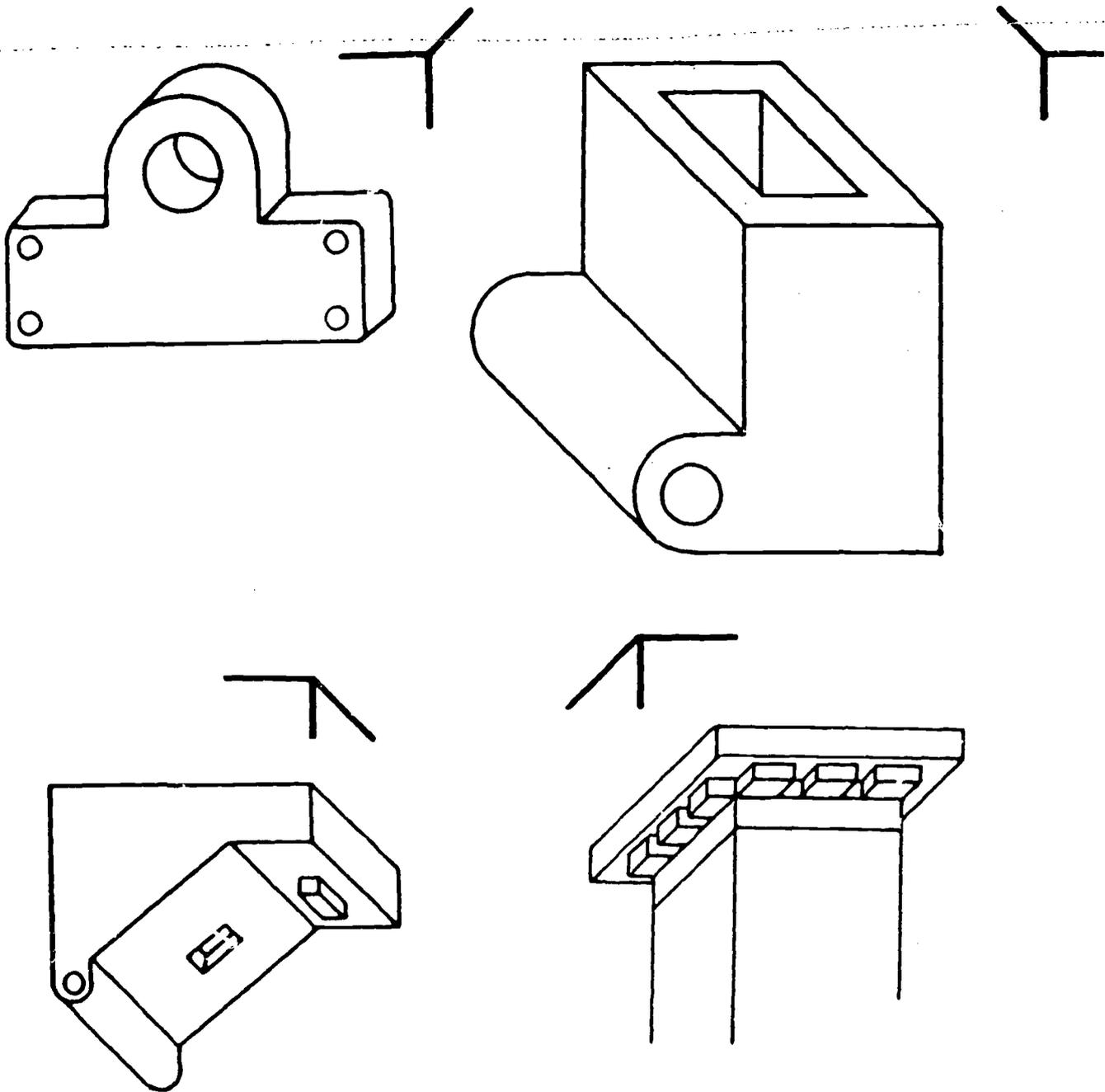


Figure 9-13. Various ways of drafting oblique drawings.

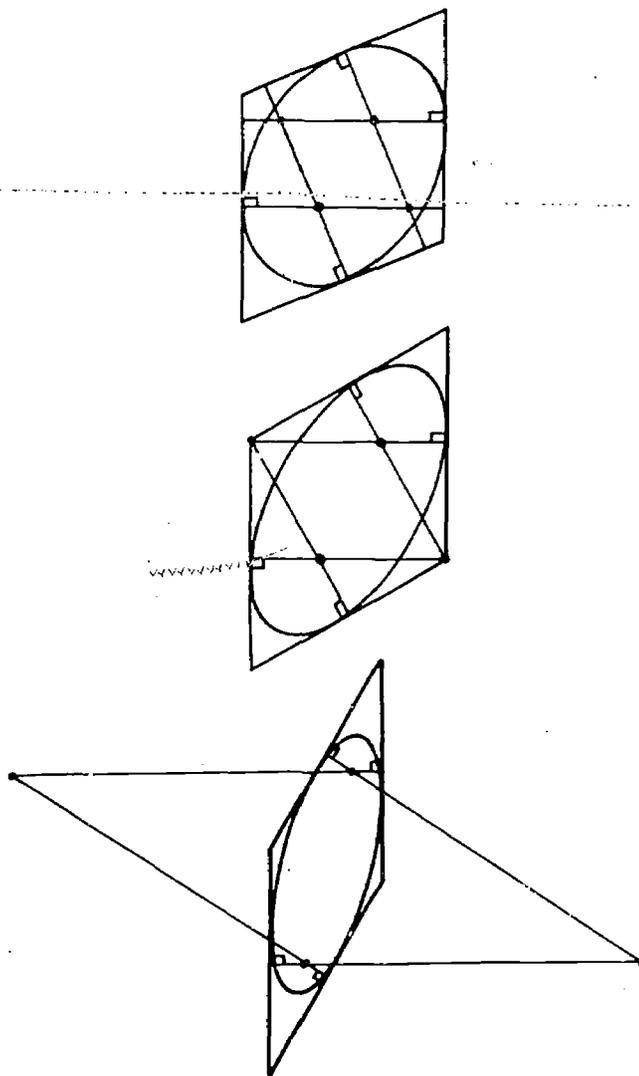


Figure 9-19. Oblique circles.

Section IV. PICTORIAL SKETCHING

9-19. Freehand Technical Drawing

a. Applications. There are many occasions when graphic size-shape data can be presented more conveniently in a freehand sketch than in a drawing prepared with instruments. A freehand technical drawing is the most suitable way for a designer to show a draftsman what is wanted in a finished drawing. The man who is sent out to record information about a bridge that needs repair will find it easier to move around with a sketch pad and pencil than with a drawing board and a complete set of instruments. In both cases, the primary need is to furnish essential information quickly and efficiently. A technical sketch is a freehand orthographic drawing. A pictorial sketch is a freehand isometric drawing. The principles of orthographic projection and isometric drawing are the same whether a drawing is exe-

cuted freehand or with instruments. Although it is expected that an experienced draftsman will develop an individual style, the fundamentals presented in this chapter will provide the beginner with a satisfactory technique for preparing accurate, legible freehand sketches.

b. Classification. Sketches may be classified in relation to the building of an object, or structure. There are two general categories: those that precede the building of the object, and those that follow it. In the first category are principally design sketches representing the designer's instructions to the draftsman and working sketches that may be used as a substitute for working drawings. Sketches made after a structure has been completed generally are for the purpose of repair or reconnaissance and fall in the second category. A sketch showing a part requiring repair

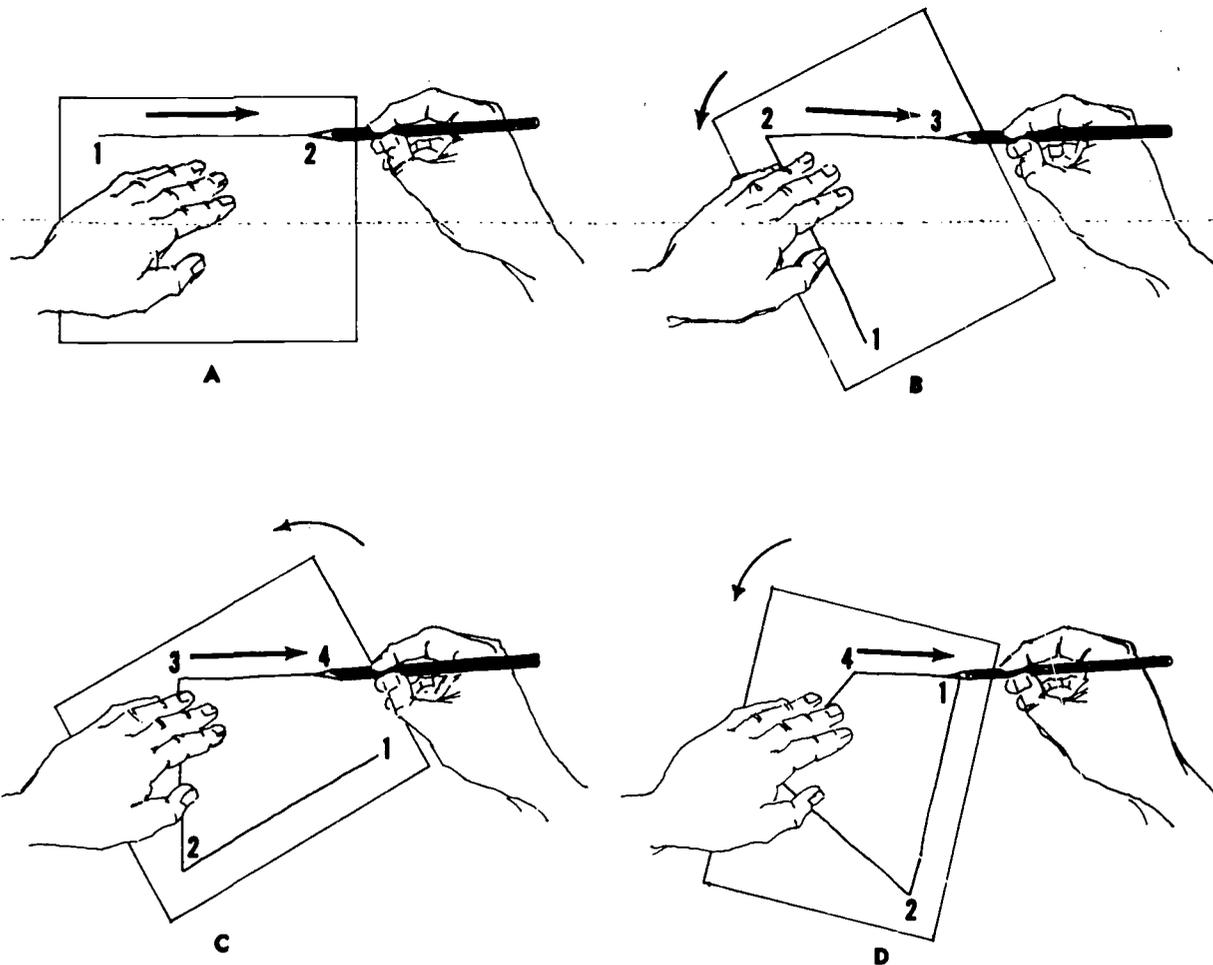


Figure 9-20. Sketching straight lines.

may be as complete as a working drawing. A reconnaissance sketch is required to establish relative locations rather than to furnish accurate size and shape descriptions.

c. Materials. Paper, pencils, sharpening equipment, an eraser, and a measuring instrument are the only materials required for freehand sketching.

(1) *Pencil.* A soft pencil, H or HB, is best for freehand lines. Sharpen the pencil to a long conical point. A pocket knife and a sandpaper or small file should be carried to maintain a sharp point. As in an instrument drawing, the sharpest lines are the most legible and are produced with a sharp pencil point.

(2) *Paper.* A pad $8\frac{1}{2}$ x 11-inch cross section is recommended. For sketching, the most satisfactory grids are composed of $\frac{1}{4}$ -inch squares or 16 squares to the inch. Cross section paper is an aid in drawing straight lines and in maintaining a reasonable accurate scale.

(3) *Eraser.* Carry a rubber or gum eraser to

remove unwanted lines and to keep the drawing clean.

(4) *Measuring equipment.* The choice of measuring equipment is determined by the size of the object to be sketched. For small machine objects, a machinist's steel scale and calipers are adequate. A 6-foot folding rule is satisfactory for most routine construction measurements. Measurements over 40 feet in length can be made more easily with a 100-foot surveyor's tape. The size of the object will also decide the value to be assigned each grid square, that is, the scale to which the object is drawn.

9-20. Technique

As in instrument drawing, the purpose of developing a satisfactory technique is to produce lines of direction, weight, and characteristic construction to provide the reader with a single, clear understanding of their meaning. The pencil should rest on the second finger and be gripped lightly by the thumb and index finger about $1\frac{1}{2}$ inches from the tip. It is held in a vertical plane and inclined at about 30° in the direction of the

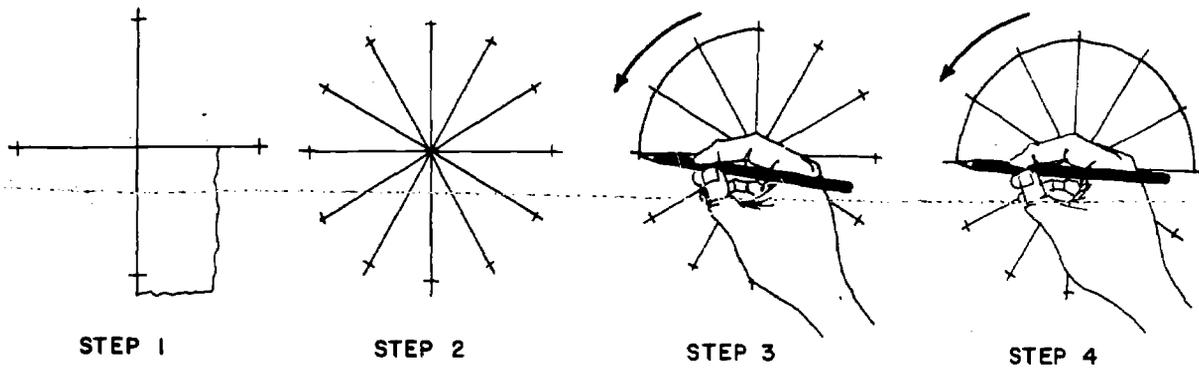


Figure 9-21. Radial method of sketching circles.

line being drawn. A draftsman should be able to observe the point of the pencil during the execution of each stroke. The layout is made first in light construction lines. The lines are darkened in after the layout has been checked for accuracy. The same procedure is used for both light and heavy lines.

9-21. Straight Lines

a. Procedure. Straight lines are usually drawn from left to right and from the top down with wrist and finger movements. The paper may be turned and the pencil held in any convenient manner—as the only purpose is to make the lines “freehand” and “straight”. Figure 9-20 shows how the paper may be turned to make lines 1-2, 2-3, 3-4, and 4-1 all horizontal and thus capable

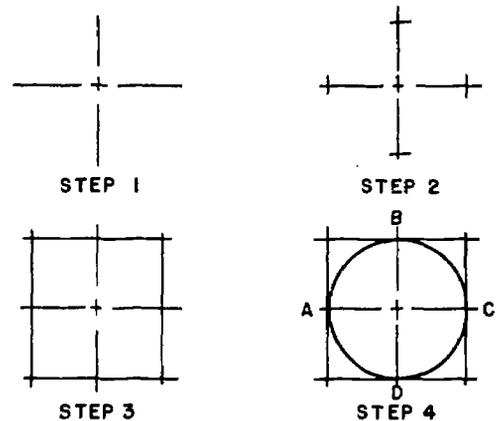


Figure 9-22. Outline method of sketching circles.

of being drawn most naturally with a left-to-right wrist movement. It is good practice to mark the

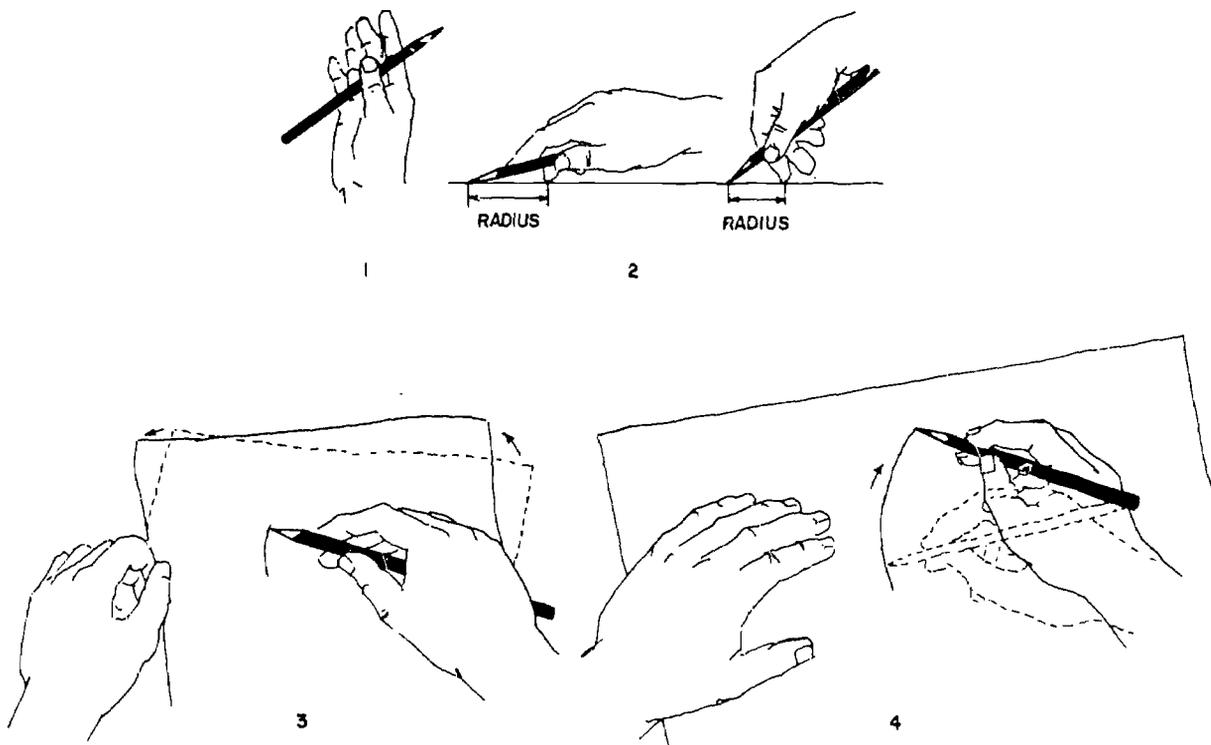


Figure 9-23. Hand compass method of sketching circles.

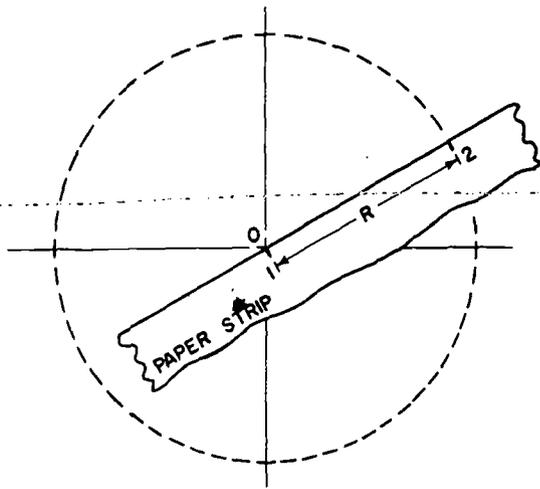
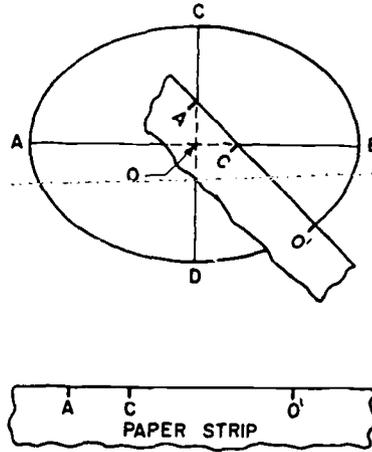
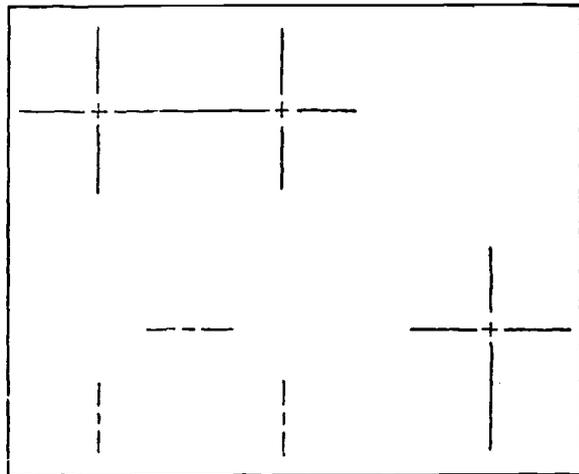


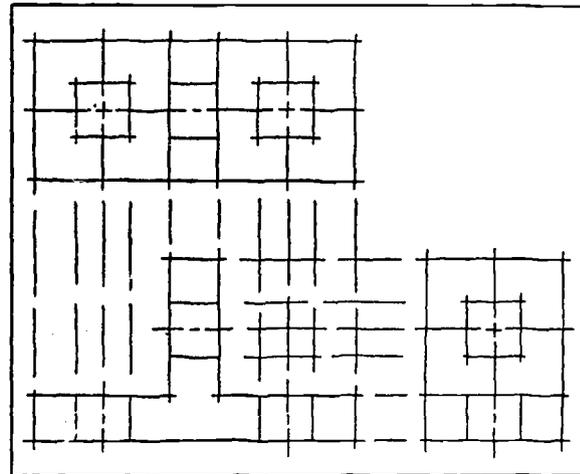
Figure 9-24. Paper strip method of sketching circles.



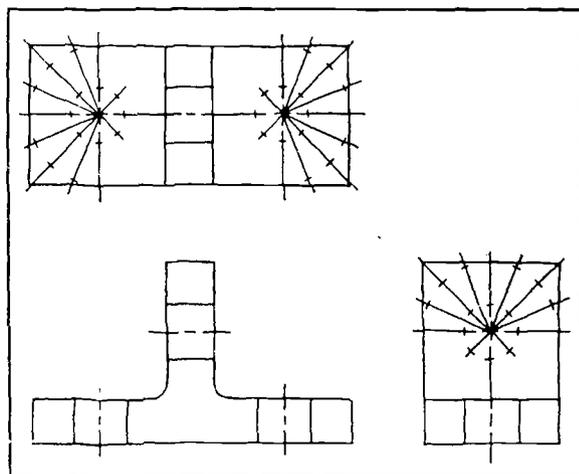
9-25. Ellipse-paper strip method.



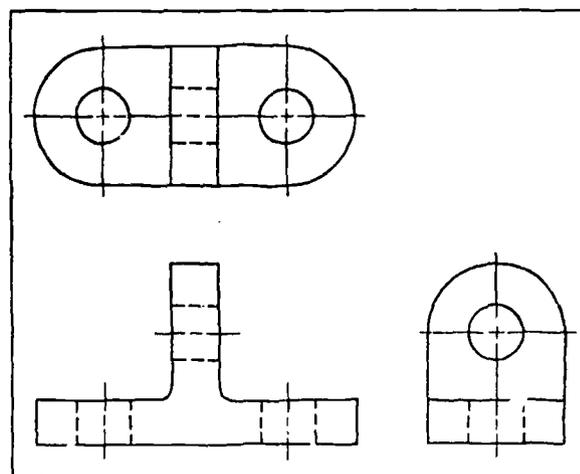
① SKETCH CENTERLINES LIGHTLY FOR ALL VIEWS



② EXTEND PROJECTORS AND BLOCK IN VIEWS



③ ESTABLISH POINTS AND DRAW ARCS



④ DARKEN OUTLINES AND DRAW HIDDEN LINES

Figure 9-26. Sketching a simple object.

extremities of a line with dots, or long lines with several dots, before drawing. Two or more line segments should meet end to end without overlap. A practice motion without making a mark is sometimes advisable to be sure the hand can complete the desired stroke without error.

b. Alternate Methods. An experienced draftsman may find it quicker to draw vertical lines from the top down, using a finger motion rather than turning the sketch pad to draw horizontal lines. Inclined lines slanting from upper left to lower right may be drawn in horizontal position by turning the sheet slightly, and inclined lines slanting from upper right to lower left may be drawn in vertical position by turning the sheet slightly. Inclined lines slanting from upper right to lower left may be drawn in vertical position by turning the paper the required amount in the opposite direction.

c. Line Weights and Conventions. The same line conventions used in instrument drawing are used in sketching to denote the function of a line or its position with respect to the viewer. Whereas three line weights are prescribed for ink drawings, only two are required for technical sketching: medium for outline, hidden, cutting-plane, and alternate-position lines; and thin for section, center, extension, and dimension lines. The width and intensity of freehand lines are determined by the size of the pencil point and the amount of pressure applied to it. Circles and arcs require particular attention in sketching because it is more difficult to produce a curved line of uniform weight than a straight line.

9-22. Circles and Arcs

The same procedure is used for sketching circles and circular arcs. Four methods are acceptable.

a. Radial Method. Sketch the horizontal and vertical axes to intersect at the center point. Mark off the radius of the circle, on a scrap of paper, with two points and transfer the measurement to the main axes (step 1, fig. 9-21). Sketch diagonal lines at approximately 30° intervals and use the piece of paper to transfer the measurements to the radial lines (step 2, fig. 9-21). After all points have been marked with light, distinct dashes, sketch the circle one quadrant at a time (steps 3 and 4, fig. 9-21). By rotating the sketch pad, the stroke can be swung in the same direction each time.

b. Outline Method. Sketch the main axes (step 1, fig. 9-22) and mark off the radius (step 2, fig. 9-22) for small circles. Construct a square (step 3, fig. 9-22) by drawing lines parallel to the main

axes at the radius points. Draw the circle (step 4, fig. 9-22) within the square and tangent to it at the midpoint of the sides. For larger circles, add two intersecting lines drawn at 45° to the horizontal. Mark off the radius on the lines and sketch an octagon. Draw the circle within the octagon and tangent to it at the midpoint of each side.

c. Hand Compass Method. Grasp the pencil as shown in 1 and 2, figure 9-23, so that it is the radius distance from the fingernail that is to be used as the pivot finger. (It may be preferable for some people to use the little finger instead of the forefinger as shown.) Then place the fingernail of the pivot finger on the point that is to be the center of the circle and turn the paper (3 and 4, fig. 9-23) using the hand as a compass to draw the circle.

d. Paper Strip Method. First locate the center point O, by drawing the vertical and horizontal centerlines (fig. 9-24). Then mark off the radius (line 1-2) of the circle on the strip of paper. With point 1 always on O, rotate the strip and mark off points where 2 falls. Then sketch in the circle through all points located.

9-23. Ellipse

Figure 9-25 illustrates a paper strip method of sketching an ellipse if the center and both axes are known. First draw the major and minor axes AB and CD intersecting at center O. Mark off one-half of major axis (O'A) and one-half of minor axis (O'C) on a strip of paper. Move the paper so that point A is always on the minor axis and point C is always on the major axis. For each change in position of A and C, as the paper strip is rotated, mark off point O' on the sketch sheet. Connect all points located by movement of point O'.

9-24. Irregular Curves

An irregular curve can be drawn by locating a series of individual points (by dots) along its path at $\frac{1}{2}$ -inch intervals. Sketch a smooth curve through all points located, without overlapping strokes.

9-25. Technical Working Sketches

A systematic procedure should be followed in preparing a technical working sketch. Draftsmen will find that this not only aids in laying out the views on the sheet but also provides a checklist for including the necessary details methodically.

a. Preliminary Work. Examine the object carefully, and select for a front view the surface that offers the most characteristic shape or requires the least number of hidden lines. Determine the

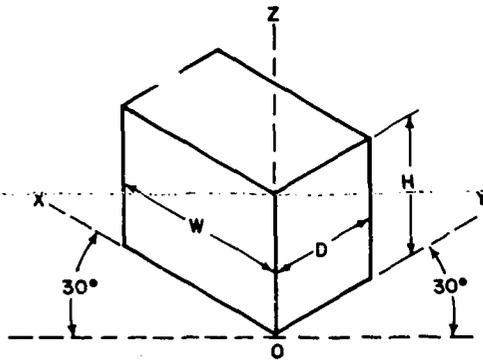


Figure 9-27. Application of isometric sketching.

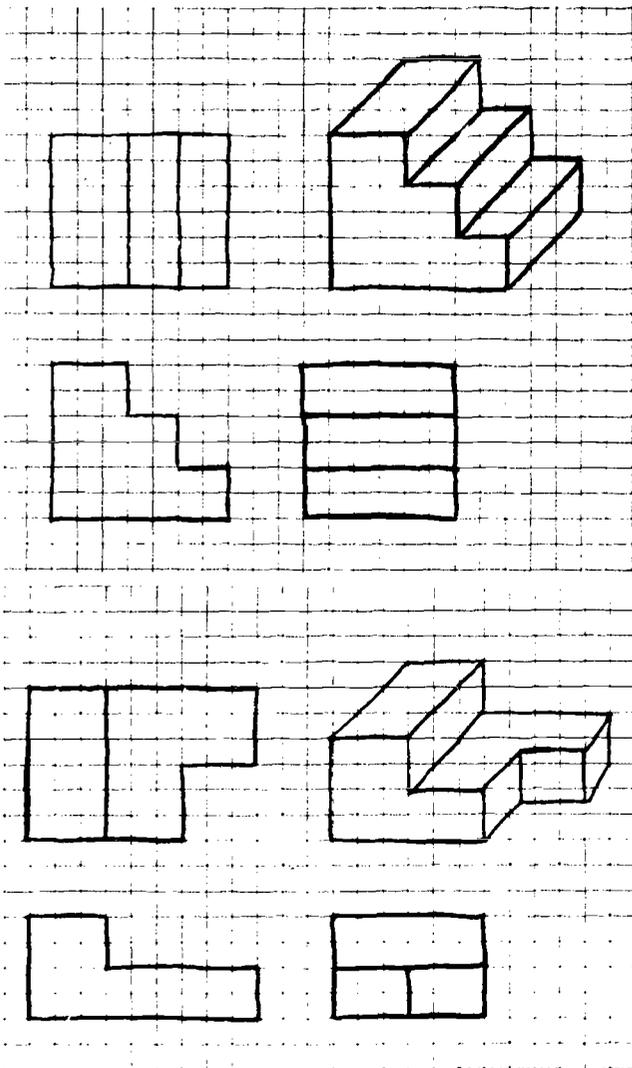


Figure 9-28. Oblique sketching.

number of views necessary to describe the object adequately. Form a mental picture of the arrangement of the views on the sketch sheet and the spacing required between them.

b. Sketching Sequence. Locate the main centerlines of the views, remembering to leave enough space between views for notes and dimensions

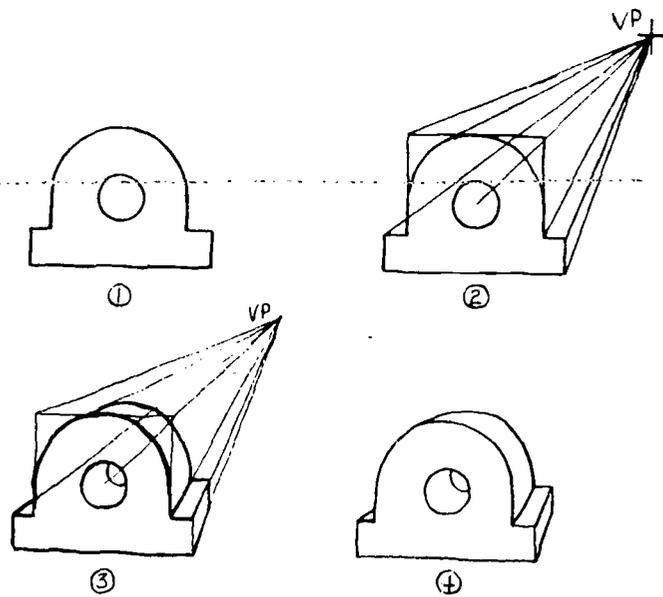


Figure 9-29. One point perspective (sketched).

①, fig. 9-26). Remember also that all preliminary lines are sketched lightly. Block in the views with the principal dimensions of each rectangle proportional to the dimensions of overall dimensions of each view (②, fig. 9-26). Keep all views in projection. Next locate all radius points and sketch in circles, arcs, curves, and rounded edges (③, fig. 9-26). As a final step in drawing construction lines, put in the hidden lines (④, fig. 9-26). After checking the drawing to see that all views are complete, darken the outlines to provide the proper line weight and intensity.

c. Dimensioning. Objects are sketched in proportion, not drawn to scale as in instrument drawings. The rules for dimensioning are the same in all drawing. Sketch extension and dimension lines first to indicate where dimensions are required. Next measure the object and record the necessary dimensions. As a final step, add notes and a title block. Sketches should always be dated.

9-26. Pictorial Sketching

Sketches made in isometric projection (fig. 9-27) are satisfactory for purposes of pictorial representation. Isometric sketches conform to the principles of isometric drawing presented in section II. The freehand technique is the same as for technical sketching. A draftsman should understand that the angle of the receding isometric axes, when drawn freehand, will only approximate 30° with the horizontal.

a. Advantages. The advantages of a freehand pictorial sketch lie principally in the visualizing of a new object when it shows three dimensions

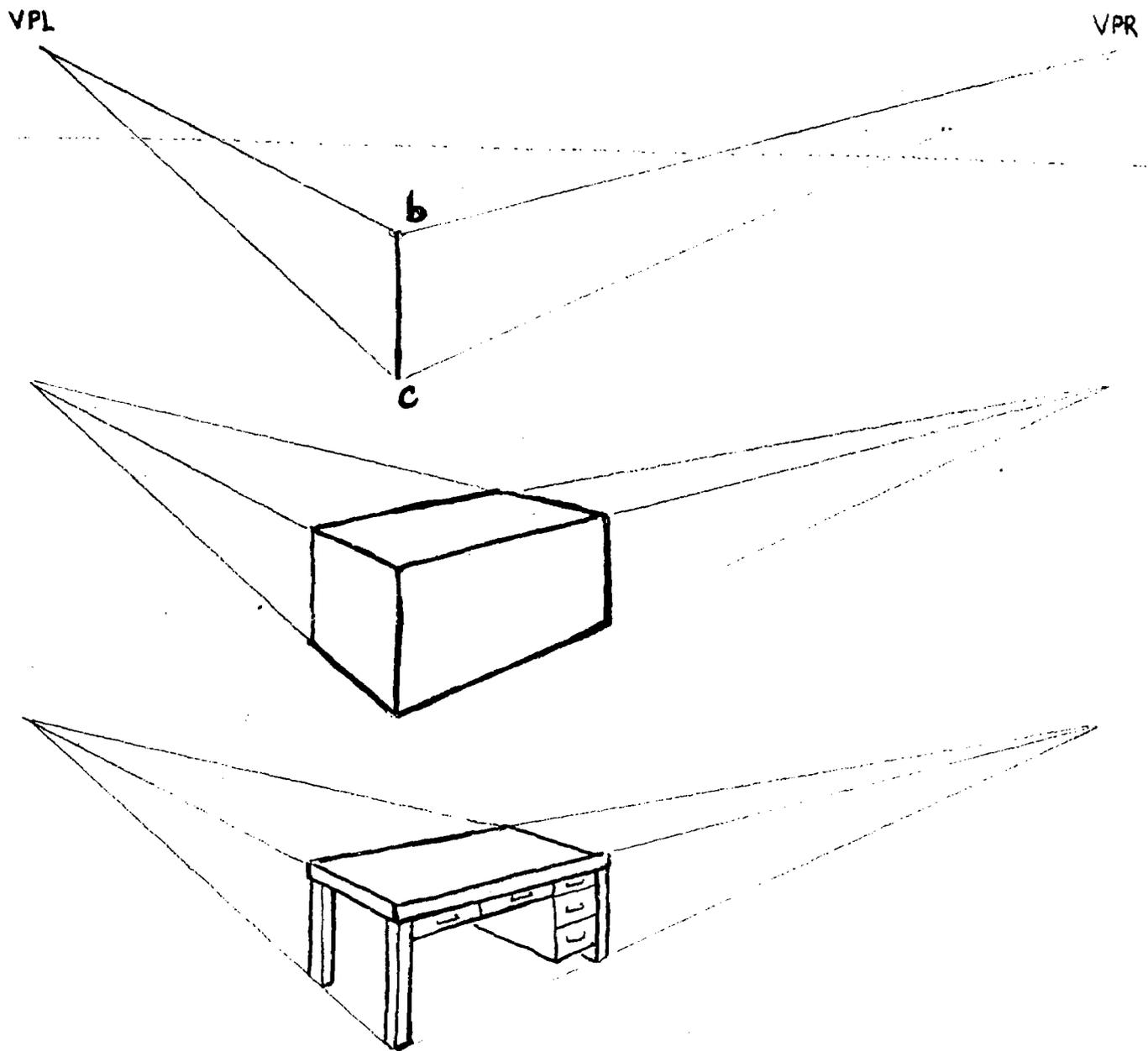


Figure 9-30. Two point perspective (sketched).

in the same view. Draftsmen will find isometric sketching an assistance in reading an orthographic drawing. At other times, a technical sketch will often be clarified if accompanied by an isometric sketch.

b. Object Orientation. As in technical sketching, a primary requirement in pictorial sketching is good proportion. Objects should be viewed so that the most complex faces are represented on a receding plane.

c. Use of Isometric Graph Paper. Refer to paragraph 9-13, Isometric Paper, which gives instruction on isometric sketching on isometric graph paper.

9-27. Oblique Sketching

Ordinary cross-section paper is suitable for oblique sketching. Two views of an object are shown in figure 9-28. The dimensions are determined by counting the squares. Sketch lightly the inclosing box construction. Sketch the receding lines at 45° diagonally through the squares. To establish the depth, sketch the receding lines diagonally through half as many squares as the given number shown in the orthographic views. Sketch all arcs and circles, and heavy-in all final lines.

9-28. Perspective Sketching

a. Objects that are suitable for oblique drawing

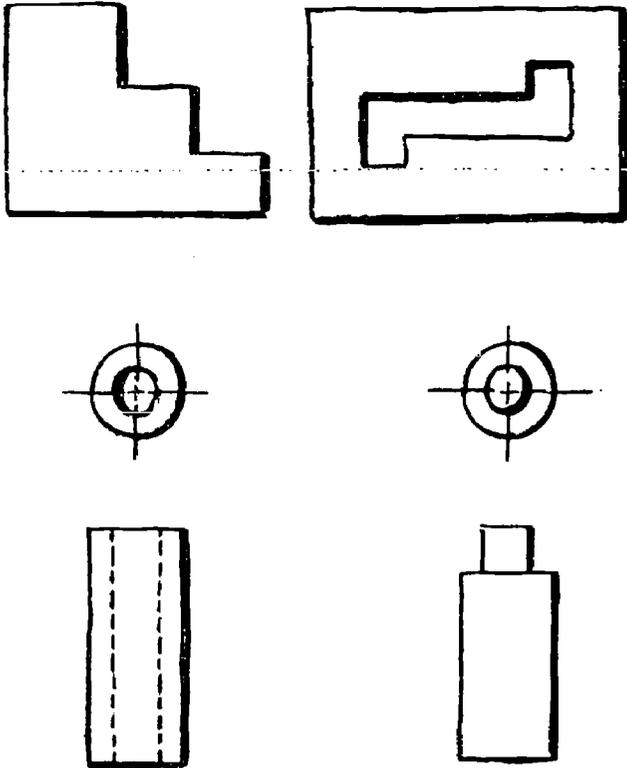


Figure 9-31. Shade lines.

are also suitable for *one-point perspective* drawings (one vanishing point) as shown in figure 9-29. Sketch true front face of the object, just as in oblique sketching. Select the vanishing point (VP) for the receding lines. In most cases, it is desirable to place VP above and to the right of the picture, as shown, but it can be placed anywhere in the vicinity of the picture. If placed too close to the center, the lines will converge too sharply, and the picture will be distorted. Sketch receding lines toward VP. Estimate the depth to look right, and sketch in the back portion of the object. Erase all construction lines with artgum, and heavy-in all final lines.

b. *Two-point perspective* (two vanishing points) is the most "true to life" of all pictorial methods, but requires some natural sketching ability or considerable practice for best results. A simple method is shown in figure 9-30 that can be used successfully by the non-artistic student. Sketch front corner in true height, line *bc*, and locate two vanishing points on a horizon line (eye level). The

distance may vary—the greater it is, the higher the eye level will be and the more we will be looking down on top of the object. For a natural perspective the left vanishing point should be about the same distance from the center of the horizon as the right vanishing point is from the center of the horizon. Unequal distance will exaggerate the perspective (as shown in figure 9-30). Estimate the depth and width and sketch lightly the inclosing box construction. Block-in all details; note that all parallel lines converge toward the same vanishing point. Erase construction lines with artgum and heavy-in all final lines.

9-29. Perspective Grid Paper

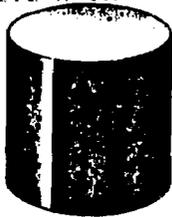
An excellent aid to the beginner and those not interested in spending much time in making perspective drawings is the perspective grid, which is a printed sheet of grid lines arranged for the most commonly used positions. The master grid is simply placed under a sheet of tracing paper and the sketch is easily made by following the grid lines for distance and direction.

9-30. Shading

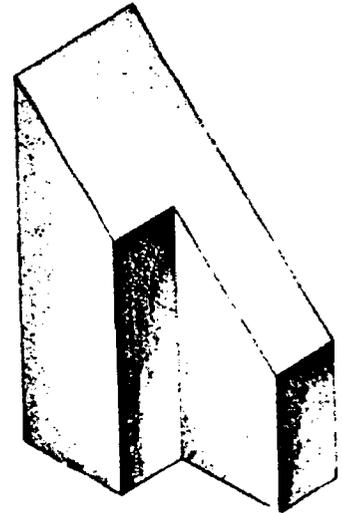
According to the general effect desired for the final sketch or drawing, and to the method of reproduction, different methods of shading can be selected.

a. *Shade Lines.* A simple method of adding some effect of light and shade to the sketch is by shade lines. This is done by using heavy lines only for the left vertical and upper horizontal edges of the dark faces (fig. 9-31). Holes and other circular features are drawn with heavy lines on the shade side.

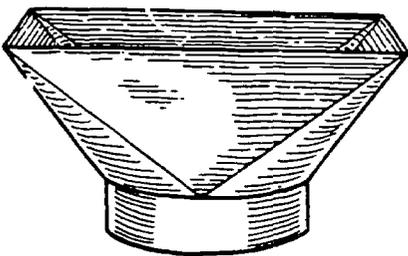
b. *Line Shading and Tone Shading.* Line shading is done by lines alone, varying the thickness of lines, and the distance apart, rendered either by pencil or pen. Tone shading is done by a continuous-tone such as a soft pencil with its point flattened and drawn on a medium-rough paper, or a water paint wash applied with a brush. Whether shading is done by line or tone, it is first necessary to acquire an understanding of the simple one-light method of illumination. Figure 9-32 shows various examples. After some practice and study, a feeling for tone values will be developed.



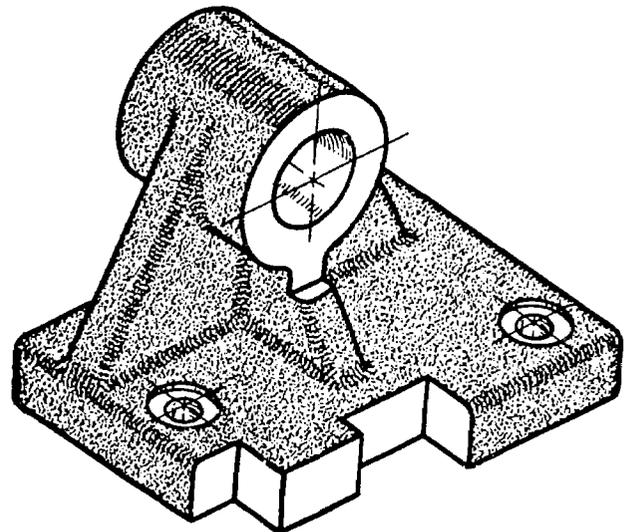
LIGHT AND SHADE



CONTINUOUS TONE SHADING



LINE TONE SHADING



STIPPLED SHADING

CHAPTER 10

DIMENSION AND NOTES

Section I. SIZE DESCRIPTION

10-1. Introduction

The discussion of technical drawing so far has covered the methods and instruments used for *shape description*. Technical methods of graphic description were discussed in preceding chapters on orthographic projection and pictorial drawings. In this chapter, methods of *size description* will be discussed. Accurate and exacting methods of size description save the reader of plans a great deal of time which otherwise might be lost because of dimensions that are not clear, legible, or that can be interpreted in more than one way. The reliability of the drawing is assured by giving both the scale and the exact size description of every important part of the object. Mil-Std-8C defines "dimension" as follows: "A dimension is a numerical value expressed in appropriate units of measure. It is indicated on drawings in conjunction with lines, symbols, and notes to define the geometrical characteristics of an object." For a complete discussion of dimensioning not covered in this chapter refer to Mil-Std-8C "Dimensioning and Tolerancing."

10-2. Theory of Dimensioning

Any object can be dimensioned easily and systematically by breaking it down into a group of assembled, simple geometric shapes. Prisms, cylinders, cones, and pyramids are examples of basic geometric forms. The dimensioning of each follows familiar geometric practice. An object is dimensioned by giving the individual sizes of the component geometric forms and establishing their location relative to each other (fig. 10-1). Two types of dimensions are required to describe an object; size dimensions and location dimensions (fig. 10-2).

a. Size Dimensions. A size dimension is a specified value of a diameter, width, length, or other

geometrical characteristic directly related to the size of an object.

(1) *Prisms and slots.* Prisms and slots are dimensioned by giving the height, width, and depth. In a drawing, two dimensions are given in the principal view and the third in a related view.

(2) *Cylinders and holes.* The size of cylinders and holes is shown by two dimensions when it appears in a profile view. One dimension gives its length, the other accompanied by the note "DIA", gives its diameter.

(3) *Pyramids.* Pyramids are dimensioned by three dimensions. Width and depth are given in the view showing the base; height is given in a related view.

b. Location Dimensions. A location dimension is one that specifies the position or distance relationship of one feature of an object with respect to another. Location dimensions give distances between centers (center to center), between a surface and a center, or between two surfaces.

(1) *Datum elements.* Datum surfaces, datum planes, and so on, are features of a part and are assumed to be exact for purposes of computation or reference, although another feature or other features of the part may vary with respect to the datum. The zero lines of a local grid are datum lines because significant construction points, such as foundation walls, are located with respect to the zero lines. The finished floor or building is a datum plane. Door and window heights are established with location dimensions relative to the finished floorline.

(2) *Reference dimensions.* A reference dimension is a dimension used for informational purposes only and does not govern shop operations in any way. Reference dimensions will be indicated on the drawing by writing the abbreviation REF directly following or under the dimension.

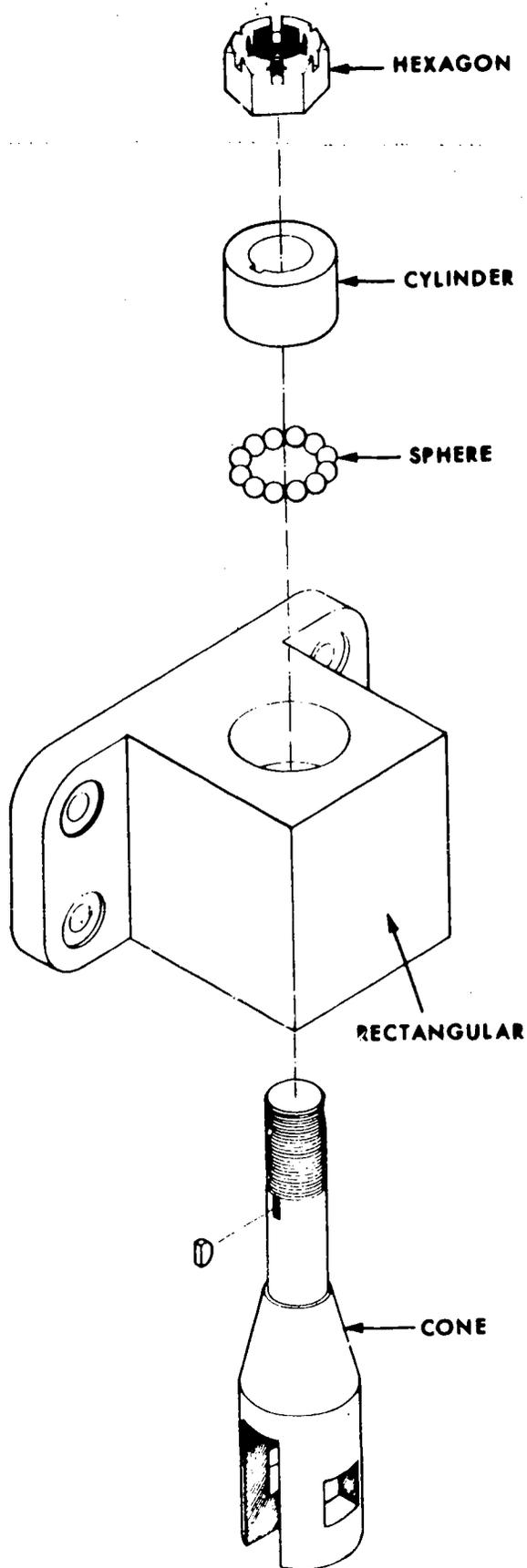


Figure 10-1. Defining geometric characteristics.

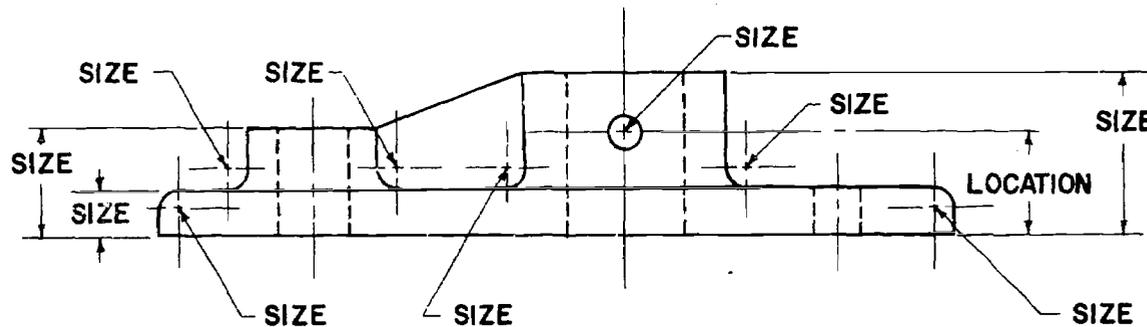
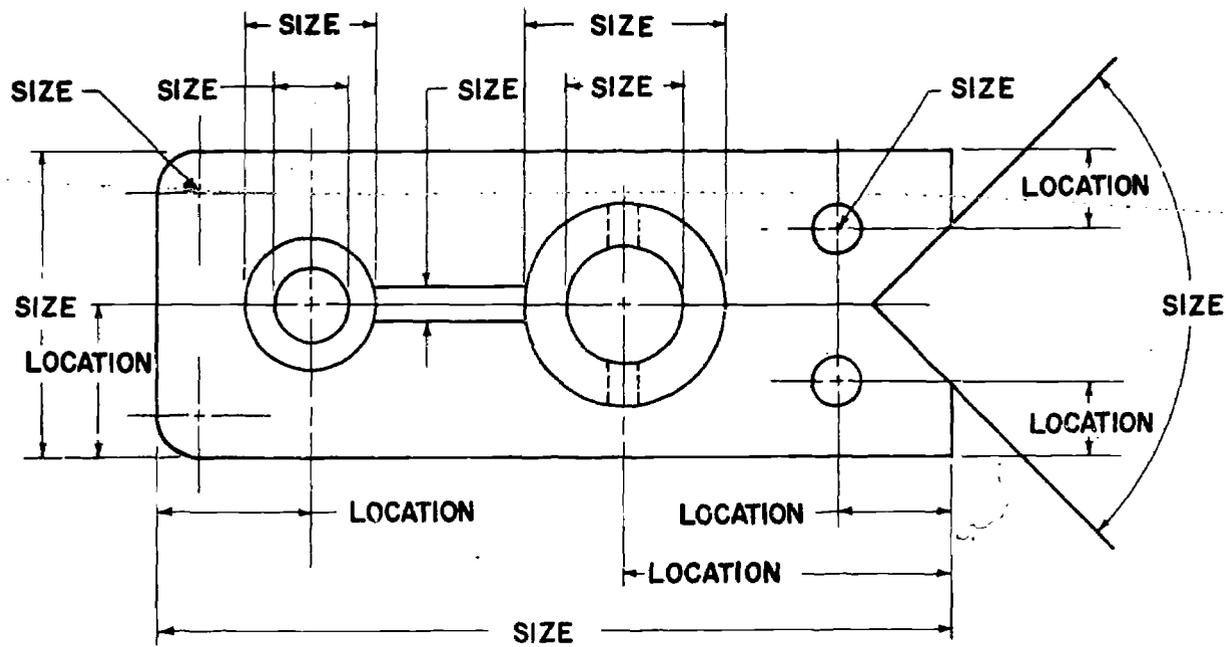


Figure 10-2. Size and location dimensions.

Section II. ELEMENTS OF DIMENSIONING

10-3. Dimension Lines

a. Numerals. A dimension line, with its arrowheads, shows the direction and extent of a dimension. Numerals indicate the number of units of a measurement (par. 10-8). Dimension lines shall not pass through these numerals (1, fig. 10-3). On structural drawings and architectural drawings, it is universal practice to place the numerals above a continuous dimension line (2, fig. 10-3). If there are two sets of numerals, one is placed above and the other below the line (3, fig. 10-3).

b. Spacing. Generally the first dimension line is placed $\frac{1}{2}$ inch from the object. All other parallel

dimension lines should be spaced at intervals of $\frac{3}{8}$ inch (fig. 10-4). Do not use centerlines, extension lines, or lines that are part of the outline of the object, or a continuation thereof, as dimension lines. Do not use dimension lines as extension lines. Avoid crossing dimension lines, if possible.

c. Angles. The dimension line of an angle is the arc drawn with its center at the apex of the angle and terminating at the two sides (fig. 10-5).

10-4. Extension Lines

It is usually undesirable to terminate dimension lines directly at lines that represent surfaces of

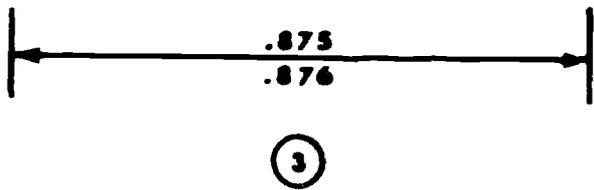
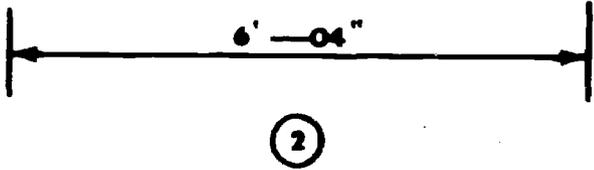
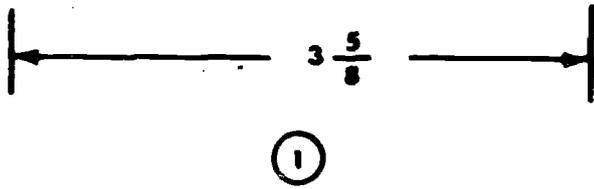
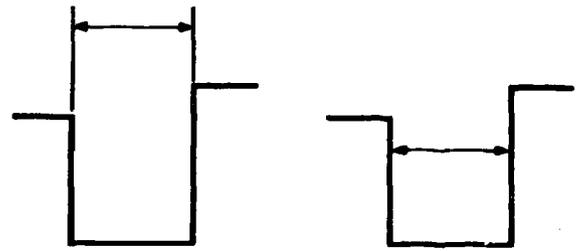


Figure 10-3. Dimension lines with numerals.

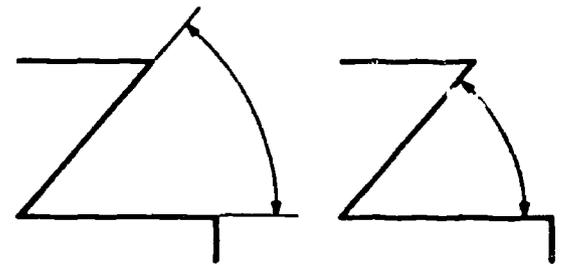


Figure 10-5. Angle dimensions.



Recommended

Not Recommended



Recommended

Not Recommended

Figure 10-6. Use of extension lines.

inch beyond the outermost dimension line. Extension lines are usually drawn perpendicular to dimension lines, but may be at other angles if their meaning is clear. Wherever possible, extension lines should neither cross one another nor cross dimension lines. To reduce crossings to a minimum, draw the shortest dimension line nearest the outline of the object, and adjacent parallel dimension lines in order of their length, with the longest line the outermost. Where extension lines cross other extension lines, dimension lines, or object lines, they should not be broken. However, if an extension line crosses a dimension line close to an arrowhead, a break in the extension line is recommended (fig. 10-7).

10-5. Leader

A leader is used to direct an expression in note form to the intended place on the drawing. It shall

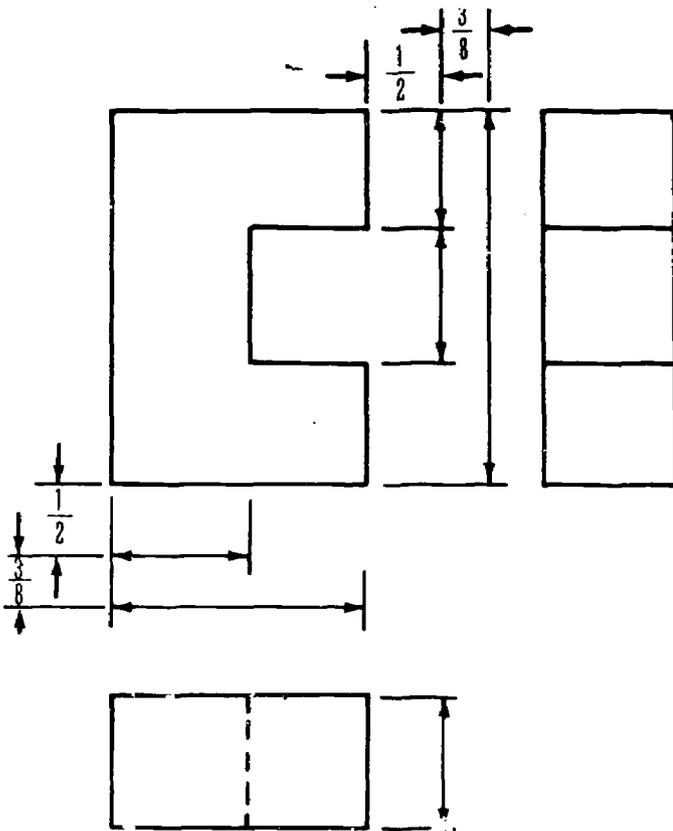


Figure 10-4. Spacing of dimension lines.

the actual object portrayed by the drawing. To avoid this, extension lines are used to show where numerical or other expressions are intended to apply (fig. 10-6). An extension line drawn to an outline representing a surface shall start with a visible gap from the outline and extend about $\frac{1}{8}$

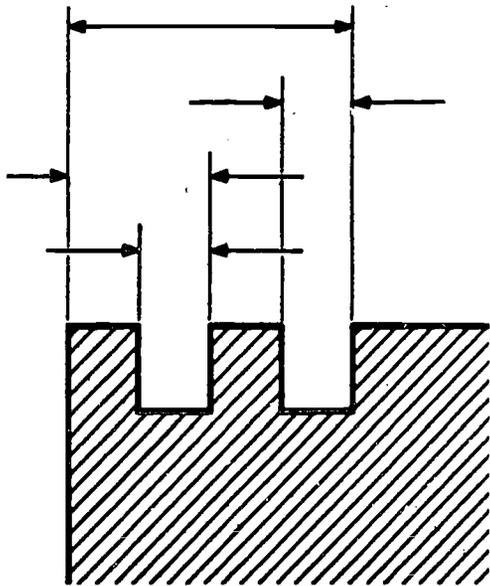
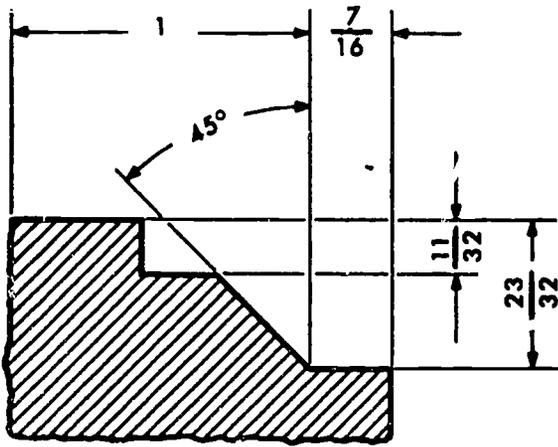
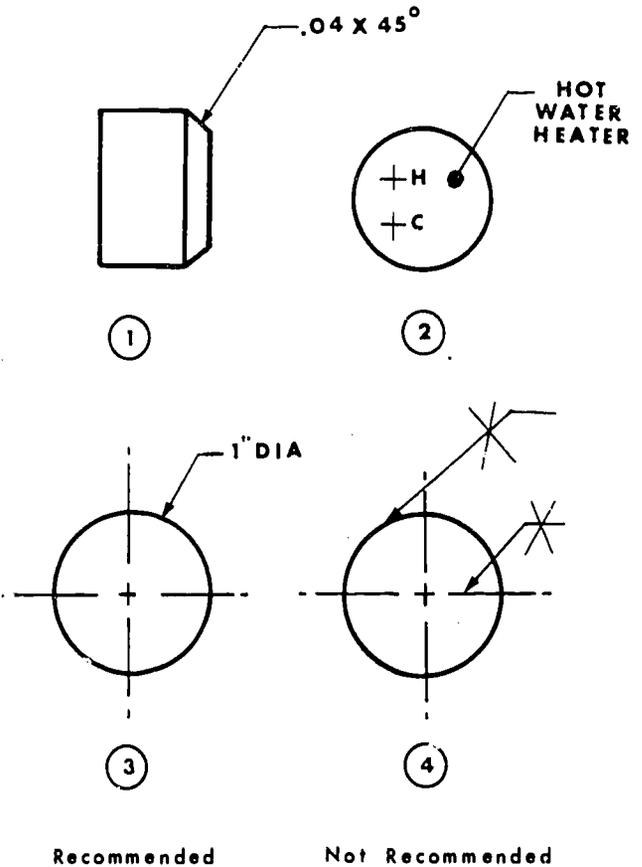


Figure 10-7. Intersecting extension lines.

terminate in an arrowhead or dot. Arrowheads should always terminate on a line (①, fig. 10-8) and dots should be within the outline of the object (②, fig. 10-8). A leader should generally be an oblique straight line except for a short horizontal portion extending to midheight, preferably of the first or last letter or digit of the note. Two or more leaders to adjacent places on the drawing should be drawn parallel if practicable. Leaders to circles should be in radial directions (③, fig. 10-8). If possible, avoid the following: crossing leaders; long leaders; leaders in a horizontal or vertical direction; and leaders parallel to adjacent dimension lines, extension lines, or section lines.

10-6. Arrowheads

Arrowheads terminate each dimension line or leader and indicate the end of the line. Uniformity in drawing arrowheads greatly improves the appearance of a drawing. The arrowhead is



Recommended Not Recommended

Figure 10-8. Leaders.

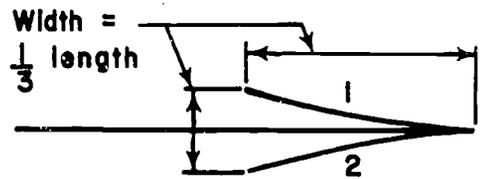


Figure 10-9. Typical arrowheads.

drawn at a three to one ratio, length to width. The tip of the arrowhead will touch the point of reference (fig. 10-9).

10-7. Finish Marks

Finish marks indicate the surfaces of metal to be machined and that allowance must be made for the amount of metal used for the machining operation. Finish marks need not be used on drilled,

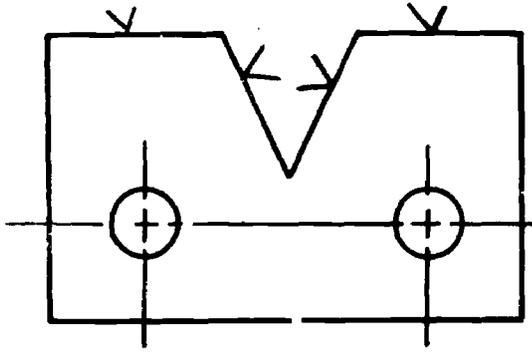


Figure 10-10. Finish marks.

reamed, or counterbored holes or when the note "Finish all over" (FAO) is used. The symbol for a finish mark (fig. 10-10) is a 60° V with its point touching the line representing the edge view of the surface to be machined, and placed on the "inside" of the surface.

10-8. Numerical Figure

The numerical figures which give the actual dimension will be lettered in single stroke, Gothic, capital. Guidelines must be used at all times, and should be placed on all dimension lines before the lettering is begun. The horizontal or vertical guidelines should be parallel to the dimension lines when dimensioning a structural drawing,

and centered on the broken dimension line when dimensioning a mechanical drawing (fig. 10-3). The number 3 hole on the lettering triangle should be used for guidelines. Fractions are twice as high as whole numbers with the fraction bar centered on the whole number and parallel to the dimension line. The figures in a fraction do not touch the fraction line and the fraction lines do not touch dimension lines.

10-9. Units of Measurement

When all dimensions on a drawing are inches, as on a machined object, inch marks are not required. If, on a machine drawing, any single dimension exceeds 6 feet, both feet and inch marks are used except where a dimension is inches alone.

EXAMPLES

- $\frac{1}{2}$ = $\frac{1}{2}$ inch on a machine drawing
- 3" = 3 inches on an architectural drawing
- 1' — 0" = 1 foot on an architectural drawing
- 12 = 12 inches on a machine drawing
- 1' — 0 $\frac{1}{4}$ " = 1 foot and $\frac{1}{4}$ inch on an architectural drawing

Whenever feet and inch dimensions occur on a single drawing, the architectural method of dimensioning results in the least confusion and the neatest work. Note the use of zeros to prevent a mistake on the part of the reader, who may feel that the draftsman has left out some figures, as 1' — 0".

Section III. DIMENSIONING METHODS

10-10. Reading Direction of Figures

a. *Aligned dimensioning.* The preferred method, aligned dimensioning, is placing the figures aligned

with the dimension lines and read only from the bottom and the right side of the sheet (①, fig. 10-11). For this reason, dimension lines in the 45

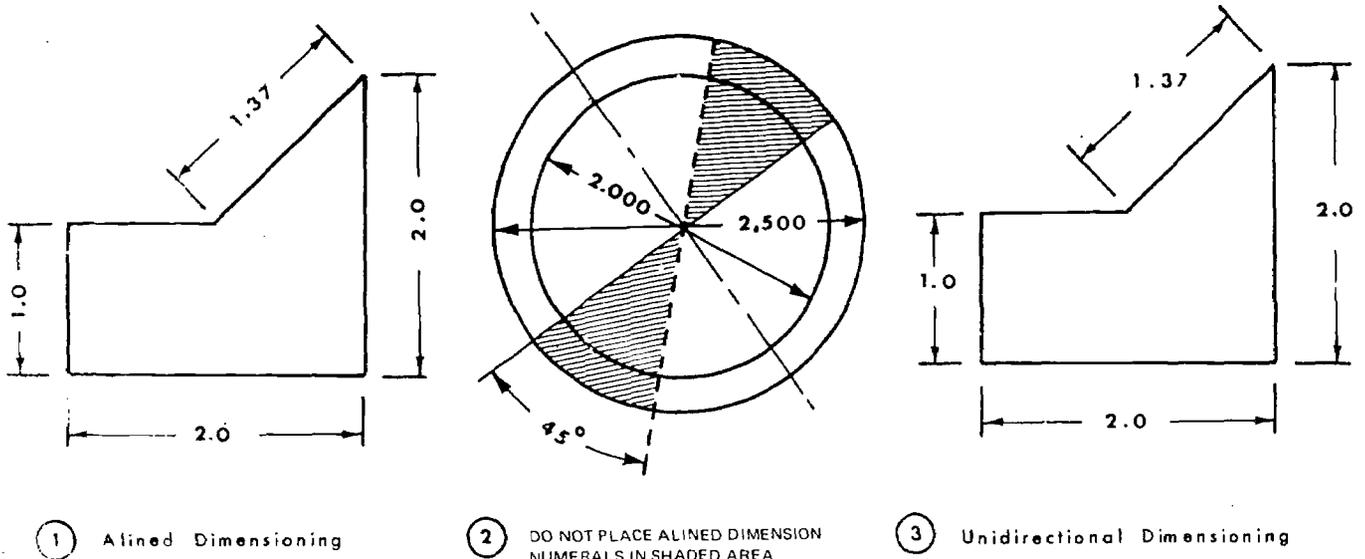
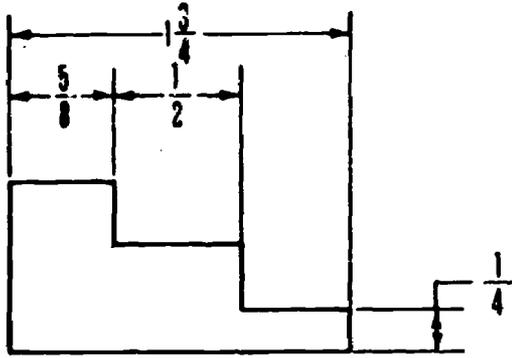
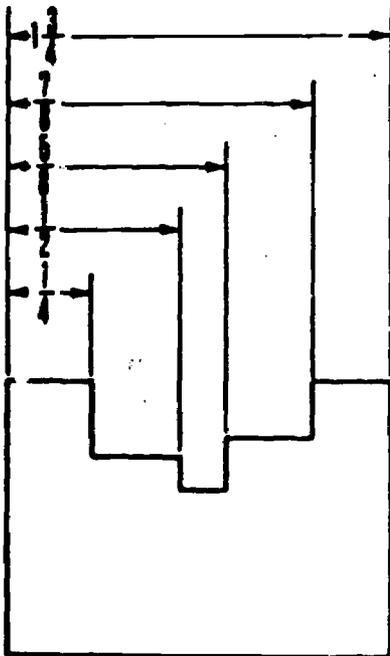


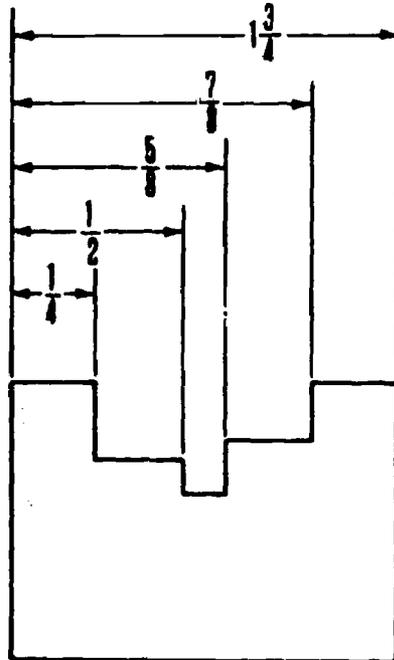
Figure 10-11. Reading direction of figures.



1 GROUPING DIMENSIONS



NOT RECOMMENDED



RECOMMENDED

2 STAGGERING DIMENSIONS

Figure 10-12. Grouping and staggering dimensions.

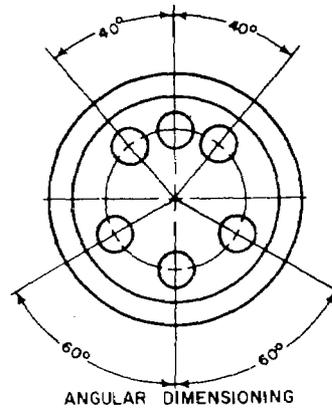
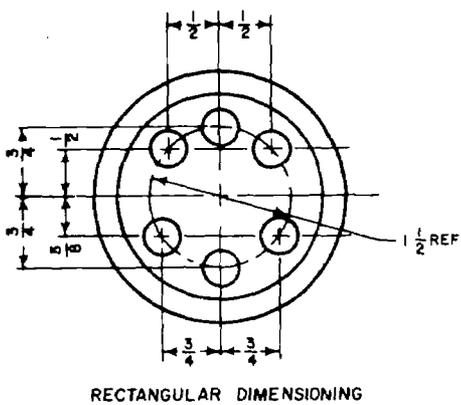


Figure 10-13. Rectangular and angular dimensions.

45° zone indicated by shading in ②, figure 10-11 should be avoided.

b. Unidirectional Dimensioning. This method is used particularly on drawings in long rolls. The figures are uniformly placed in one direction only so as to be read from the bottom of the sheet (③, fig. 10-11)

c. Notes. In either of the above methods, all notes are placed horizontally so as to be read from the bottom of the sheet only.

10-11. Placement of Dimensions

a. General. Dimensions must be placed where they will be most easily understood. Generally, they are attached to the view which clearly shows the features to which they apply; this results in most of the dimensions being placed on the principal view, which is the front view, or elevation. Dimensions should be kept off the object to avoid cluttering the drawing. Only when necessary to avoid misunderstanding is the dimension placed on the object. All extension and dimension lines should be drawn before arrowheads are filled in and before the numerical figures, notes, and titles have been lettered. Be careful to place the size dimensions where they describe the object, but do not crowd them or get them too far away from the object. Avoid crossing extension lines and save room for notes. Select locating centerlines and surfaces after giving careful consideration to mating parts and related pieces. Place the location dimensions so that each geometrical form is located with reference to a centerline or finished surface.

b. Grouping Dimensions. Clarity is improved by placing dimension lines and numerals where space permits when grouping dimensions (①, fig. 10-12).

c. Staggering Dimensions. Dimension figures should be located at the center of the dimension line except when another line interferes. When space is restricted or a number of parallel dimension lines occur together, it is desirable to stagger columns or dimensions in two or more rows (②, fig. 10-12).

d. Rectangular Dimensioning. This is a method of indicating distances, locations and sizes with linear dimensions measured parallel to reference lines or planes that are perpendicular to each other (fig. 10-13).

e. Angular Dimensioning. This system indicates the position of a point, line, or surface by linear dimensions and angles other than the 90° angle

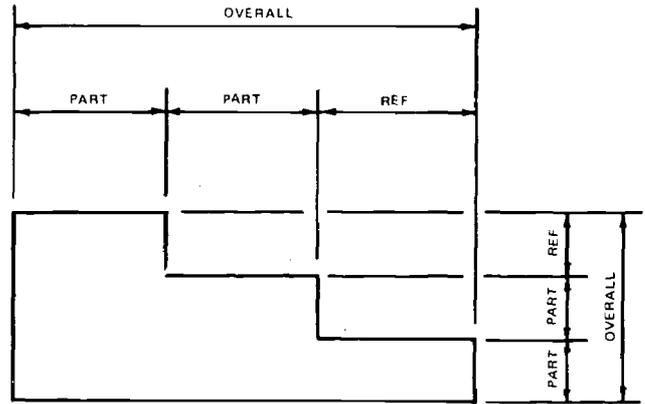


Figure 10-14. Overall dimensions.

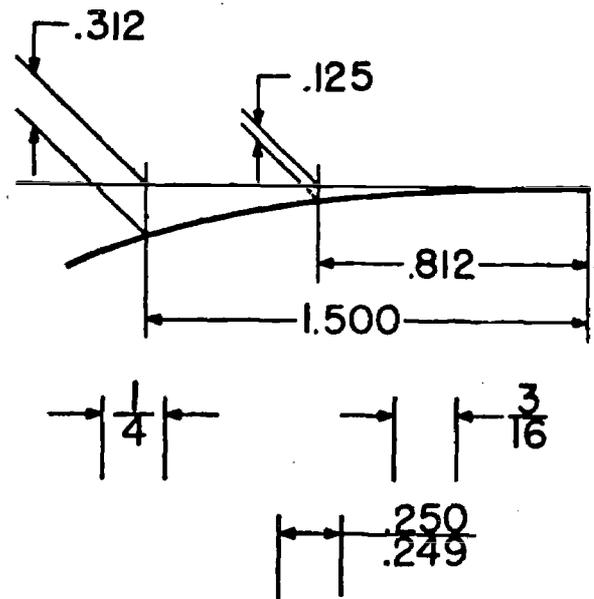


Figure 10-15. Dimensioning in limited spaces.

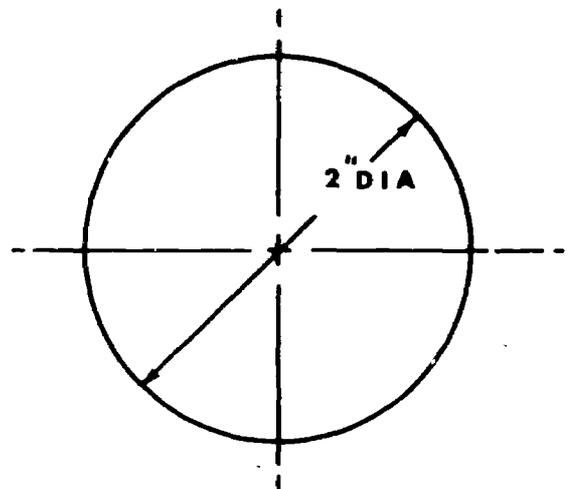


Figure 10-16. Dimensioning large circles.

formed by the horizontal and vertical centerlines (fig. 10-13).

f. Overall Dimensions. Overall dimensions (fig.

10-14) are the total of the parts of such dimensions as height, length, and width. Overall dimensions are useful in several ways: they tell the machinist what size of material to start with; they tell the builder what space is required for the house; and they tell the engineer what width truck the bridge can carry. If any overall dimension is variable, such as the length of a vise, the swing radius of a crane, or the height of a draftsman's stool, be sure to give the minimum and maximum overall dimensions on the same dimension line or in a note. When giving overall dimensions do not give dimensions of all the parts. Leave one part out or it will be a duplication and may lead to confusion. Particularly in mechanical work, the machinist starts with a given piece of stock and machines pieces from it. The last remaining dimension has to be whatever is left of the original stock. The remaining dimension can be dimensioned if the note "REF" (reference) is added. This reference dimension means it is a dimension without tolerance, used for information purposes only and does not govern machining or inspection operations. However, in structural and architectural drawings, the object to be built, such as a building, is made of many individual parts that must be fastened together to make up the overall dimension of the finished structure. Therefore, in structural and architectural drawings, the overall dimensions plus all the individual dimensions are given.

g. Limited Space. Legibility should never be sacrificed by crowding dimensions into small spaces. Methods illustrated in figure 10-15 may be used when this problem occurs. Other alternatives are:

(1) To use a note instead of a numerical dimension.

(2) To extract and enlarge the section in another drawing.

h. Large Circles. Dimensioning large circles is done by placing the dimension line at an angle through the center of the circle terminating with arrowheads at the circumference of the circle and placing the figure horizontally breaking the dimension line, followed by the letters "DIA" or symbol \emptyset (fig. 10-16).

i. Small Circles. Use a leader pointing toward the center of the circle terminating with an arrowhead at the circumference. Add a short horizontal line to the leader followed by the diameter of the circle (fig. 10-17).

j. Arcs. The dimension line is a radius from the small cross which represents the center of the arc

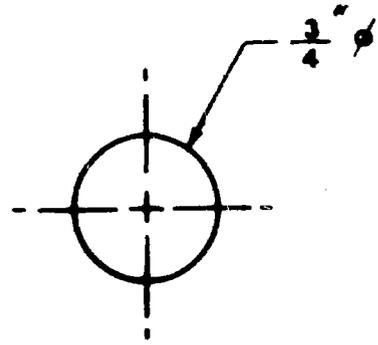


Figure 10-17. Dimensioning small circles.

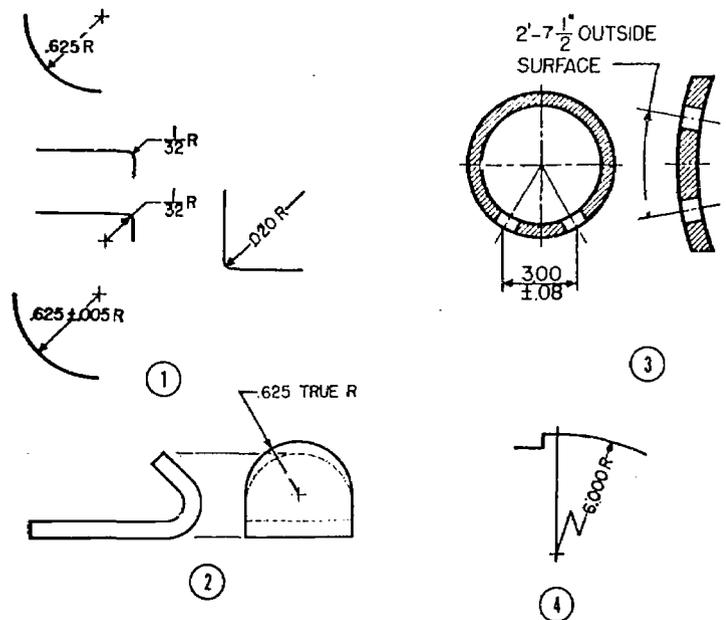


Figure 10-18. Dimensioning arcs.

to the arc terminating with an arrowhead. The numerical figure is followed by an "R" (radius). Figure 10-18 shows some acceptable methods of dimensioning arcs. (2), figure 10-18 shows how to dimension an arc not perpendicular to the plane of projection (inclined and distorted). (3), figure 10-18 shows how to give linear distances along the arc. Where space does not permit showing the complete radius dimension line to scale, the line may be foreshortened (4, fig. 10-18). The portion of the dimension line ending in the arrowhead is drawn in the radial direction.

k. Fillets and Rounds. In instances where there are a large number of fillets or rounded edges of the same size, it is acceptable to specify them in the form of a note rather than specifying each radius on the drawing of each part. Such notes may read:

All Edges— $1/8 R$ unless otherwise specified.

All Fillets— $1/4 R$ unless otherwise specified.

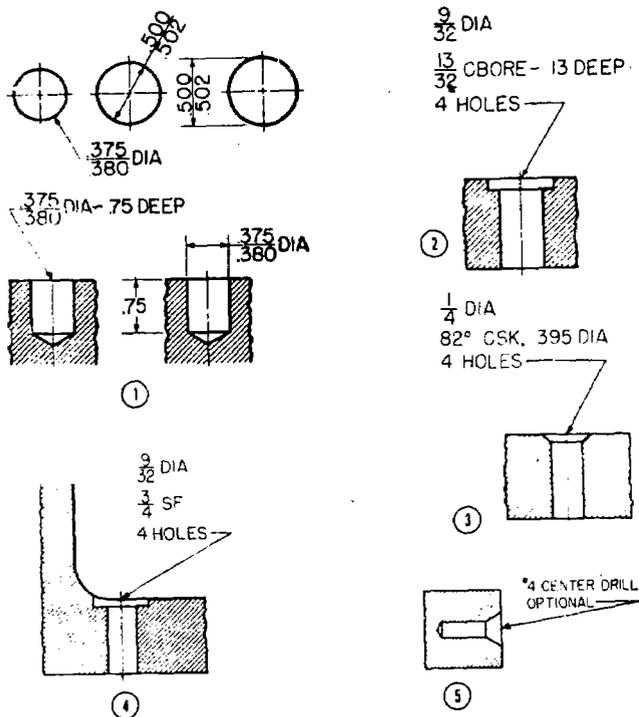


Figure 10-19. Dimensioning holes.

l. Holes

(1) *Plain round holes.* Depending on design requirements and manufacturing methods, round holes are dimensioned in various ways as shown in (1), figure 10-19.

(2) *Counterbored holes.* The diameter and depth of the counterbore should be indicated (2), fig. 10-19). In some cases, the thickness of the remaining stock may be dimensioned rather than the depth of the counterbore.

(3) *Countersunk holes.* The diameter and the angle of the countersink should be indicated (3), fig. 10-19).

(4) *Spot-faced holes.* The diameter of the faced area should be indicated (4), fig. 10-19). Spot face may be specified by a note only, and not delineated on the drawing.

(5) *Countersunk center holes.* Shaft centers, center drills, or countersunk center holes may be required in shafts, spindles, and other cylindrical or conical parts during manufacture and inspection. The dimensioning shown in (5), figure 10-19 specifies what is needed; the work may be done by using a standard combined drill and countersink, or by drilling a straight hole and then countersinking the hole as a separate operation. If the center drill is necessary, omit the word OPTIONAL. A center drill may be specified by a note and not delineated on the drawing.

m. Location of holes.

(1) *Centerline coordinates.* Figure 10-20

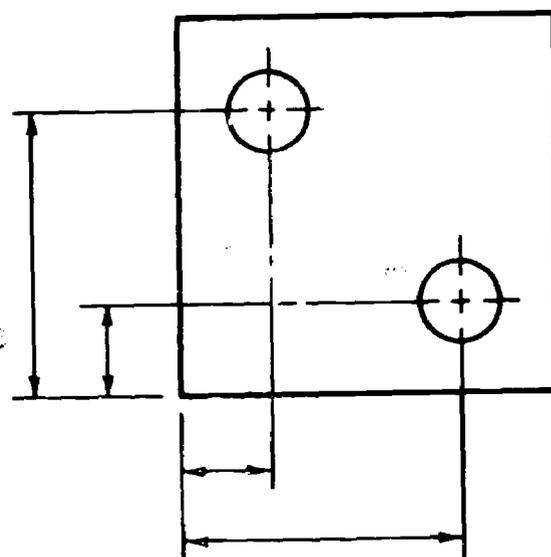
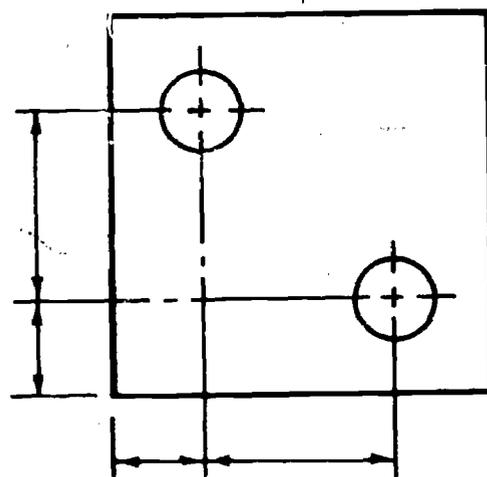


Figure 10-20. Locating holes by centerline coordinates.

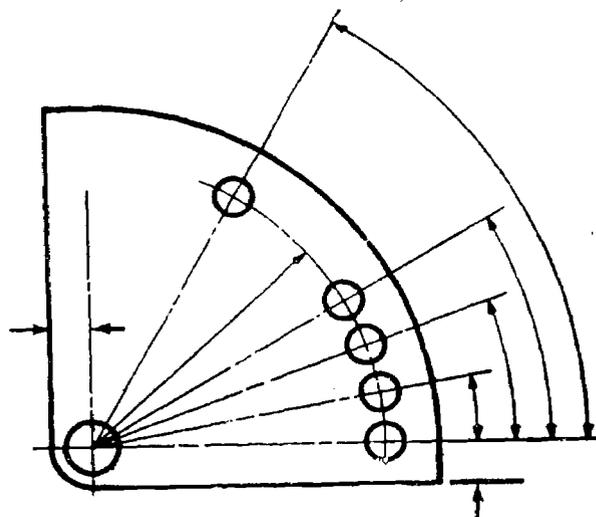


Figure 10-21. Locating holes by polar coordinates.

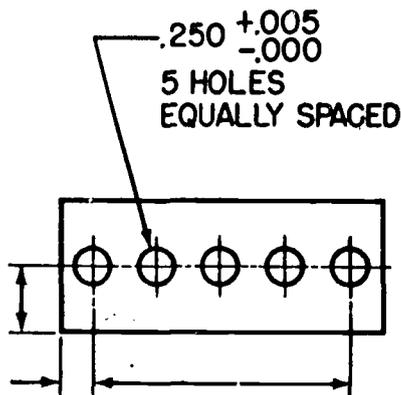
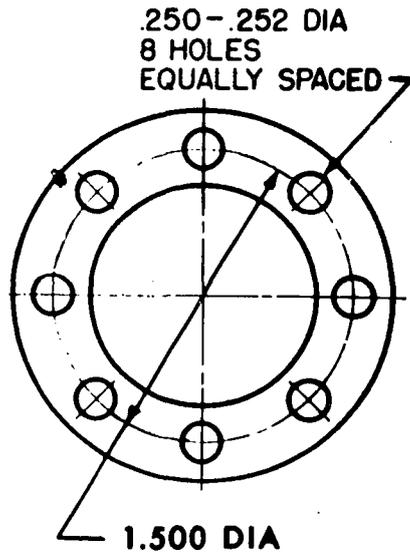


Figure 10-22. Locating holes by symmetrical coordinates.

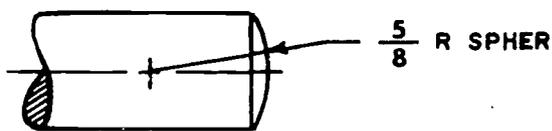


Figure 10-23. Dimensioning spherical surfaces.

shows how holes can be located by dimensions to extensions of centerlines.

(2) *Rectangular coordinates.* Generally, precision holes should be located by rectangular coordinates (fig. 10-13).

(3) *Angular coordinates.* Nonprecision holes may be located by the angular dimensioning system if their centers lie on a common circle, such as a circular flange (fig. 10-13).

(4) *Polar coordinates.* When modern, accurate shop equipment is available for locating holes by angle, holes can be located by indicating the angle from a dimensioned datum line (fig. 10-21).

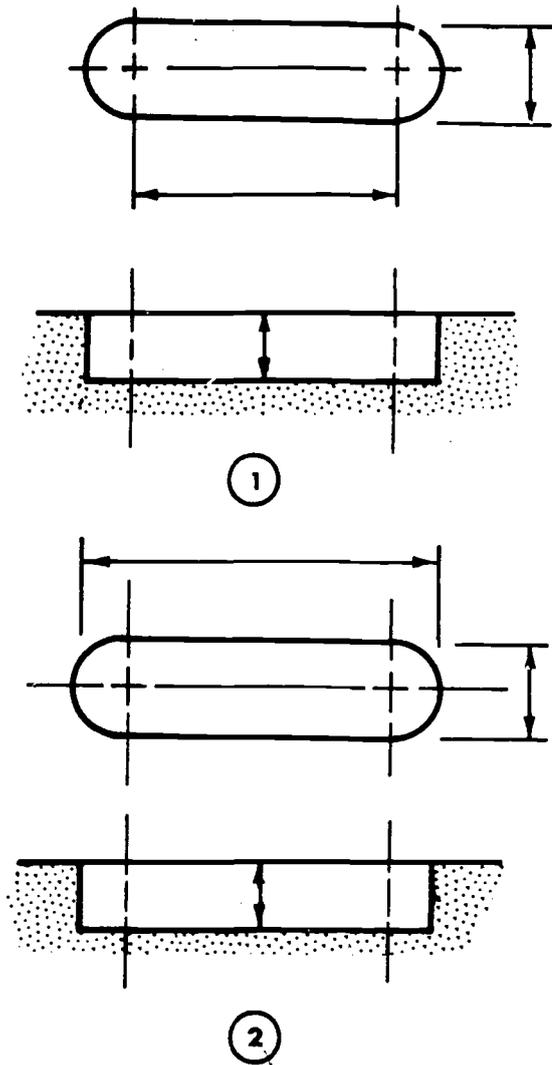


Figure 10-24. Dimensioning slots and surfaces with rounded ends.

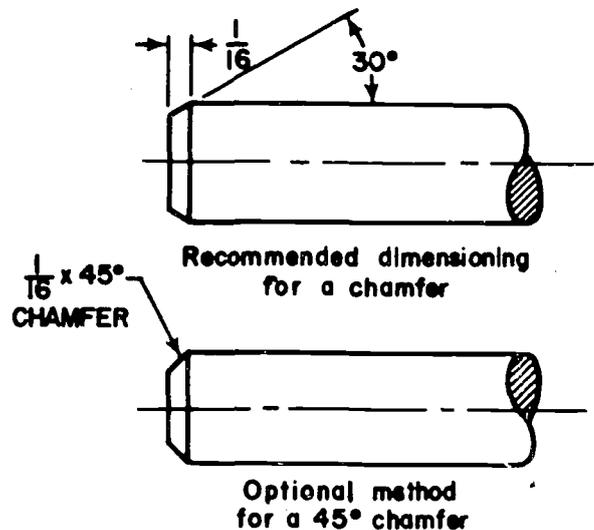
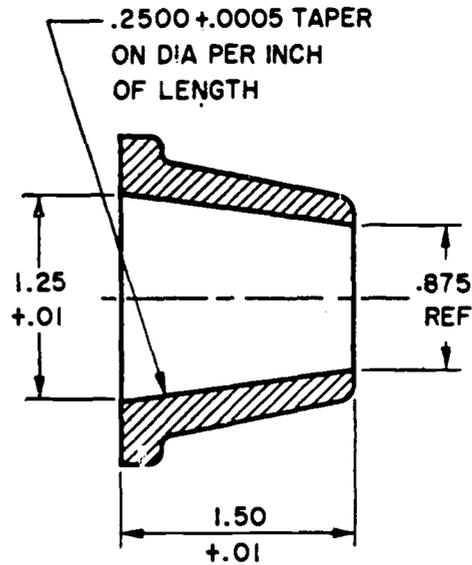
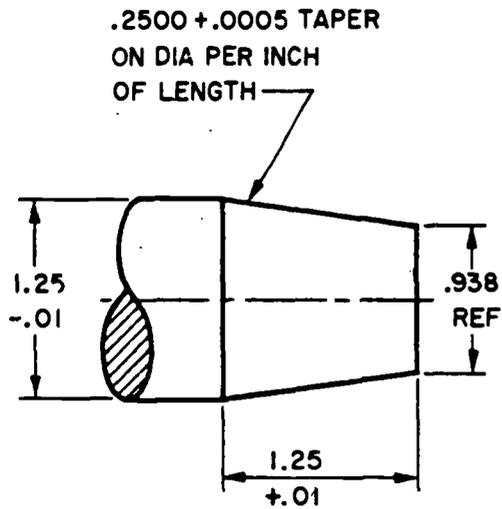
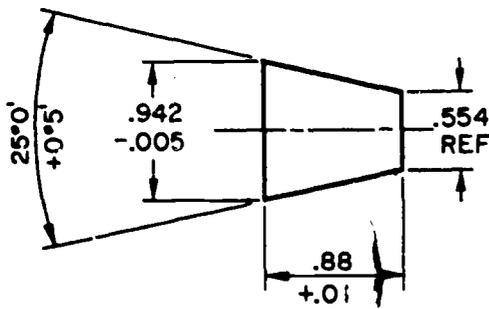


Figure 10-25. Dimensioning chamfers.

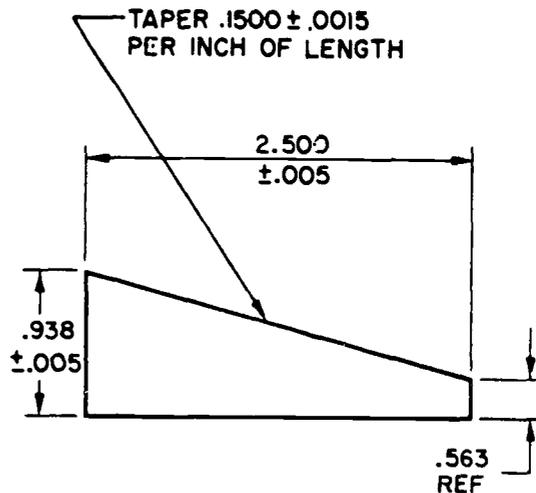
(5) *Symmetrical coordinates.* When applicable, equally spaced holes on a circle or in a line



①



②



③

Figure 10-26. Dimensioning tapers.

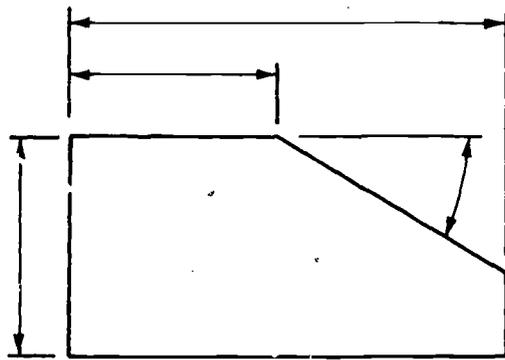
can be located by giving the radius or diameter and a note "Equally spaced" (fig. 10-22).

n. *Spherical Surfaces.* Spherical surfaces are dimensioned by giving the radius followed by the abbreviation "SPHER" (fig. 10-23).

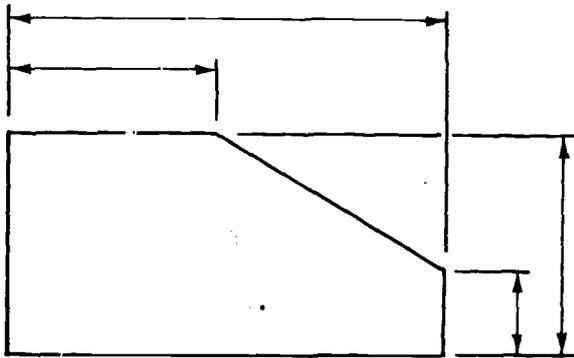
o. *Slots and Surfaces With Rounded Ends.* These should be dimensioned according to their method of manufacture. ①, figure 10-24 shows a slot, machined from solid stock with an endmilling cutter. The dimensions give the diameter of the cutter and the distance of the milling machine

table. The slot shown in ②, figure 10-24 is similar to that of (1) but it is dimensioned for quantity production, where, instead of the distance from center to center, the over-all length is desired for gaging purposes. The center to center distance and radii are given as this is how it will be laid out.

p. *Chamfers.* The recommended method for dimensioning a chamfer is to give an angle and a length (fig. 10-25). For angles of 45°, only the alternate method is permissible since chamfers of

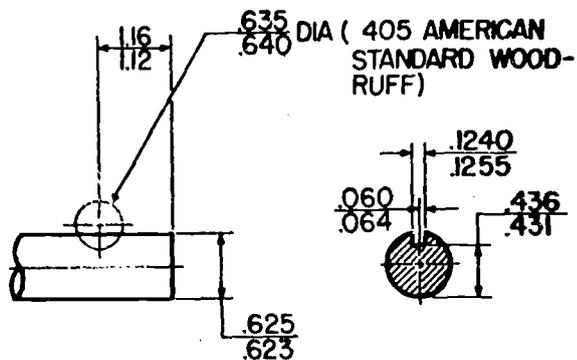


① Angular

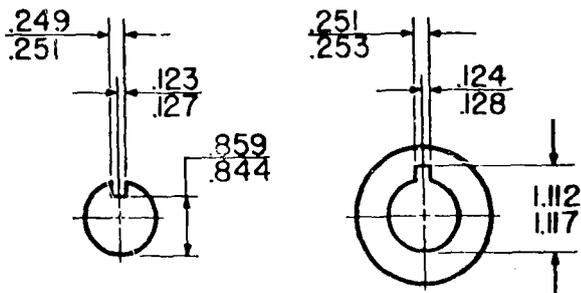


② Linear

Figure 10-27. Dimensioning angular surfaces.



①



②

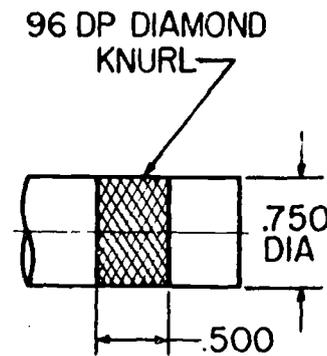
Figure 10-28. Dimensioning keys and keyways.

45° form right isosceles angles, which means the legs (horizontal and vertical dimensions) are equal. Chamfers are never measured along the angle (hypotenuse). The word "chamfer" may be omitted in the drawing.

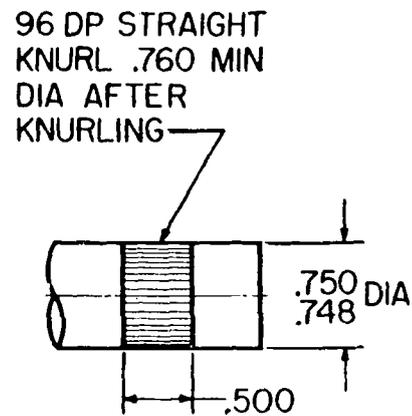
q. Conical Tapers.

(1) There are two approved methods of dimensioning and tolerancing tapers; form dimensioning and basic dimensioning. For details, refer to paragraph 6.6.7, Mil-Std-8C. The selection of the method for a particular application is determined by the functional characteristics of the part or the manufacturing process. The four fundamental dimensions which control the form of a conical tapered section are—

- (a) Diameter at the large end.
- (b) Diameter at the small end.
- (c) Length of the axis of the taper.
- (d) Amount of taper for entire length or per unit length, or the included angle.



①. For decoration or gripping



②. For a press-fit

Figure 10-29. Knurls for decoration or gripping.

(2) Three of these four dimensions are specifically toleranced. The fourth may be given as a reference dimension. ①, figure 10-26 is an example of the proper method of dimensioning and tolerancing a tapered section where the most important requirement is the accuracy of the taper. ②, figure 10-26 illustrates a method of dimensioning the same type of tapered section by use of an angular tolerance instead of a tolerance on the taper. This method, though permissible, is not commonly used.

v. *Flat Tapers.* The methods recommended for dimensioning conical tapers can be adapted to tapered flat pieces. ③, Figure 10-26 gives an example of the adaptation of one of the methods to the dimensioning of flat tapers.

s. *Angular Surfaces.* Locating angular surfaces may be done by a combination of linear dimensions and an angle, or by linear dimensions alone depending on what tolerances are critical (fig. 10-27).

t. *Keys and Keyways.* Figure 10-28 illustrates satisfactory methods of expressing dimensions for keyways.

u. *Knurls.* Close tolerances are not necessary in connection with knurls that provide a rough surface for gripping or that are used as decoration. For these purposes it is common to specify only the pitch of the knurl, the type of knurling, and the axial length of the knurled area (①, fig. 10-29). To specify knurling for a press fit between two parts, the diameter after knurling should be given, with a tolerance, and included in the note that specifies the circular or diametrical pitch (CP or DP, respectively) and type of knurl (②, fig. 10-29).

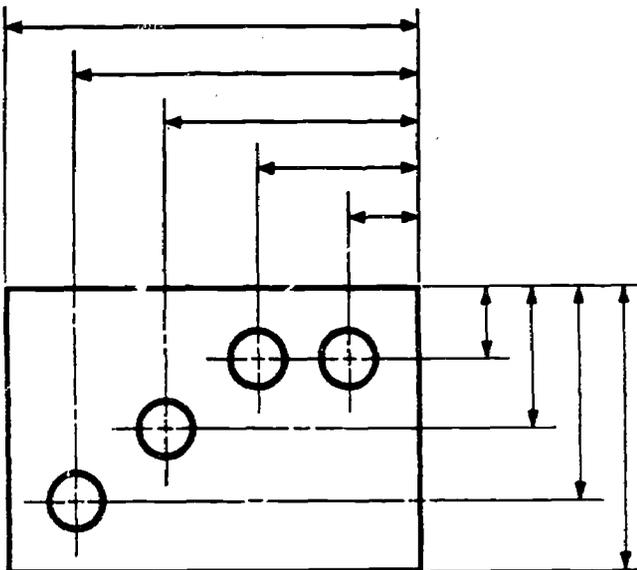


Figure 10-30. Dimensions from datum lines.

10-12. Types of Dimensioning

The method of manufacture or construction of an object involves either a high or a low degree of accuracy. Two types of dimensioning are in use to satisfy the particular demands of each type of job.

a. *Datum Line Dimensions.* In accurate work such as die making or structural steel layout dimensions are usually referred to the datum line. The datum line may be any finished surface or centerline which can be identified by the machinist or construction man before work starts. All dimensions are started and measured from this datum line, both in the shop and the field, thus reducing the chance for error and eliminating any cumulative error. If datum line dimensioning is required on a drawing, it must be specified by the engineer who requests the drawing (fig. 10-30).

b. *Progressive Dimensions.* The most common type of dimensioning, and the type used in the illustrations in this chapter, is progressive dimensioning. Progressive dimensions start at a finished surface or centerline and continue progressively across the object from one point to the next. With the progressive method, errors in scaling can result in a cumulative error in construction of the object, since each successive dimension depends on the previous one. Normally the accuracy of manufacture is low enough that progressive dimensions are acceptable. Progressive dimensions can further be subdivided into two classes:

(1) *Continuous.* On construction drawings, the object to be built, such as a building, is made of many individual parts that must be fastened together to make up the overall dimension of the finished structure. Therefore, in construction drawings, the overall dimensions plus all the individual dimensions are given (fig. 10-31).

(2) *Noncontinuous.* In mechanical work, the machinist starts with a given piece of stock and

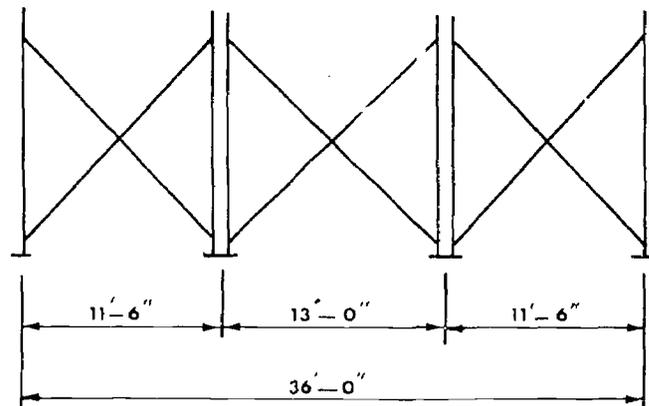


Figure 10-31. Continuous progressive dimensioning.

machines pieces from it. The overall dimension and all but one of the individual dimensions are needed since the last remaining individual dimension has to be whatever is left of the original stock. The remaining individual dimension can be given if the note "Ref" (reference) is added. This reference dimension is a dimension without tolerance, used for information purposes only and does not govern machining or inspection operations (fig. 10-32).

10-13. Dimension Rules

Since dimensions are valuable both to the workman and supervising foreman or engineer, sufficient size and location dimensions must be placed on the drawing, so that all concerned can extract the information needed with a minimum of figuring. The drawing must be clear in all respects to the reader. The following rules will help guide the draftsman in placing the proper dimensions on a drawing:

a. General

(1) A dimension should be clear and permit only one interpretation.

(2) Deviation from the rules of dimensioning is permissible only if clarity can be improved.

(3) All dimensions should be completed without repetition.

(4) Each surface, line, or point is located by a set of dimensions.

(5) Dimension lines are placed uniformly, preferably $\frac{1}{2}$ inch from views and $\frac{3}{8}$ inch from each other.

(6) Location and size dimensions are placed where the shapes are best shown.

(7) Dimensions applying to related views are placed between them whenever possible.

(8) Dimensions applying to more than one view are placed on the view which shows the feature clearly and undistorted.

(9) Dimensions for the entire drawing are placed so that they all read from the bottom or the right side of the sheet. The aligned system of dimensioning is preferred. The unidirectional system may be used where it is more advantageous.

(10) Small dimensions are placed near the object, and increasingly larger dimensions farther away from the object.

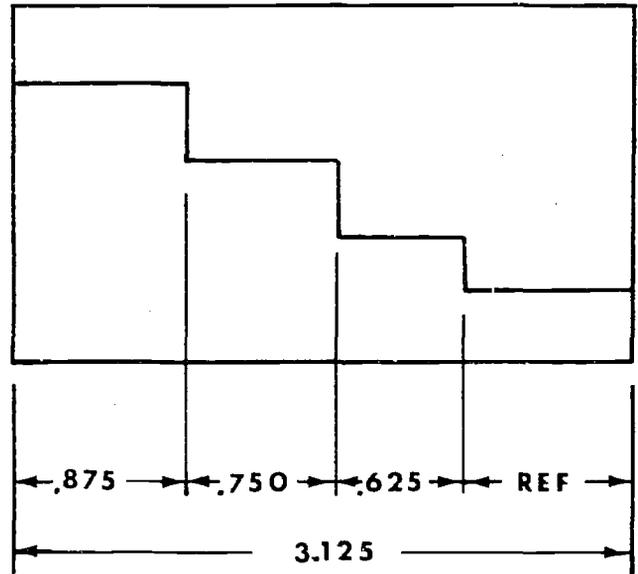


Figure 10-32. Noncontinuous progressive dimensioning.

(11) Placing dimensions directly on the object should be avoided.

(12) When practicable, dimensions of hidden lines are avoided. It is better to dimension another view; a sectional view may be necessary.

(13) Crossing dimension lines with leaders, extension lines, or other dimension lines is to be avoided.

(14) Crowding dimension lines or extension lines is to be avoided.

(15) Dimension lines and center lines are not extended from view to view.

b. Special for Machine Drawings.

(1) Place finish marks on all surfaces to be machined in all views where the surfaces appear as an edge (visible or hidden), unless the part is to be F.A.O. (finished all over) or the surfaces are noted as being bored, drilled, milled, and so on.

(2) Do not give unnecessary or duplicate information. Some added or duplicate dimensions may be given but only for clarity and then should be marked REF.

(3) Assume the following tolerances unless otherwise noted:

(a) Fractional, $\pm 1/64$

(b) Decimal, two-place, $\pm .01$; three place $\pm .001$

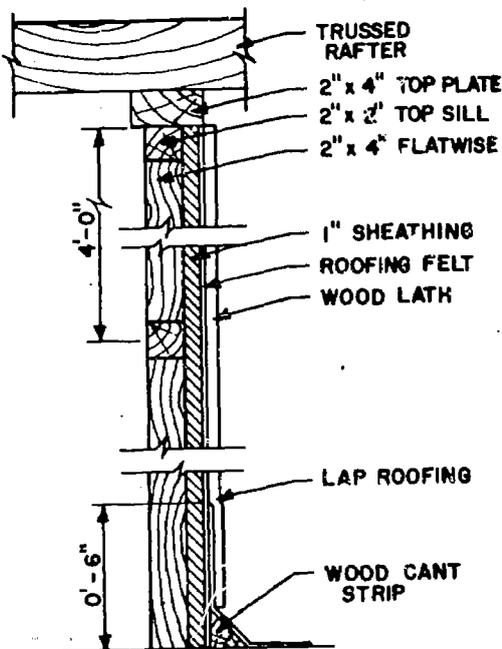
(c) Angular, $\pm 1/2^\circ$

Section IV. NOTES

10-14. Word Dimensions

Certain aspects of size description cannot be satisfactorily stated by means of numerical figures. The desirability of keeping dimensions off the views, and the effectiveness and efficiency gained by directing the manufacturing procedure on the drawing have created a need for notes, or word dimensions. Notes can adequately describe cuts or holes which are too small to be dimensioned with numerical figures. Depending on what they describe, notes may be either specific or general.

a. Specific Notes. Specific notes pertain to an individual feature or characteristic of an object



NOTE:

1. 2" x 4" STUDS FLATWISE FOR ALL INTERIOR PARTITIONS
2. ALL SILLS AND BLOCKING TO BE 2" x 2"

Figure 10-33. Specific and general notes.

such as a hole, a slot, size of timber used, nomenclature of pieces, or even specific instructions on how to connect individual parts of the finished object. The notes are placed horizontally in the nearest clear area to the part described, and attached to the part with a leader which starts from the beginning or end of the note and terminates with a dot or arrowhead at the described part. The leader should be as short as possible and should not be parallel to the extension and dimension lines of the object. Specific notes are placed on the drawing as near to the object as possible without crowding. When many notes appear on a single drawing, careful planning is required to avoid confusion (fig. 10-33).

b. General Notes. A general note applies to whole objects instead of individual parts. Therefore, the general note is not placed near the object with a leader, but it is moved to the title block area or to the lower right of the working area. When there is more than one general note, all the notes are grouped under the title "General Notes." If numerous general notes apply to electrical features while others describe heating requirements, each type of note may be grouped under its own heading. Notes in a group are numbered consecutively for easy reference (fig. 10-33).

10-15. Specification Lists

Nonstandard construction methods or materials are stated or specified in a separate list of instructions in a structural drawing. The list is called a specifications list, or specifications for a set of construction drawings. Working information contained in the specifications, such as door and window sizes, materials used for flooring and interior walls, and so on, is included in the general notes and presented under the appropriate schedule heading.

CHAPTER 11

REPRODUCTION

Section I. INTRODUCTION

11-1. Reasons for Reproduction

A completed original drawing requires a great deal of time to finish and is costly due to the engineering and drafting work involved. Therefore, it is apparent that original drawings are not practical for shop or field use. Aside from the time and cost involved, the use of an original drawing is impractical from the standpoint of handling and the number of copies required. If only one drawing were available for use, it would soon become unreadable due to the dirt and smudge from being handled. Therefore, more than one copy is required. If copying must be done by

hand, it is necessary to multiply the time and cost factors by the number of copies desired. An original drawing is a valuable record and must be preserved and treated as such.

11-2. Requirements for Reproduction

In order for an original drawing or a duplicate of one to be reproduced, certain requirements must be met. Preferably the drawing will be done in ink on translucent tracing paper or tracing cloth. A drawing may be done in pencil provided the line weight is sharp, uniform, and dark enough to provide sharp, clear reproductions. If a drawing is to be photographed, it need not be traced in ink.

Section II. PRODUCTION PROCESS

11-3. Negative Contact Processes

a. Blueprints. A blueprint is made by placing a tracing (transparent or translucent original) in contact with a sensitized paper and exposing the paper through the tracing. When the paper is developed, the unexposed portions where the light is blocked by lines on the original remain white, while the exposed portions turn dark blue. This produces a print with white lines on a blue back-

ground. Blueprints, in general, have better contrast than other commonly used processes of comparable cost, but the wet developing process causes some distortion and marking on the prints is difficult (fig. 11-1).

(1) *Blueprint paper.* Blueprint paper must be a high quality wet strength paper because it must be submerged in water during development. This type paper usually has a high rag pulp content in

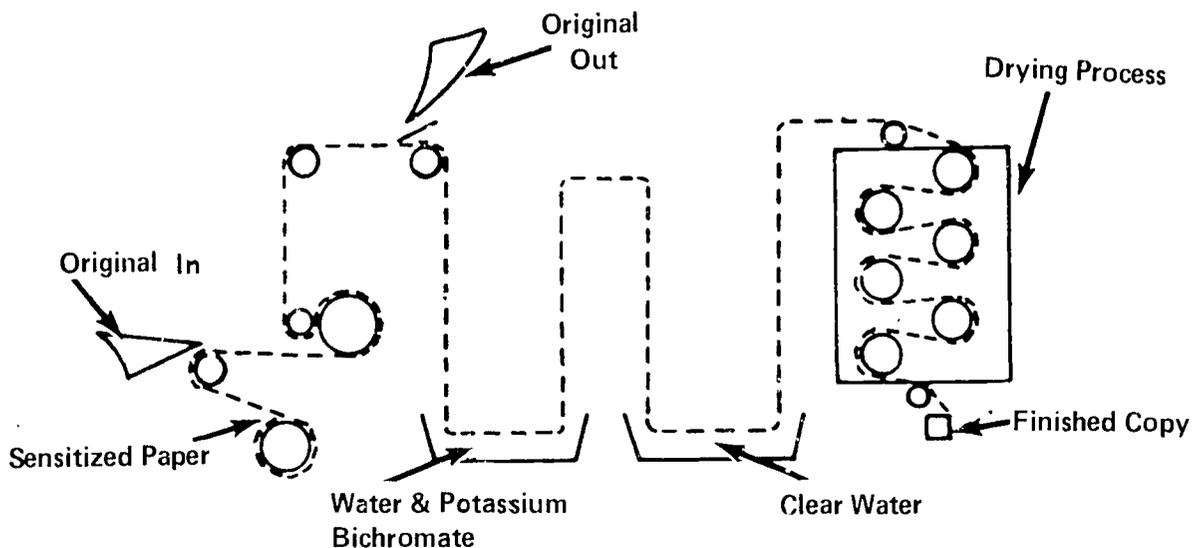


Figure 11-1. Blueprint process.

its makeup. The paper may be obtained in either roll or cut form in specific sizes and widths. Because this paper is light sensitive, it is necessary to keep it in light-tight containers. The coated side of new blueprint paper is a yellowish green color but once it is exposed to light it gradually turns a bluish gray color and loses its usefulness for reproduction. Blueprint paper usually has a limitation printed time stating its useful life. This is dated on the container in much the same manner as camera film. The quality of reproduction desired from blueprint paper depends on several things; the kind of paper used, the amount of time it has been exposed to light, and the age of the paper.

(2) *Blueprint machines.* Modern blueprint machines are of two general types, continuous and uncontinuous types. A continuous blueprint machine combines exposure, washing, and drying in one continuous operation utilizing paper in roll form. A noncontinuous blueprint machine, on the other hand, uses cut sheets that are fed through a machine for exposure only and then washed in separate machines. Due to the fact that a continuous type blueprint machine is a large and expensive piece of machinery it is not generally used for military reproduction.

b. *Brownprints.* Brownprints, also referred to as Vandyke prints, are basically the same as blueprints. There are a few differences, however; a silver nitrate is added to the light sensitive coating on the paper giving an end result of a brown rather than a blue color. Also the paper itself is thin and transparent in nature.

(1) *Development process.* Brownprints are processed through regular blueprint machines. However, due to the use of different chemicals in the coating on the paper, a different solution is required to fix the print. The developing solution or *hypo* is made by mixing four ounces of fixing salts in a gallon of water. After being washed in the hypo bath the prints are dried in the same manner as normal blueprints.

(2) *Uses.* When a brownprint is developed the background turns a brown-black color on which the line work and shaded areas appear clear because the paper itself is transparent. This then is a negative from which copies can be made. By using a brownprint with blueprint paper a blueline or reverse blueprint can be obtained.

11-4. Positive Contact Prints

a. *Blueline.* The blueline process is a contact process like blueprinting, but the unexposed areas of the sensitized paper turn blue when developed

in ammonia vapor, producing blue lines on a white background. Blueline prints are sometimes called Ozalid prints. Papers are also available which yield blacklines. The development in this process is dry, causing less distortion than the blueprint process, but the contrast is not usually as good.

b. *Brownline.* Brownline prints have the same function in the blueline process as the brownprints do in the blueprint process. They produce brown lines on a transparent background and are often used as an intermediate for making blueline prints. Brownline prints are often called sepia intermediates.

c. *Special Materials.* Materials are available for use with the blueline process which produce a large variety of results, including many colored lines on white paper or colored lines on a clear plastic background.

11-5. Optical Processes

a. *Electrostatic.* An electrostatic copier projects an image on paper and then causes an electrostatic charge to be deposited where the image of a line occurs. A black powder is then applied to the paper and adheres where the charge occurs. The image is then fused to the paper.

b. *Photostat.* The photostat process is a photographic process using a special camera and film. The photostat process produces white lines on a black background (negative photostat) which can then be rephotographed to produce a black image on a white background (positive photostat). The image can be enlarged or reduced in the photostat process, usually to $\frac{1}{2}$ or 2 times original size in each stage.

c. *Microfilm.* For economy of storage, many drawings no longer in frequent use are copied on microfilm. Equipment is available for the rapid sorting and viewing of microfilm copies. Since the image must undergo several photographic processes (reduction, development, enlargement) the chance of distortion is high.

11-6. Diazo Process

a. *Diazo Process.* The diazo process produces a direct positive print, that is, the background on the copy is clear, the same as on the original, and the line work or shaded areas of the copy are pigmented exactly the same as the corresponding areas of the original drawing. This process was developed in Germany and the Netherlands during the 20s and 30s to speed up the mass production of drawings and other technical data. Diazo

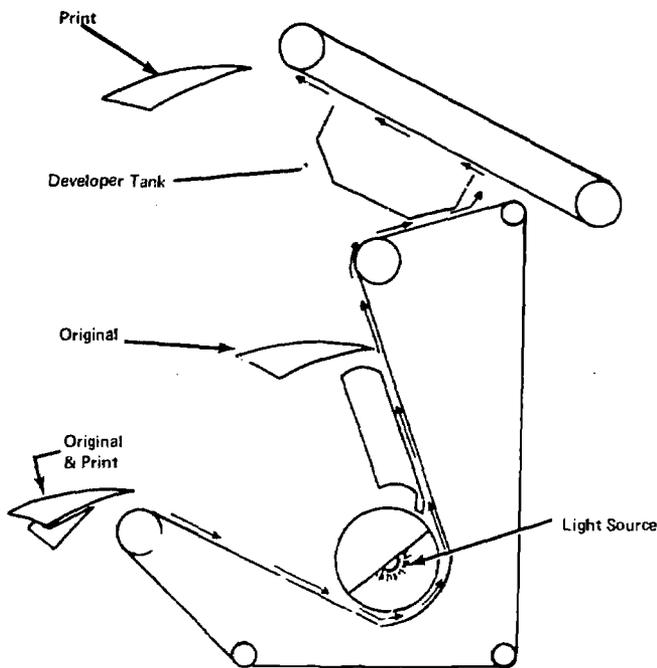


Figure 11-2. Diazoprint process.

type prints are generally referred to as white prints or diazo prints. At present a large majority of reproduction done in the drafting field uses this method (fig. 11-2).

b. Printing and Developing. There are two basic techniques used to make diazo type prints; the dry or ammonia developing system, and the semi-dry or moist developing system. Each requires special processing equipment and different papers or cloths. Both systems use the same basic components; a diazonium salt and a coupler. Through the choice of the coupler used, almost any desired color dye can be formed. The main difference between the two systems is that in the dry process the diazo and the coupler are coated on the paper, while in the moist process the diazo is on the paper and the coupler is applied after exposure of the paper to ultra violet light. To produce a print by either process, the sensitized paper or cloth, together with a translucent master, is exposed to an ultraviolet light. The part of the sensitized paper's surface that is not protected by the line work or shaded areas is "burnt out," that is, the diazo decomposes leaving the normal paper surface. At this point in the dry process the exposed paper or cloth is brought in contact with an ammonia vapor which causes a reaction between the remaining diazo and the coupler that forms a dye. In the moist process the exposed paper is moistened with a developing solution which brings out the dye.

11-7. Sepia Prints

Sepia prints use basically the same process as

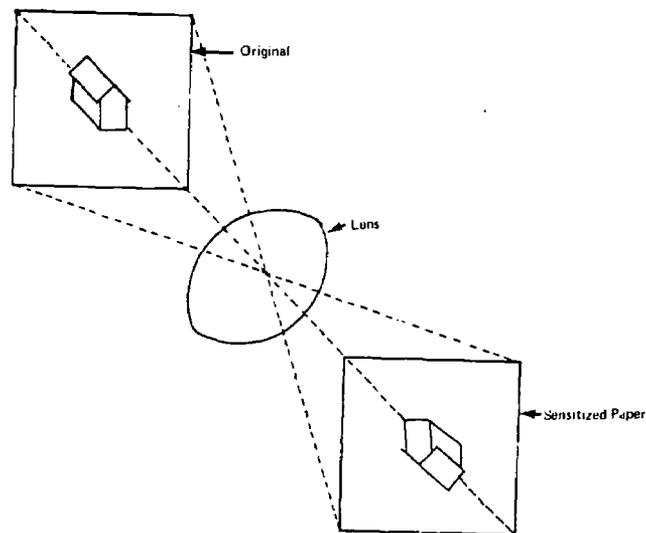


Figure 11-3. Photoprint process.

diazo prints except that they form a dark yellow-brown dye and are printed on translucent paper or plastics. They are generally used to make master copies of original drawings for use in reproduction. Sepias are also used to make changes from master copies. Through the use of special purpose fluids, changes can be made on the masters, thereby altering the resulting copies. This method is used mostly in "as built" field work where drawings are made in the field and the changes are made on the corresponding parts of the construction plans.

11-8. Photoprints

a. Printing Procedures. Photoprints are made by placing a special sensitized paper in a fixed position and focusing the image of the original through a lens on to it in much the same manner as in photography. However, unlike a photographic negative the photoprint's negative is not reversed. After a print is made, developed, and dried the result is a negative print with white lines on a near black background (fig. 11-3).

b. Uses. Photoprint negatives are used to make a positive print with near black lines on a white background. One major use of photoprints is in enlarging and reducing the size of the original drawing. The maximum size for a single photoprint is 24 x 36 inches; however, prints can be made in overlapping pieces to produce any desired sizes. Photoprints can also be used to produce prints as small as $\frac{1}{3}$ the size of the original. By making the original a large drawing and then reducing it through the use of photoprints, the drawing can be made to appear sharp and clear. This method can be used to "clean up" sloppy line weights and poor lettering.

c. *Limitations.* Because of the special cameras and other equipment necessary to produce photoprints its use is limited to areas where such equipment is available. Another problem with photoprints is that each time a print is enlarged or reduced it is distorted to some degree. If the negative is changed in size the distortion is not noticeable but if the positive print is altered in size the distortion is greater.

11-9. Field Expedients

a. *Use of Local Materials.* When a draftsman is forced to work under field conditions, that is, in areas where it is difficult or impossible to obtain equipment or supplies by normal supply methods, it becomes necessary to make use of local materials. It is often possible to obtain sensitized paper of reasonable quality in local areas when it is difficult to get usable material through supply channels because of the amount of time it takes to reach the draftsman. Also developing solutions and other useful materials used in reproduction may be obtained in a similar manner.

b. *Sun Frame.* While in the field there will be times when it is impossible to obtain one of the developing machines which have been mentioned previously. If this situation arises it is possible to construct a simple machine with which the draftsman can reproduce drawings in an efficient manner. The simplest type of field expedient device for reproducing drawings is called the sun frame. It works on the same principle as a blueprint or diazoprint process does; that is, when light sensitive paper is exposed through a translucent master, the exposed area of the paper decomposes

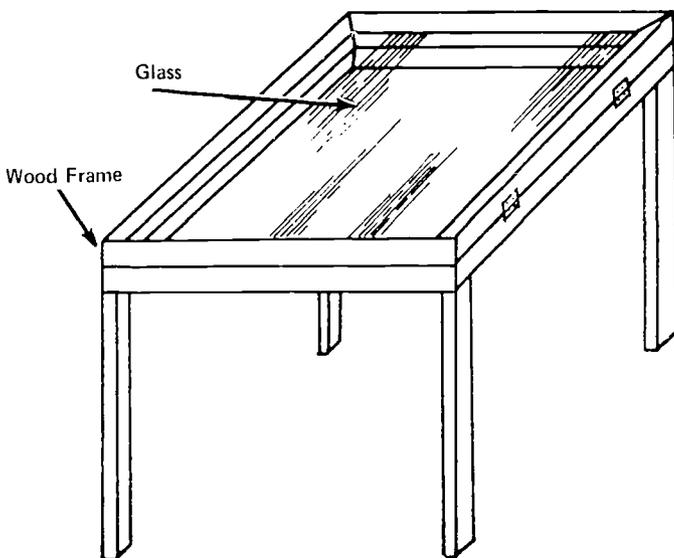


Figure 11-4. Sun frame.

leaving a clear white surface. The unexposed area can then be developed through the use of ammonia.

(1) The aforementioned is accomplished by constructing a frame with a glass front and a removable back, similar to a picture frame. By removing the back and placing the translucent drawing against the glass with the inked or printed side facing the glass, then the blueprint paper with sensitized surface is placed against the master. Insure that the frame causes firm contact between the master and the sensitized paper (fig. 11-4).

(2) When the sun frame's glass front is exposed to bright sunlight from 20 seconds to 4 minutes, depending on local conditions, the sensitized paper will print from the master. After exposure is complete, the print will then be developed by placing it in a cylinder which contains an ammonia vapor (fig. 11-5).

(3) The sun frame can be modified by placing high intensity lights in the frame and exposing this sensitized paper to them rather than bright sunlight. These light sources can be either regular light bulbs or fluorescent lights, which distribute the light more evenly (fig. 11-6).

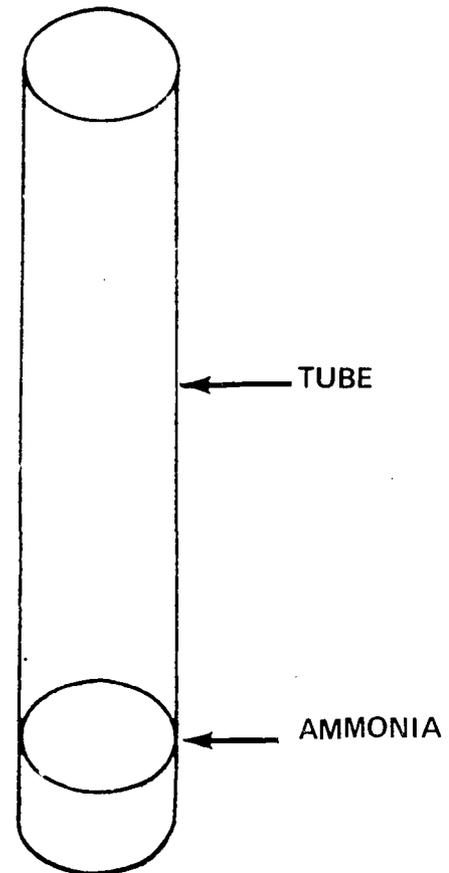


Figure 11-5. Developing tube.

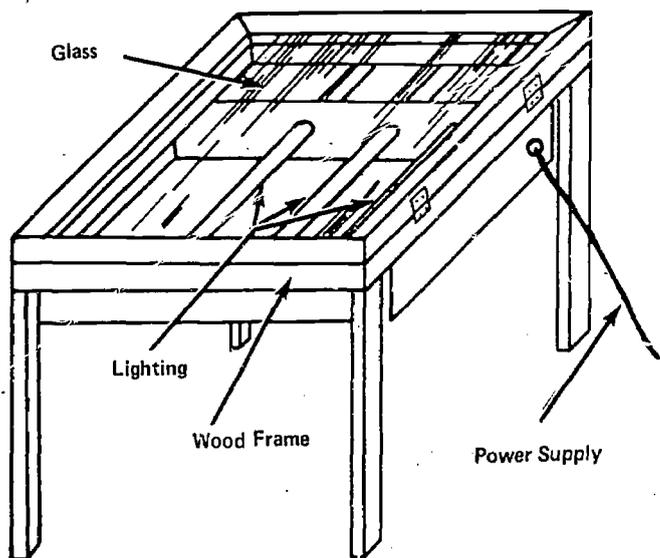


Figure 11-6. Modified sun frame.

11-10. Selection of Reproduction Methods

a. The most efficient and economical duplicating method should be selected (tables 11-1 and 11-2), based upon:

- (1) Purpose
- (2) Number of copies required
- (3) Use
- (4) Time allotted
- (5) Permanency required
- (6) Size of reproduction
- (7) Dimensional stability

b. Quality is determined by the following standards:

- (1) Poor: Off-scale in both directions and much more in one than the other.

Table 11-1. Duplicating Methods, Contact Process

Type	Material	Process	Color image	Dimension stability	Maximum width (in.)	Durability	Advantages	Disadvantages
Blue and brown lines.	Paper	Contact from any negative.	Blue line on white.	Poor	54	Permanent	Tough, high quality.	Do not use when additional work is to be put on prints and prints made therefrom.
	Cloth	do	Brown line on white.	Fair	54	Permanent	Use where a great deal of work is to be done on the print itself, over a long period of time.	Brown line prints are more apt to discolor with age, due to improper washing. Use thin weight instead of heavy weight when prints are to be folded, to eliminate cracking.
Blueprints	Paper	Contact from positive translucent original.	White lines on blue.	Poor	54	Permanent	Withstands hard field use, and direct sunlight for long periods. Readable in sunlight and after contact with grease.	Corrections only by use of eradicating fluids or colored pencils. Cannot be kept to scale.
Brown prints (vandyke).	Cloth	do	do	Fair	54	Permanent	do	Do.
	Paper	Contact from negative from translucent original.	White on brown.	Poor	54	Permanent	Use as an intermediate for producing positives. Excellent insurance against loss of original.	Negative printed in reverse.
	Cloth	do	do	Fair	54	Permanent	do	Do.
	Film	do	do	Good	48	Permanent	do	Do.

Table 11-1—Continued

Type	Material	Process	Color image	Dimension stability	Maximum width (in.)	Durability	Advantages	Disadvantages
Direct positives (photographic).	Paper	Contact from line original.	Black line on white or translucent base.	Fair	42	Permanent	Duplicate is sharper than original. Copy printed on one or both sides can be duplicated. Pen or ink additions can be made easily.	Intermediate print should be made reverse-reading for better contact in printing copies from them.
	Vellum	do	do	Fair	42	Permanent	do	Do.
	Cloth	do	do	Good	42	Permanent	do	Do.
	Film	Contact from line or half-tone original.	do	Excellent	42	Permanent	Easy to correct. Excellent sharpness and clarity of fine detail.	Once tear is started, film tears easily.
Diazo	Paper	Contact positive from translucent original.	Blue, black, red, sepia.	Excellent	54	Not permanent.	Can be written on in pencil. Tends to hold scale better than wet process print.	Dirt and grease make them unreadable. Will not hold up under sunlight and will discolor with age. Old and dirty tracings are difficult to print. Do not have strength of a blueprint. Reflect strong sunlight when outdoors.
	Vellum	do	Black, sepia.	Excellent	54	Not permanent.	Durable yet cheaper than cloth.	Do.
	Cloth	Contact from translucent original.	Blue, black, sepia.	Excellent	54	Not permanent.	Used as an intermediate.	Not recommended for permanent tracings.
	Film	do	Blue, black, red, sepia.	Excellent	40	Not permanent.	Allows many film reproductions at low cost if prints in volume are needed.	Film reproductions gradually fade.
Duplicate tracings (reproduced intermediate).	Paper	Contact from any negative.	Black line on white or blue tint material.	Fair	54	Permanent	Cheapest of materials.	Not as sharp in detail as vellum or cloth.
	Vellum	Contact from any negative.	Black line on white or blue tint material.	Fair	42	Permanent	Cheaper than cloth.	Indefinite life.

Table 11-1—Continued

Type	Material	Process	Color image	Dimension stability	Maximum width (in.)	Durability	Advantages	Disadvantages
Duplicate tracings (continued).	Cloth	do	do	Excellent	54	Permanent	Sharper than original. Erasures are made easily. Eliminates necessity for ink drawing on cloth.	Indefinite life.
Lithograph transparencies.	Photographic water-proof paper.	Contact from line positive and reduced or enlarged rather than photographic lens.	Black and white or translucent base.	Good	44	Permanent	Excellent medium for reproductions of diazo or blueprints.	Dimensional stability inferior to film. Undependable and unpredictable.
Photo contacts.	Paper	Contact negative from opaque or translucent original.	do	Fair	48	Permanent	Used when lines on the original are faint. Possible to bleach dense portions.	More costly than vandyke.
	Cloth	do	do	Good	54	Permanent	do	Do.
	Film	do	do	Excellent	48	Permanent	do	Do.

Table 11-2. Duplicating Methods, Camera Process

Type	Material	Made from	Color image	Dimension stability	Maximum width (in.)	Durability	Special factors
Blowback	Paper	35mm 70mm 105mm	Black on white or translucent.	Fair	54	Excellent	Also card stock.
	Vellum	do	do	Fair	42	Excellent	Do.
	Cloth	do	do	Fair	54	Excellent	Do.
	Film	do	do	Fair	48	Excellent	Do.
Colored print.	Plastic and paper base.	Colored original	Like	Fair	24	Good	Do.
Continuous tone film.	Film	Any original	Full tone range on translucent.	Good	24	Good	
Duplicate tracings.	Paper	Any line original or line negative.	Black line on white or translucent base.	Fair	54	Excellent	Matte film available.
	Vellum	do	do	Fair	42	Excellent	Do.
	Cloth	do	do	Good	54	Excellent	Do.
	Film	do	do	Excellent	48	Excellent	Do.

Table 11-2.—Continued

Type	Material	Made from	Color image	Dimension stability	Maximum width (in.)	Durability	Special factors
Halftone film	Film -----	Negative—any original. Positive—half-tone original.	Black on translucent.	Good -----	20 x 24 ---	Good -----	Various line screens.
Line film	Film -----	Any line original or line negative.	Black on translucent.	Excellent	48 -----	Excellent ---	Matte or clear.
Miniaturization.	Film -----	Any original	White on translucent.	Excellent	35mm --- 70mm --- 105mm ---	Excellent ---	
Photocopies	Paper -----	Negative—original. Positive—original.	Positive—black on white. Negative—white on black.	Fair -----	18 x 24 ---	Good -----	Do.
Photographic prints.	Paper -----	Film negative	Black or sepia on white.	Fair -----	40 -----	Good -----	Do.
	Film -----	do-----	do-----	Good -----	Special sizes.	Good -----	Do.

(2) Fair: Error not more than 1/4 inch in 36 inches.

(3) Good: Error not more than 1/8 inch in 36 inches.

(4) Excellent: Error not apparent in 36 inches using the standard 12-inch scale.

11-11. Definitions

The following are definitions of the different reproduction processes and allied terms.

a. Actinic Light. That radiation to which diazo to blueprint paper is sensitive. Actinic light falls near the ultraviolet spectrum.

b. Alkali. A base chemical capable of neutralizing acid.

c. Ammonia Process. A diazo process whereby the acidic stabilizers are neutralized with ammonia vapors.

d. Blueprint Process. Reproduction by the use of light-sensitive iron salts producing a negative blue image from a positive original.

e. Brownprint Process. Reproduction by the use of light-sensitive iron and silver salts, producing a negative sepia image from a positive original.

f. Composite Print. Print made by combining the whole or parts of two or more originals.

g. Contact Print. Print made by placing original in contact with light-sensitive material during exposure to light.

h. Diazo. Light-sensitive, organic dyes.

i. Mylar. A polyester, non-tearing dimensionally stable film base sensitized with diazo and photographic emulsions.

j. Negative Process. Process which reverses the light and dark areas of the original being reproduced.

k. Positive Process. Reproduction method in which light and dark areas on copies are true to the original.

l. Restorer. An oily fluid used to improve reproduction qualities of tracings and some transparent prints.

m. Reverse Reading. Copy produced by contact of original face (or drawn) side to coated side of copy material.

n. Right Reading. Term to describe an image which is directly readable, as opposed to "reverse reading".

o. Sensitize. Application of light-sensitive coating to base material.

p. Sepia. A yellow-brown color. Colloquially used to mean reproducible ozalid print of this color.

q. Translucent. Semi-transparent material capable of transmitting diffused light.

r. Tooth. Ability of a surface to accept pencil lead.

s. Tracing Paper. Translucent sheet used for making pencil or ink drawings.

t. Vandyke. Brownprint process.

APPENDIX A

REFERENCES

A-1. Army Regulations (AR)

310-25	Dictionary of United States Army Terms
310-50	Authorized Abbreviations and Brevity Codes
340-22	Microfilming of Records
340-18-15	Maintenance and Disposition of Facilities Function Files
380-series	Security
611-201	Personnel Selection and Classification (MOS Codes)

A-2. Department of the Army Pamphlets (DA PAM)

108-1	Index of Army Motion Pictures and Related Audio-Visual Aids
310-series	Military Publications and Indexes
325-10	Standards of Statistical Presentation

A-3. Field Manuals (FM)

5-1	Engineer Troop Organizations and Operations
5-34	Engineer Field Data
21-5	Military Training Management
21-6	Techniques of Military Instruction
21-26	Map Reading
21-30	Military Symbols
21-31	Topographic Symbols
100-10	Combat Service Support

A-4. Technical Manuals (TM)

5-232	Elements of Surveying
5-233	Construction Surveying
5-240	Compilation and Color Separation of Topographic Maps
5-302	Construction in the Theater of Operations
5-303	Bills of Materials and Equipment of the Engineer Function Components System
5-312	Military Fixed Bridges
5-330	Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations
5-333	Construction Management
5-360	Port Construction and Rehabilitation
5-370	Railroad Construction
5-443	Field Classification Surveys
5-551B	Carpenter
5-551K	Plumbing and Pipefitting
5-700	Field Water Supply
5-704	Construction Print Reading in the Field
5-742	Concrete and Masonry
5-744	Structural Steelwork
5-745	Heating, Ventilating and Sheet Metal Work
5-760	Interior Wiring
5-765	Electrical Power Transmission and Distribution
5-809-series	Structural Design

A-5. Corps of Engineer, Military Standards (MIL-STD)

8C	Dimensioning and Tolerancing
9A	Screw Thread Conventions and Methods of Specifying
12C	Abbreviations for use on Drawings and in Technical-Type Publications
14A	Architectural Symbols
15-1A	Graphic Symbols for Electrical and Electronic Diagrams
15-3	Electrical Wiring Symbols for Architectural and Electrical Layout Drawings
17B-1	Mechanical Symbols
18A	Structural Symbols
100A	Engineer Drawing Practice

A-6. Other Agencies

NAVFAC DM-6	Design Manual, Drawings and Specification (US Navy)
EP 415-1-260	Resident Engineers' Management Guide (Corp of Engineers)
through -264	Welding Symbols (Joint Army-Navy)
JAN-STD-19	Industrial Security Manual for Safeguarding Classified (DOD) Information
DIA	Glossary of Mapping, Charting and Geodetic Terms
DIA	American Institute of Steel Construction Manual (AISC)
NAVPERS	Draftsman 3 and 2
NAVPERS	Draftsman 1 and C
USACERC	Shore Protection, Planning and Design
Tech Rep 4	Design by Elwyn E. Seelye, Published by John Wiley and Sons, Inc.

APPENDIX B

ABBREVIATIONS*

About	ABT	Application	APPL
Above	ABV	Approve	APPV
Access	ACS	Approved	APVD
Access opening	AO	Approximate	APPROX
Access panel	AP	Arc weld	ARCW
Accessory	ACCESS	Architecture	ARCH
Accordance with	A/W	Armature	ARM
Accurate	ACCUR	Army-Navy-Air Force	ANAF
Acetate	ACTT	Arrangement	ARR
Acetylene	ACET	Arrestor	ARSR
Acid resisting	AR	Artificial	ARTF
Acidproof floor	APF	As drawn	AD
Acknowledge	ACK	As required	AR
Acem screw thread	ACME	As soon as possible	ASAP
Acoustic	ACST	Asbestos	ASB
Acoustic tile ceiling	ATC	Asbestos-cement	AC
Acoustical plaster ceiling	APC	Asphalt	ASPH
Across	ACR	Asphalt-tile floor	ATF
Across flats	ACRFLT	Assembly	ASSEM
Actual	ACTUL	Assistant	ASST
Adapter	ADPTR	Associate	ASSOC
Addendum	ADD	Association	ASSN
Adhesive	ADH	Asymmetric	ASYM
Adjacent	ADJ	At a later date	ALD
Adjust	ADJ	Atomic explosion	AT XPL
Advance	ADV	Attachment	ATCH
Aeronautic	AERO	Attention	ATTN
Aeronautical material specification	AMS	Authorize	AUTH
After	AFT	Automatic	AUTO
Aggregate	AGGR	Automatic data processing	ADP
Air condition	AIR COND	Automation	AUTOMN
Air-to-air	A-A	Auxiliary	AUX
Air-to-ground	A-G	Auxiliary power unit	APU
Aircooled	ACL	Auxiliary switch	ASW
Aircraft	ACFT	Auxiliary switch (breaker) normally closed	ASC
Aircraft approach light	AAL	Auxiliary switch (breaker) normally open	ASO
Airport	APRT	Average	AVG
Alarm	ALM	Aviation	AVN
Alignment	ALIGN	Azimuth	AZ
Allowance	ALLOW	Bakery	BAK
Alternate	ALTN	Ball bearing	BBRG
Altitude	ALT	Ballast	BLST
Aluminum	AL	Barracks	BKS
Amendment	AMEND	Barrel	BBL
American	AMER	Barrels per day	BPD
Americal Steel Wire Gage	AWSG	Barrel per hour	BPH
American Wire Gage	AWG	Barrier	BARR
Ammeter	AMM	Base	B
Anchor bolt	AB	Base line	BL
Antenna	ANT	Basement	BSMT
Antiaircraft	AA	Basic	BSC
Aperture	APERT		
Apparatus	APPAR		
Appendix	APPX		

* These abbreviations are from Mil-Std-12B, Abbreviations for Use on Drawings and in Technical-Type Publications; Style Manual, Government Printing Office; and AR 310-50, Authorized Abbreviations and Brevity Codes.

Battalion	BN	Cement mortar	CEM MORT
Battery	BTRY	Cement plaster	CPL
Battery (electrical)	BAT	Cement plaster ceiling	CPC
Bearing	BRG	Center	CTR
Bedding	BDNG	Center distance	CD
Bedroom	BR	Center line	CL
Before	BFR	Center of gravity	CG
Bell-alarm switch	BA SW	Center to center	C TO C
Below	BLW	Central	CTL
Bench	BNCH	Centrifugal	CNTFGL
Bench mark	BM	Ceramic tile	CT
Between	BETW	Ceramic-tile floor	CTF
Between centers	BC	Certify	CERT
Bevel	BEV	Chain	CH
Beverage	BVGE	Chamfer	CHAM
Bill of exchange	B/E	Change	CHNG
Bill of lading	B/L	Change order	CO
Bill of material	B/M	Channel	CHAN
Bill of sale	B/S	Chassis	CHAS
Billet	BL	Check	CHK
Bituminous	BITUM	Check valve	CV
Black	BLK, BK	Chemically pure	CP
Black and white	B&W	Chief	CH
Blackboard	BKD	Chief of Engineers	CofENgrs
Block	BLK	Chief of Staff	CofS
Blue	BLU, BL	Chilled	Chld
Blue indicating light	BIL	Chilled drinking water return	CDWR
Blueprint	BP	Circle	CIR
Board	BD	Circuit	CKT
Boiler	BLR	Circular	CIRC
Boiler pressure	BOPRESS	Circumference	CRCMF
Bolt	BLT	Clamp	CLP
Both faces	BF	Class	CL
Both sides	BS	Classification	CLASS
Both ways	BW	Clay pipe	CP
Bottoms	BOI	Cleanout	CO
Boundry	BFY	Cleanout flush with finished floor	FCO
Branch	BR	Clear	CLR
Brass	BRS	Clearance	CL
Brick	BRK	Clockwise	CW
Bridge	BRDG	Close	CL
Broadcast	BC	Closed-circuit television	CCTV
Brown	BRN, BR	Closed end	CLE
Building	BLDG	Closure	CLC
Bulletin	BULL	Coarse	CRS
Bushing	BSHG	Coated	CTD
By (between dimensions)	X	Cold-drawn steel	CDS
Cable	CA	Cold-rolled steel	CRS
Cable duct	CD	Cold water	CW
Cabling diagram	CAD	Collar	CLR
Caliber	CAL	Color	CLR
Cam box	CBX	Column	COL
Candlepower	CP	Combination	COMB
Capacitor	CAPST	Command	CMD
Capacity	CAP	Commercial	COML
Cargo	CAR	Commercial Standard	CS
Carload	CL	Common	COM
Carrier	CARR	Communication	COMM
Carton	CTN	Compartment	COMPT
Cartridge	CRTG	Complete	COMPL
Case	CS	Component	CMPNT
Cast iron	CI	Composition	CMPNS
Cast-iron conduit box	CICND BOX	Composition floor	COMPF
Cast-iron pipe	CIP	Composition roof	COMPR
Ceiling	CLG	Compound	CPD
Cement	CEM	Compound pressure	CPRESS
Cement base	CB	Compressed air	COMPA
Cement floor	CF	Compressor	CPRSR
		Computer	CMPTR

Concave	CNCV	Diesel engine	DENG
Concealed	CNCL	Difference	DIFF
Concentric	CNCTRC	Dimension	DIM
Concrete	CONC	Distance	DIST
Concrete block	CCB	Distribution box	DB
Concrete ceiling	CCC	Distribution panel	DPNL
Concrete floor	CCF	District	DIST
Conductor	CNDCT	District Engineer	DE
Conduit	CND	Ditto	DO
Confidential	CONF	Document	DOC
Conformance	CONF	Does not apply	DNA
Connection	CONN	Door	DR
Connection diagram	CONN DIAG	Down	DN
Consist of	C/O	Dozen	DOZ
Construction joint	CJ	Drafting	DFTG
Construction specification	CON SPEC	Drain	DR
Contents	CONT	Drawing	DRG
Contour	CTR	Drawing list	DL
Contracting officer	CONTRO	Drill	DR
Contractor	CONTP	Each	EA
Contractor-furnished equipment	CFE	Each face	EF
Control	CONT	Each layer	EL
Control room	CR	Each way	EW
Cooling fan	CF	Edge thickness	ET
Cooper	COP	Elbow	ELB
Cord	CD	Electric	ELEC
Cork	CK	Electric-motor driven	EMD
Cork board	CKBD	Electric power distribution	EPD
Cork floor	CKF	Electronic	elct
Corner	COR	Electronic Control	ELECTC
Corporation	CORP	Electronics	ELEX
Corrosion-resistant	CRE	Elevation	EL
Corps of Engineers	CE	Emergency	EMER
Corrugate	CORR	Emergency power	EPWR
Counterbore	CBORE	End to end	E TO E
Counterbore other side	CBOREO	Engine	ENG
Counterdrill	CDRILL	Engineer	ENGR
Counterdrill other side	CDRILLO	Engineering	ENGRG
Countersink	CSK	Engineering change order	ECO
Countersink other side	CSKO	Engineering work order	EWO
Coupling	CPLG	Entrance	ENTR
Critical	CRIT	Equal	EQL
Cross section	XSECT	Equally spaced	EQL SP
Cubic centimeter	cc	Equip and install	E&I
Cubic foot	cu. ft.	Equipment	EQPT
Cubic feet per minute	c.f.m.	Equivalent	EQUIV
Cubic feet per second	c.f.s.	Except	EXC
Cubic inch	in. 3 or cu. in.	Existing	EXST
Cutoff	CO	Expansion joint	EXP JT
Cycle	CY	Explosion-proof	EP
Cycles per minute	c.p.m.	Exterior	EXT
Cycles per second	c.p.s. or Hz	Extra	EX
Cylinder	CYL	Extra fine (threads)	EF
		Extra heavy	XHVV
		Extra strong	XSTR
Damper	DMPR	Fabricate	FAB
Dated	DTD	Face to face	F TO F
Daylight	DL	Facing	FCC
Decrease	DECR	Far side	FS
Deep	D	Federal Specification	FS
Delete	DELE	Federal Stock Number	FSN
Department of Defense	DOD	Feet or foot	ft
Depth	DP	Feet board measure	ft. b.m.
Design	DSGN	Fiberboard	FBRBD
Detail	DET	Field	FLD
Development	DEV	Figure	FIG
Diagonal	DIAG	Fillet	FIL.L
Diagram	DIAG	Finish	FNSH
Diameter	DIA		
Diesel	DSL		

Finish all over	FAO	Government	GOVT
Finish one side	F1S	Government-furnished equipment	GFE
Finish specification (number)	FS	Government-furnished material	GFM
Finish two sides	F2S	Government-furnished property	GFP
Fire	F	Grade	GR
Fire alarm box	FABX	Grade line	GL
Fire door	FDR	Graduation	GRDTN
Fire extinguisher	FEXT	Graphic	GRPH
Fire-hose cabinet	FHC	Graphite	GPH
Fire-hose rack	FHR	Gravel	GVL
Fire hose hydrant	FHY	Gray	GRA, GY
Fire resistant	FRES	Grease trap	GT
Fireproof	FPRF	Green	GRN, G
Fitting	FTG	Green indicating lamp	GIL
Flammable	FLMB	Greenwich mean time	GMT
Flange	FLG	Groove	GRV
Flat head	FLH	Gross weight	GRWT
Flexible	FLEX	Ground	GND
Floodlight	FLDT	Ground-to-air	G-A
Floor	FL	Ground to ground	G-G
Floor drain	FD	Guarantee	GUAR
Fluorescent	FLUOR	Guard	GD
Flush	FL	Guard rail	GDR
Flush type	FLTP	Gypsum-plaster ceiling	GPC
Footing	FTG	Hand control	HND CONT
Forged steel	FST	Hand rail	HNDRL
Foundation	FDN	Handbook	HDEK
Four-pole	4P	Hanger	HGR
Four-pole switch	4P SW	Hard	HD
Four-way	4WAY	Hard-drawn	HD DRN
Four-wire	4W	Hardware	HDW
Fractional	FRAC	Heat resisting	HT RES
Frame	FR	Heavy	HVY
Framework	FRWK	Heavy (insul)	H
Freezer	FRZR	Heavy duty	HD
Fresh water	FW	Height	HGT
From below	FR BEL	Hexagonal head	HEX HD
Front	FR	High	H
Front view	FV	High-carbon steel	HCS
Fuel line	FLN	High frequency	HF
Fuel oil	FO	High voltage	HV
Fuel tank	FTK	High-water line	HWL
Full scale	FSC	Highway	HWY
Full size	F'S	Hinge	HNG
Furnish	FURN	Holder	HLDR
Furniture	FURN	Hollow	HOL
Fuse box	FUBX	Hollow metal	HM
Gage	GA	Hollow metal door and frame	HMDF
Gallon	gal.	Horizontal	HCRIZ
Galvanize	GALV	Horizontal center line	HCL
Galvanized iron	GALVI	Hose bib	HB
Galvanized steel	GALVS	Hose connector	HCONN
Gas weld	GAS/W	Hospital	HOSP
Gasket	GSKT	Hot-rolled steel	HRS
Gasoline	GAS	Hot water	HW
Gasoline engine	GENG	Hot-water circulating	HWC
Gasoline engine driven	GED	Hot-water heater	HWH
Gate valve	GTV	House	HSE
Gearbox	GRBX	Housing	HSG
General	GENL	Hydraulic	HYDR
General contractor	GEN CONT	Identification	IDENT
Generator	GEN	Identification number	ID NO
Glass	GL	Impregnate	IMPRG
Glass (insul)	G	Improvement	IMPROV
Glaze	GLZ	In accordance with	IAW
Glazed wall tile	GWT	Incandescent	INCAND
Globe valve	GLV	Inch	in.
Gold	GLD	Incinerator	INCIN

Inclined	INCLN	Line drawing	LD
Include	INCL	Line-of-sight	LOS
Incoming	INCM	Link	LK
Incomplete	INCOMP	Linoleum	LINOL
Incorporated	INC	Linoleum floor	LF
Incorrect	INCOR	Lintel	LNTL
Increase	INCR	Liquid	LIQ
Independent	INDT	List of material	LM
Index	IDX	Lock washer	LK WASH
Index list	IL	Locus of radius	L/R
Indicating lamp	IND LP	Long	L
Industrial	INDL	Longitude	LONG
Information	INFO	Longitudinal expansion joint	LEJ
Inlet	INL	Loudspeaker	LS
Inner	INR	Louver	LVR
Input	INP	Louvered door	LVD
Input-output	I/O	Low	L
Insect screen	IS	Low frequency	LF
Insert screw thread	INST	Low voltage	LV
Inside	INS	Low-water line	LWL
Inside diameter	ID	Lumber	LBR
Installation	INSTAL		
Installation and maintenance	I&M	Machine screw	MSCR
Instruction	INSTR	Machined surface	MASU
Instrument	INSTR	Magnetic	MAG
Insulation	INSUL	Mahogany	MAH
Intake	INTK	Main	MN
Interior	INTR	Main distributing frame	MDF
Internal combustion engine	ICE	Major	MAJ
International Pipe Standard	IPS	Malleable	MAL
International Standard Thread (metric)	IST	Malleable iron	MI
Iron pipe	IP	Manhole	MH
Iron pipe size	IPS	Manhole cover	MC
Iron pipe thread	IPT	Manual	MNL
Isometric	ISO	Manually operated	MNL OPR
Issue	ISS	Manufacture	MFR
		Manufactured	MFD
Job order	JO	Manufacturing information	MFG INFO
Joint Army-Navy-Air Force	JANAF	Manufacturing instruction	MI
Joints	NPSM	Marble	MR
Joists and planks	J&P	Marble base	MRB
Junction box	JB	Marble floor	MRF
		Marine	MAR
Keyboard	KYBD	Mark	MK
Keyway	KWY	Masonry	MSNRY
Kiln-dried	KD	Master layout duplicate	MLD
Kilovolt-ampere meter	KVAM	Master layout original	MLO
Kilowatt-hour meter	KWHM	Master switch	MSW
Knurl	KNRL	Mastic	MSTC
		Mastic joint	MJ
Landmark	LD MK	Material	MATL
Large	LGE	Material list	ML
Laser detection and ranging	LADAR	Maximum capacity	MAX CAP
Latitude	LAT	Maximum working pressure	MWP
Lawn faucet	LF	Mean high tide	MHT
Layout	LYT	Mean low tide	MLT
Leader	LDR	Mean sea level	MSL
Left	L	Mechanical	MECH
Left hand	LH	Mechanically cooled	MCHCL
Left side	LS	Median	MDN
Length	LG	Medium	MDM
Length over-all	LOA	Melting point	MP
Level	LVL	Membrane waterproofing	MWP
Light	LT	Meridian	MER
Light distribution box	LDB	Metal	MET
Light switch	LTSW	Metal door	METD
Lightning	LTG	Metal flashing	METF
Lightning arrester	LA	Metal jalousie	METJ
Lightweight concrete	LWC	Metal rolling door	MRD
Limestone	LS		

Meter	MTR	Nonreversible	NRVSBL
Method	MTHD	Nonslip tread	NST
Middle	MDL	Normal	NORM
Military	MIL	Normally closed	NC
Military standard (book)	MIL-STD	Normally open	NO
Military standard (sheet)	MS	Not applicable	NA
Mineral	MNRL	Not available	NA
Miniature	MINTR	Not in contract	NIC
Minimum	MIN	Not to scale	NTS
Minute	MIN	Number	NO
Miscellaneous	MISC	Nylon	NYL
Miter	MIT	Nylon (insul)	N
Mixture	MXT		
Mobile	MBL	Obsolete	OBS
Model	MOD	Office	OFCE
Modification	MOD	Ohmmeter	OHM
Moisture	MSTRE	Oil burner	OBRNR
Molding	MLDG	Oil circuit breaker	OCB
Month	MO	Oil cooled	OCLD
Monument	MON	Oil level	OLVL
Motor	MOT	Oil pressure	OPRS
Motor belt drive	MBD	Oil tank	OTK
Motor driven	MTRDN	Oilproof	OP
Motor generator	MG	On center	OC
Motor operated	MO	One-way	1/W
Motorized	MTZ	Opening	OPNG
Mount	MT	Operating steam pressure	OSP
Mounted	MTD	Opposite	OPP
Mounting	MTG	Optional	OPTL
Movable	MVBL	Orange	ORN, O
Multiple	MULT	Orange indicating light	OIL
Multiple unit	MU	Order	ORD
		Ordinary	ORD
Namely	VIZ	Organization	ORG
Narrow	NAR	Origin	ORIG
Narrow gage	NG	Original	ORIG
National	NATL	Otherwise specified	O&S
National Electric Safety Code	NESC	Out to out	O TO O
National Electrical Code Standards	NECS	Outlet	OUT
National Wire Gage	NWG	Output	OUT
Natural	NAT	Outside	OUT
Nautical	NAUT	Outside diameter	OD
Naval	NAV	Outside face	OF
Navy Primary Standards	NPS	Oval head	OVH
Navy Secondary Standards	NSS	Over	OV
Near face	NG	Over-all	OA
Near side	NS	Overflow	OVFL
Necessary	NEC	Overhaul and repair	O&R
Negative	NEG	Overhead	OVHD
Negative print	NEGPR	Oxygen	OXY
Neon indicating light	NEIL	Ozalid print	O/P
Neoprene	NPRN		
Net weight	NTWT	Page	P
Neutral	NEUT	Paint	PNT
Nickel	NKL	Painted	PTD
Nickel copper	NICOP	Pair	PR
Nickel plated	NP	Panel	PNL
Nickel-silver	NISIL	Panoramic	PAN
Nickel steel	NS	Paper	PPR
No change	NC	Paper (insul)	P
No connection	NC	Paragraph	PARA
No drawing	ND	Parallel	PRL
Noise frequency	NF	Parkway	PKWY
Nomenclature	NOMEN	Part	PT
Noncombustible	NCOMBL	Parts catalog	PC
Noncorrosive metal	NCM	Part number	PN
Nonmetallic	NM	Part of	P/O
Nonprocurable	NP	Partial	PART
Nonreinforced concrete pipe	NRCP	Partition	PTN
		Parts list	PL

Passage	PASS	Proposed	PRPSD
Peak to peak	P-P	Protective	PROT
Penetration	PEN	Public address	PA
Percent	PCT	Publication	PUBN
Perforated	PERF	Pull and push plate	P&PP
Performance	PRFM	Pull switch	PS
Permanent	PERM	Pump	PMP
Perpendicular	PERP	Purple	PRP
Perspective	PERSP	Purple indicating light	PIL
Pewter	PWTR	Push button	PB
Phillips head	PHH	Push-pull	PP
Photocopy	PHOC	Quality	QUAL
Piece	PC	Quantitative	QUANT
Pillar	PLR	Quantity	QTY
Pipeline	PPLN	Quarter	QTR
Pitch	P	Quartz	QTZ
Pitch circle	PC	Radur	RDR
Pitch diameter	PD	Radio	RAD
Pitch line	PL	Radius	RAD
Pitch mark	PMK	Rail	R
Pivot	PVT	Railing	RLG
Place	PL	Railroad	RR
Plain	PL	Railway	RY
Plan view	PV	Raintight	RT
Plane	PLN	Range	RNG
Plaster	PLAS	Ratchet	RCHT
Plastic	PLSTC	Rate	RT
Plate	PL	Rate of change	RC
Plate glass	PLGL	Rating	RTG
Platform	PLATF	Ratio	R
Platinum	PLAT	Raw material	RM
Plug	PL	Rayon	RYN
Plumbing	PLMB	Rayon (insul)	RA
Plus or minus	PORM	Reactivate	REACTVT
Plywood	PLYWD	Rear view	RV
Pneumatic	PNEU	Receive	RCV
Pocket	PKT	Receiver	RCVR
Point	PT	Receptacle	RCPT
Point or curve	PC	Recreation	RCN
Point of intersection	PI	Red	RED, R
Point of reverse curve	PRC	Red indicating lamp	RIL
Point of tangency	PT	Redrawn	REDWN
Pole	"	Reduce	RDC
Polyester	POLYEST	Reference	REF
Polyethylene (insul)	POLTHN	Reference line	REFL
Polyethylene-insulated conductor	PIC	Refrigerator	REFR
Porcelain	FORC	Regulator	RGLTR
Portable	PORT	Reinforce	REINF
Position	POSN	Reinforced concrete	RC
Positive	POS	Reinforced concrete culvert pipe	RCCP
Potable water	POTW	Reinforced concrete pipe	RCP
Pound	lb.	Reinforcing steel	RST
Power	PWR	Reject	REJ
Power and lighting distribution	P&L DISTR	Relative humidity	RH
Power circuit breaker	PCB	Relay	RLY
Power driven	PDVN	Relay block	RB
Power plant	PP	Relief valve	RLV
Power supply	PWR SPLY	Relocated	RELOC
Powerhouse	PWRH	Remainder	REM
Prefabricated	PREFAB	Remote	RMT
Preferred	PRD	Remote control	RC
Preliminary	PRELIM	Remote control system	RCS
Pressboard	PBD	Removable	REM
Pressure	PRESS	Removable cover	REM COV
Pressure reducing valve	PRV	Remove and replace	R&R
Primary	PRI	Repair	RPR
Printed circuit	PC	Repeat	RPT
Priority	PRI	Replace	REPL
Procurement	PRCMT		

Reproduce	REPRO	Sliding expansion joint	SEJ
Require	REQ	Slope	SLP
Required	REQD	Slotted	SLTD
Requirement	REQT	Small	SM
Requisition	REQN	Soft	S
Reserve oil tank	ROT	Solder	SLDR
Reservoir	RSVR	Solid	SOL
Retractable	RETR	Sonar	SNR
Return	RTN	Sound	SND
Reverse	RVS	Soundproof	SNDPRF
Reversible	RVSBL	Source	SCE
Revise	REV	Space	SP
Rewind	RWND	Space heater	SPH
Rheostat	RHEO	Spare	SP
Ribbed	RIB	Spart part	SP
Right	R	Special	SPCL
Right angle	RTANG	Specification	SPEC
Right hand	RH	Spherical	SPHER
Right hand side	RHS	Splash block	SB
Right side	RS	Splice	SPLC
Road	RD	Spot face	SF
Rolling steel door	RSD	Spot face other side	SFO
Room	RM	Spot weld	SW
Rotary	RTRY	Spring	SPR
Rough	RGH	Square head	SQH
Round	RND	Stainless	STNLS
Rubber	RBR	Stainless steel	SST
Rubber (insul)	R	Stairway	STWY
Rubber covered cable	RCC	Standard	STD
Rubber insulation	RINSUL	Standby	STBY
Rubber tile floor	RTF	Standpipe	SP
Rustproof	RSTPF	Start and stop	ST & SP
		Stationary	STA
Safe working pressure	SWP	Steam working pressure	STWP
Safety valve	SV	Steel	STL
Same size	SS	Step-down	STPDN
Scale	SC	Step-up	STU
Schedule	SCHED	Stock number	SNO
Screen	SCRN	Storage	STOR
Screen door	SCD	Storeroom	STRM
Screw	SCR	Straight	STR
Sea level	SL	Strokes per minute	SPM
Sealed	SLD	Strong	STRG
Secondary	SEC	Structural	STRL
Section	SECT	Submersible	SBM
Security window screen and guard	SWSG	Subsoil drain	SSD
Segment	SEG	Substation	SUBSTA
Self-locking	SLFLKG	Substitute	SUBST
Self-sealing	SLFSE	Substructure	SUBSTR
Semifinished	SF	Sufficient	SUF
Send and receive	S/R	Sump tank	SMTK
Separate	SEP	Superstructure	SUPERSTR
Serial number	SERNO	Suspended acoustical-plaster ceiling	SAPC
Service	SVCE	Suspended acoustical-tile ceiling	SATC
Sewage	SEW	Swinging door	SWGDN
Sheet	SH	Switch	SW
Shipment	SHPT	Switchboard	SWBD
Shoulder	SHLDR	Switchgear	SWGR
Shutoff valve	SOV	Symmetrical	SWMM
Signal	SIG	System	SYS
Silk (insul)	S		
Silver	SIL	Tank	TK
Silver solder	SILS	Taper	TPR
Similar	SIM	Taxiway	TWY
Single	SGL	Technical	TECH
Single phase	1PH	Technical manual	TM
Sketch	SK	Telegraph	TLG
Sleeve	SLV	Telephone	TEL
Sliding door	SLD	Teletype	TT

Temperature	TEMP	Unmounted	UNMTD
Template	TMPL	Untreated	UTRTD
Temporary	TEMP	Upper	UPR
Tensile strength	TS	Use as required	UAR
Tension	TNSN	Used on	U/O
Terminal	TERM	Used with	U/W
Terra cotta	TC	Utility	UTIL
Terrazzo	TER	Utility room	UR
Test equipment	TESTEQ		
Thermal	THRM	Vacant	VAC
Thick	THK	Vacuum	VAC
Thickness	THKNS	Valley	VAL
Thread	THD	Valve	V
Thread both ends	TBE	Valve box	VB
Threads per inch	TPI	Vapor seal	VS
Three-phase	3PH	Vaporproof	VAP PRF
Three-pole	3P	Vaportight	VT
Three-way	3WAY	Varnish	VARN
Three-wire	3W	Vault door	VD
Through	THRU	Vehicle	VEH
Tile floor	TF	Vent hole	VH
Timber	TMBR	Vent pipe	VP
Title block	T/B	Verify	VRFY
Tolerance	TOL(S)	Versus	VS
Ton(s)	ton	Vertex	VTX
Total	TOT	Vertical	VERT
Total load	TLLD	Vertical center line	VCL
Total time	TT	Violet	VIO
Transceiver	XCVR	Viscosity	VISC
Transfer	XFR	Visual	VIS
Transformer	XFMF	Vitreous	VIT
Transistor	XSTR	Vitrified clay	VC
Transmitter	XMTR	Void	VD
Transmitter receiver	TR	Voltage	V
Transparent	TRANS	Voltage regulator	VR
Transportation	TRANSP	Volume	VOL
Tread	TRD	Vulcanize	VULC
Treated	TRTD		
Treated hard-pressed fiberboard	THPFB	Wall receptacle	WR
Trim after forming	TAF	Warehouse	WHSE
Triple-pole	3P	Warning	WRN
True position	TP	Warranty	WARR
True profile	TP	Washer	WSHR
Tubing	TBG	Waste pipe	WP
Tungsten	TUNG	Water	WTR
Tunnel	TNL	Water chiller	WCHR
Turbine	TURB	Water-cooled	WCLD
Turnbuckle	TRNBKL	Water heater	WH
Two phase	2P	Water line	WL
Two-pole	DP	Water meter	WM
Two way	2WAY	Water pump	WP
Typical	TYP	Watercooler	WCR
		Waterproof	WTRPRF
Unauthorized	UNAUTHD	Waterproofing	WPG
Uncoated	UNCTD	Watertight	WTRTT
Under	UND	Watt-hour meter	WHM
Underground	UGND	Waveguide	WG
Underwater	UWTR	Weather resistant	WR
Unfinished	UNFIN	Weather seal	WSL
Uniform	UNIF	Weather stripping	WS
Union	UN	Weather-tight	WEAT
United States Gage	USG	Weatherproof	WTHPRF
United States Standard	USS	Weatherproof (insul)	WP
Universal	UNIV	Weight	WT
Unknown	UNK	Welded	WLD
Unless otherwise specified	UOS	White	WHT, W
Unlimited	UNLIM	White indicating lamp	WIL
Unloading	UNL	Wide	W
Unmarked	UNMKD	Width	WD

Width across flats ----- WAF
 Wind ----- WD
 Wind direction ----- WDIR
 Window ----- WDO
 Window dimension ----- WD
 Windshield ----- WSHLD
 Wire mesh ----- WM
 Wiring ----- WRG
 With (comb form) ----- W/
 With equipment and spare parts ----- W/E&SP
 Withdrawn ----- W/D
 Without ----- W/O
 Without equipment and spare parts ----- W/O E&SP
 Wood ----- WD
 Wood door ----- WD
 Wood door and frame ----- WDF

Wood jalousie ----- WJ
 Wood panel ----- WDP
 Wood-shingle roof ----- WSR
 Work ----- WK
 Work bench ----- WB
 Working ----- WKG
 Working pressure ----- WPR
 Working steam pressure ----- WSP
 Workshop ----- WKS
 Wrought iron ----- WI
 Year ----- YR
 Yellow ----- YEL, Y
 Yellow indicating lamp ----- YIL
 Yield point (psi) ----- YP
 Zone ----- A

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