Chapter Five

Multiviews and Visualization

Chapter Five

As lines, so loves oblique, may well
Themselves in every angle greet;
But ours, so truly parallel,
Though infinite, can never meet.

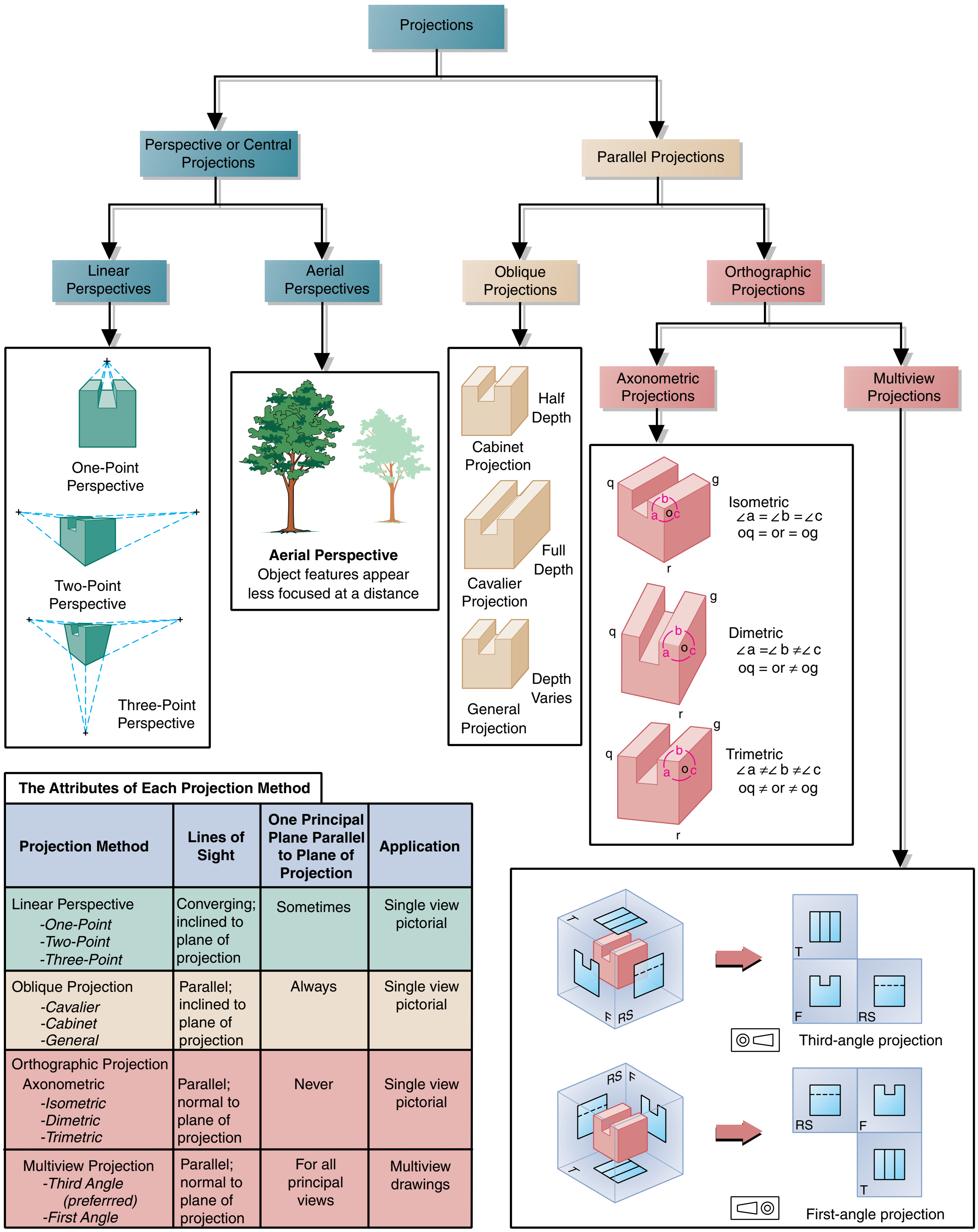
—Andrew Marvell

Objectives and Overview

After completing this chapter, you will be able to:

1. Explain orthographic and multiview projection.
2. Identify frontal, horizontal, and profile planes.
3. Identify the six principal views and the three space dimensions.
4. Apply standard line practices to multiview drawings and sketches.
5. Create a multiview drawing by sketching or CAD.
6. Identify normal, inclined, and oblique planes in multiview drawings.
7. Represent lines, curves, surfaces, holes, fillets, rounds, chamfers, runouts, and ellipses in multiview sketches.
8. Explain the importance of multiviews.
9. Identify limiting elements, hidden features, and intersections of two planes in multiviews.
10. Apply visualization by solids and surfaces to multiviews.
11. Visualize 3-D objects as multiview projections.

Chapter 5 introduces the theory, techniques, and standards of multiviews, which are a standard method for representing engineering designs.



The Attributes of Each Projection Method

Projection Method	Lines of Sight	One Principal Plane Parallel to Plane of Projection	Application
Linear Perspective -*One-Point* -*Two-Point* -*Three-Point*	Converging; inclined to plane of projection	Sometimes	Single view pictorial
Oblique Projection -*Cavalier* -*Cabinet* -*General*	Parallel; inclined to plane of projection	Always	Single view pictorial
Orthographic Projection Axonometric -*Isometric* -*Dimetric* -*Trimetric*	Parallel; normal to plane of projection	Never	Single view pictorial
Multiview Projection -*Third Angle (preferrred)* -*First Angle*	Parallel; normal to plane of projection	For all principal views	Multiview drawings

Figure 5.1

Projection methods

Projection techniques developed along two lines: parallel and perspective.

The chapter describes how to create one-, two-, and three-view sketches with traditional tools and CAD. Also described are standard practices for representing edges, curves, holes, tangencies, and fillets and rounds. The foundation of multiviews is orthographic projection, based on parallel lines of sight and mutually perpendicular views. Also introduced in this chapter are visualization techniques that can be used to help create and interpret multiviews.

5.1 Projection Theory

Engineering and technical graphics are dependent on projection methods. The two projection methods primarily used are perspective and parallel (Figure 5.1). Both methods are based on projection theory, which has taken many years to evolve the rules used today.

Projection theory comprises the principles used to graphically represent 3-D objects and structures on 2-D media. An example of one of the methods developed to accomplish this task is shown in Figure 5.2, which is a pictorial drawing with shades and shadows to give the impression of three dimensions.

All projection theory is based on two variables: line of sight and plane of projection. These variables are described briefly in the following paragraphs.

5.1.1 Line of Sight (LOS)

Drawing more than one face of an object by rotating the object relative to your *line of sight* helps in understanding the 3-D form (Figure 5.3). A **line of sight (LOS)** is an imaginary ray of light between an observer's eye and an object. In perspective projection, all lines of sight start at a single point (Figure 5.4); in parallel projection, all lines of sight are parallel (Figure 5.5).

5.1.2 Plane of Projection

A **plane of projection** (i.e., an image or picture plane) is an imaginary flat plane upon which the image created by the lines of sight is projected. The image is produced by connecting the points where the lines of sight pierce the projection plane (see Figure 5.5). In effect, the 3-D object is transformed into a 2-D representation (also called a projection). The paper or computer screen on which a sketch or drawing is created is a plane of projection.

Figure 5.2

Pictorial illustration

This is a computer-generated pictorial illustration with shades and shadows. These rendering techniques help enhance the 3-D quality of the image.

(Courtesy of Zagato Centrostile.)

5.1.3 Parallel versus Perspective Projection

If the distance from the observer to the object is infinite (or essentially so), then the *projectors* (i.e., projection lines) are parallel and the drawing is classified as a parallel projection (see Figure 5.5). **Parallel projection** requires that the object be positioned at infinity and viewed from multiple points on an imaginary line parallel to the object. If the distance from the observer to the object is finite, then the projectors are not parallel and the drawing is classified as a perspective projection (see Figure 5.4). **Perspective projection** requires that the object be positioned at a finite distance and viewed from a single point (station point).

Perspective projections mimic what the human eye sees; however, perspective drawings are difficult to create. Parallel projections are less realistic, but they are easier to draw. This chapter will focus on parallel projection. Perspective drawings are covered in Chapter 7, "Pictorial Projections."

Orthographic projection is a parallel projection technique in which the plane of projection is positioned between the observer and the object and is perpendicular to the parallel lines of sight. The orthographic projection technique can produce either pictorial drawings that show all three dimensions of an object in one view, or multiviews that show only two dimensions of an object in a single view (Figure 5.6).

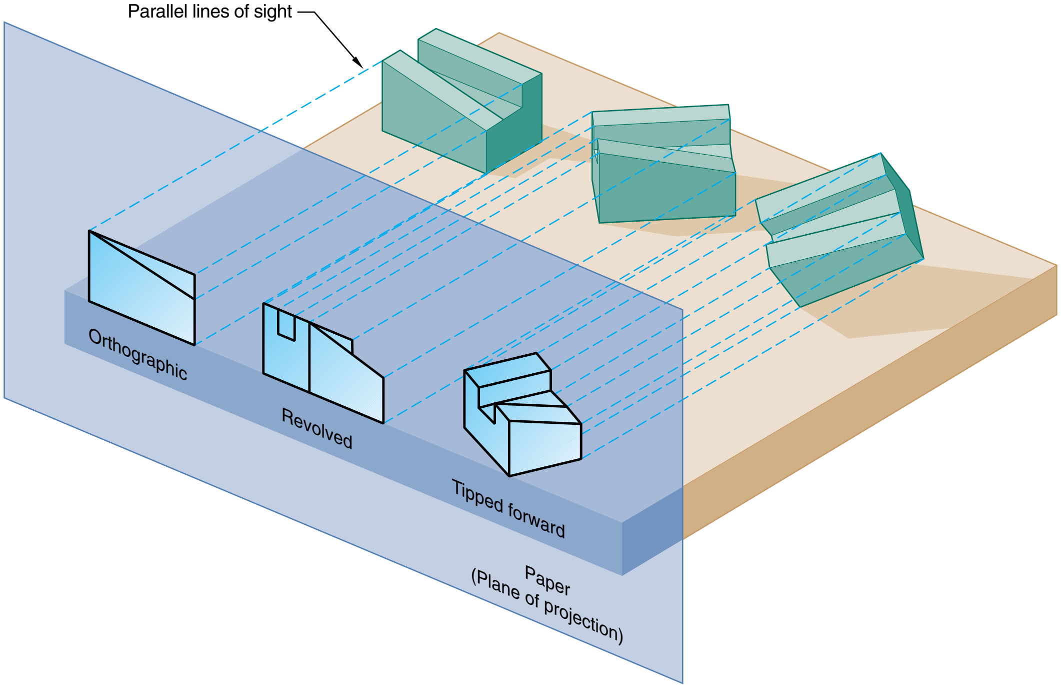


Figure 5.3

Changing viewpoint

Changing the position of the object relative to the line of sight creates different views of the same object.

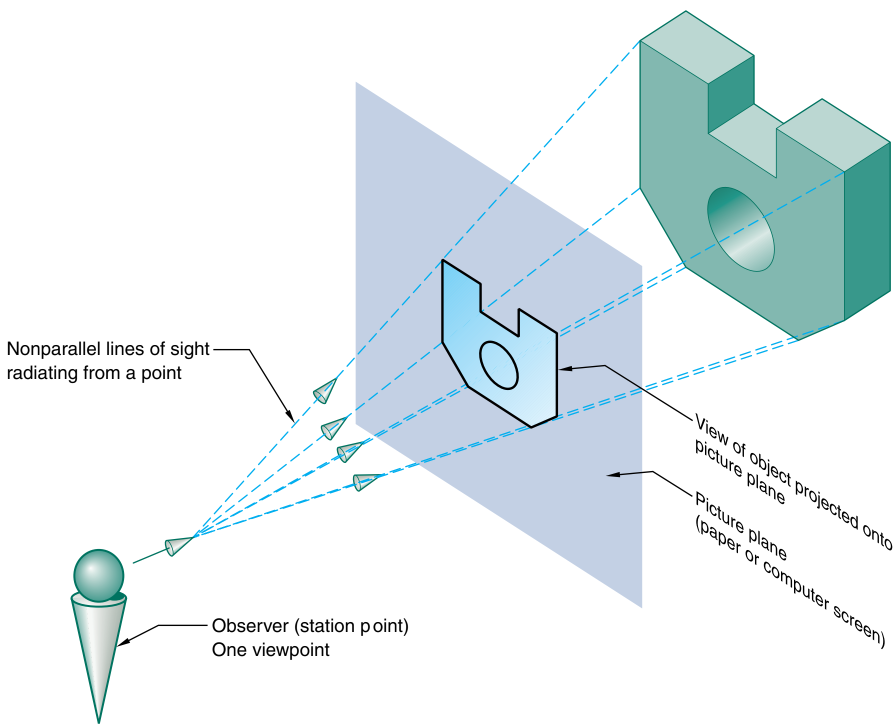


Figure 5.4

Perspective projection

Radiating lines of sight produce a perspective projection.

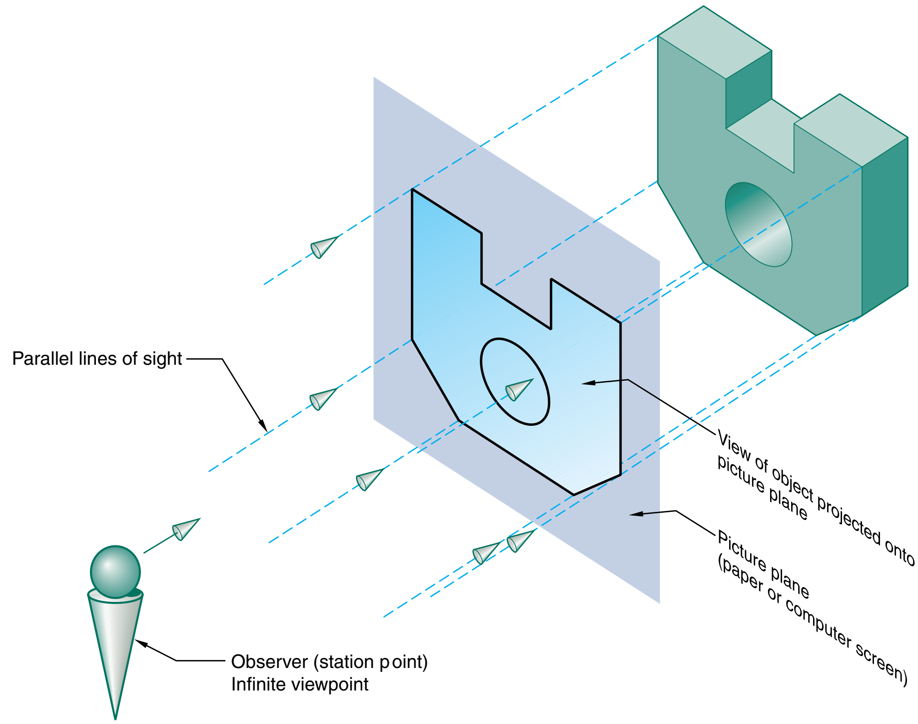


Figure 5.5

Parallel projection
Parallel lines of sight produce a parallel projection.

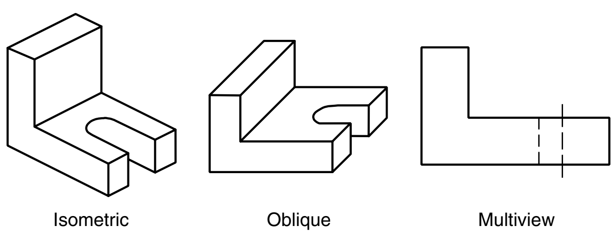


Figure 5.6

Parallel projection
Parallel projection techniques can be used to create multiview or pictorial drawings.

5.2 Multiview Projection Planes

Multiview projection is an orthographic projection for which the object is behind the plane of projection, and the object is oriented such that only two of its dimensions are shown (Figure 5.7). As the parallel lines of sight pierce the projection plane, the features of the part are outlined.

Multiview drawings employ multiview projection techniques. In multiview drawings, generally three views of an object are drawn, and the features and dimensions in each view accurately represent those of the object. Each view is a 2-D flat image, as shown in Figure 5.8. The views are defined according to the positions of the planes of projection with respect to the object.

5.2.1 Frontal Plane of Projection

The *front view* of an object shows the *width* and *height* dimensions. The views in Figures 5.7 and 5.8 are front views. The **frontal plane of projection** is the plane onto which the front view of a multiview drawing is projected.

5.2.2 Horizontal Plane of Projection

The *top view* of an object shows the *width* and *depth* dimensions (Figure 5.9). The top view is projected onto the **horizontal plane of projection,** which is a plane suspended above and parallel to the top of the object.

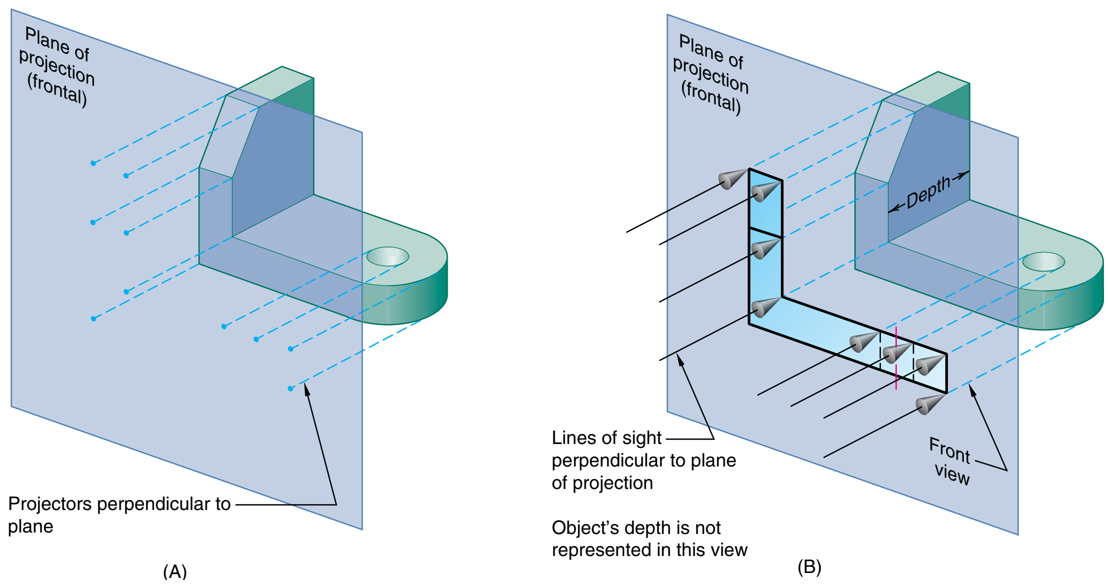


Figure 5.7

Orthographic projection

Orthographic projection is used to create this front multiview drawing by projecting details onto a projection plane that is parallel to the view of the object selected as the front.

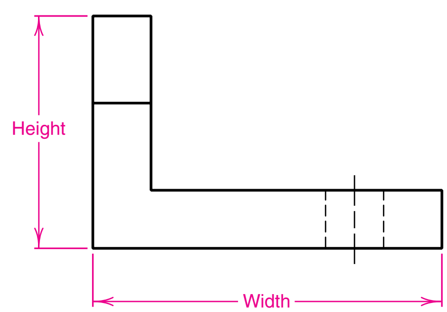


Figure 5.8

Single view

A single view, in this case the front view, drawn on paper or computer screen makes the 3-D object appear 2-D; one dimension, in this case the depth dimension, cannot be represented since it is perpendicular to the paper.

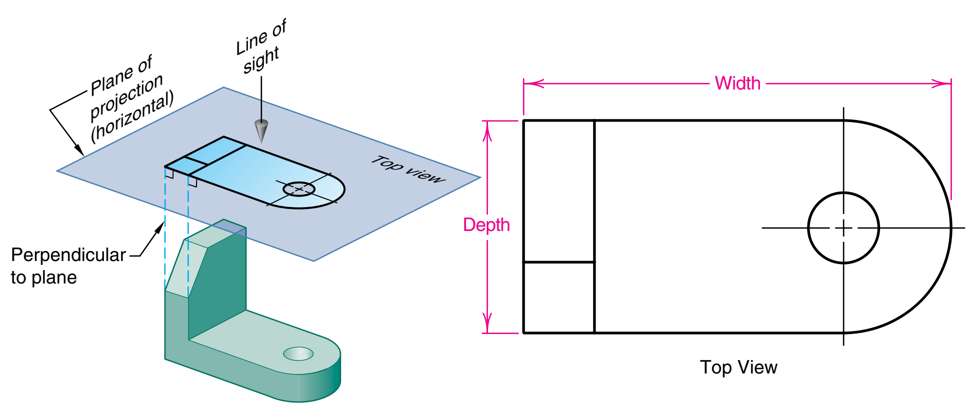


Figure 5.9

Top view

A top view of the object is created by projecting onto the horizontal plane of projection.

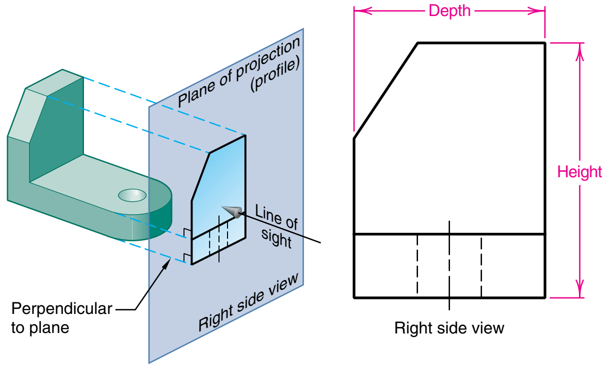


Figure 5.10

Profile view

A right side view of the object is created by projecting onto the profile plane of projection.

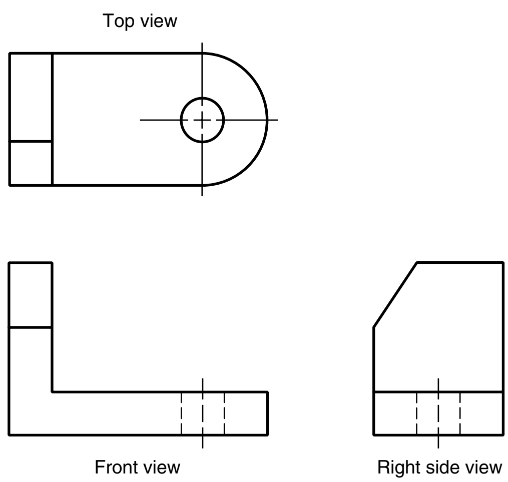


Figure 5.11

Multiview drawing of an object

For this object three views are created: front, top, and right side. The views are aligned so that common dimensions are shared between views.

5.2.3 Profile Plane of Projection

The *side view* of an object shows the *depth* and *height* dimensions. In multiview drawings, the right side view is the standard side view used. The right side view is projected onto the right **profile plane of projection,** which is a plane that is parallel to the right side of the object (Figure 5.10).

5.2.4 Orientation of Views from Projection Planes

The views projected onto the three planes are shown together in Figure 5.11. The top view is always positioned

Figure 5.12

Perspective image

The photograph shows the road in perspective, which is how cameras capture images. Notice how the telephone poles appear shorter and closer together off in the distance.

(Photo courtesy of Anna Anderson.)

above and aligned with the front view, and the right side view is always positioned to the right of and aligned with the front view, as shown in the figure.

5.3 Advantages of Multiview Drawings

In order to produce a new product, it is necessary to know its true dimensions, and true dimensions are not adequately represented in most pictorial drawings. To illustrate, the photograph in Figure 5.12 is a pictorial perspective image. The image distorts true distances, which are essential in manufacturing and construction. Figure 5.13 demonstrates how a perspective projection distorts measurements. Note that the two width

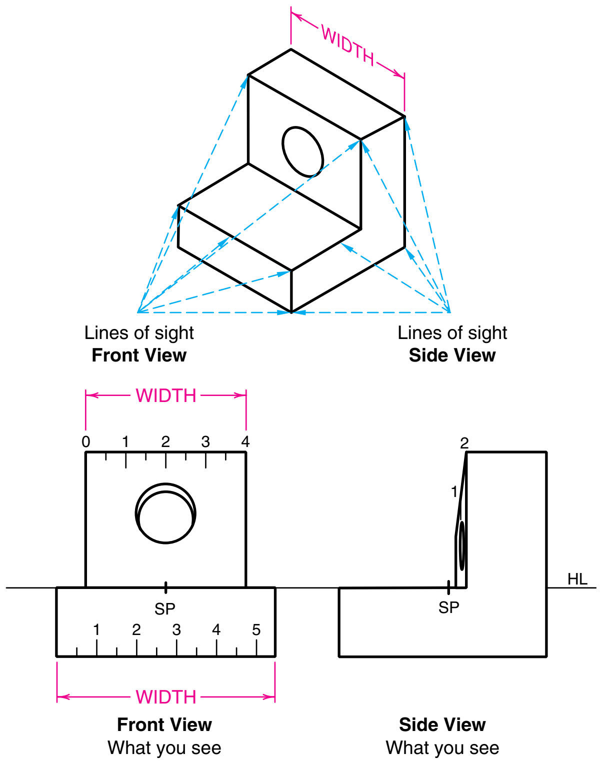


Figure 5.13

Distorted dimensions

Perspective drawings distort true dimensions.

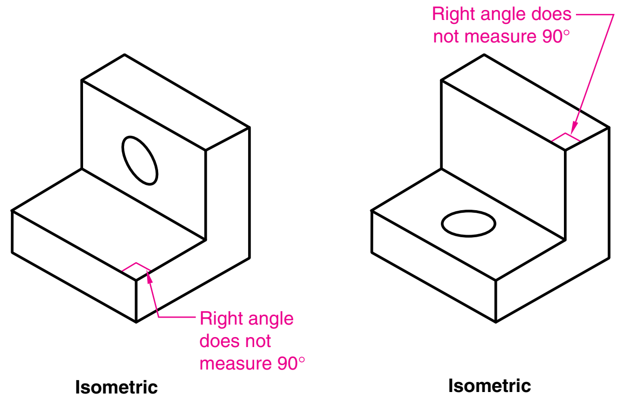


Figure 5.14

Distorted angles

Angular dimensions are distorted on pictorial drawings.

dimensions in the front view of the block appear different in length; equal distances do not appear equal on a perspective drawing.

In the pictorial drawings in Figure 5.14, angles are also distorted. In the isometric view, right angles are not shown as 90 degrees. In the oblique view, only the front surfaces and surfaces parallel to the front surface show true right angles. In isometric drawings, circular holes appear as ellipses; in oblique drawings, circles also appear as ellipses, except on the front plane and surfaces parallel to the front surface. Changing the position of the object will minimize the distortion of some surfaces, but not all.

Since engineering and technology depend on exact size and shape descriptions for designs, the best approach is to use the parallel projection technique called orthographic projection to create views that show only two of the three dimensions (width, height, depth). If the object is correctly positioned relative to the projection planes, the dimensions of features will be represented in true size in one or more of the views (Figure 5.15). Multiview drawings provide the most accurate description of three-dimensional objects and structures for engineering, manufacturing, and construction requirements.

In the computer world, 3-D models replace the multiview drawing. These models are interpreted directly from the database, without the use of dimensioned drawings (Figure 5.16).

5.4 The Six Principal Views

The plane of projection can be oriented to produce an infinite number of views of an object. However, some views are more important than others. These **principal views** are the six mutually perpendicular views that are produced by six mutually perpendicular planes of projection. If you imagine suspending an object in a glass box with major surfaces of the object positioned so that they are parallel to the sides of the box, the six sides of the box become projection planes showing the six views (Figure 5.17). The six principal views are front, top, left side, right side, bottom, and rear. To draw these views on 2-D media, that is, a piece of paper or a computer monitor, imagine putting hinges on both sides of the front glass plane and on one edge of the left profile plane. Then cut along all the other corners, and flatten out the box to create a six-view drawing, as shown in Figure 5.18.

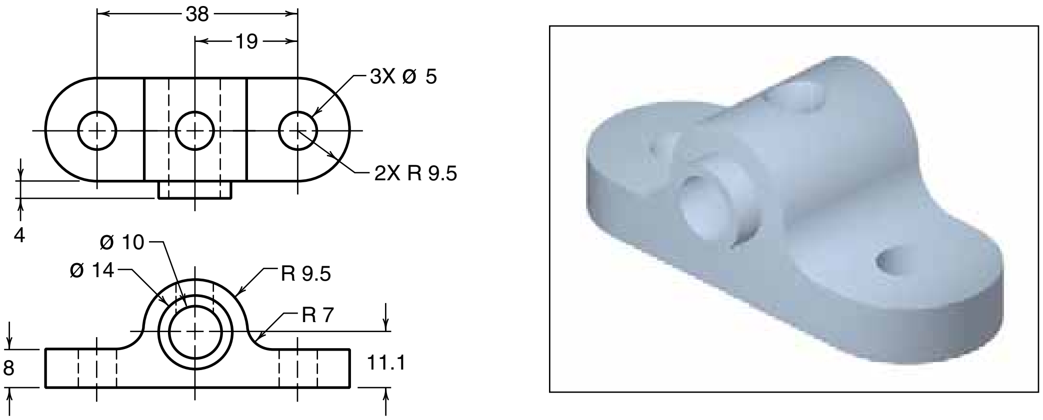


Figure 5.15

Multiview drawing

Multiview drawings produce true-size features, which can be used for dimensionally accurate representations.

The following descriptions are based on the X, Y, and Z coordinate system. In CAD, *width* can be assigned the X axis, *height* assigned the Y axis, and *depth* assigned the Z axis. This is not universally true for all CAD systems but is used as a standard in this text.

The **front view** is the one that shows the most features or characteristics. All other views are based on the orientation chosen for the front view. Also, all other views, except the rear view, are formed by rotating the lines of sight 90 degrees in an appropriate direction from the front view. With CAD, the front view is the one created by looking down the Z axis (in the negative Z viewing direction), perpendicular to the X and Y axes.

The **top view** shows what becomes the top of the object once the position of the front view is established. With CAD, the top view is created by looking down the Y axis (in the negative Y viewing direction), perpendicular to the Z and X axes.

The **right side view** shows what becomes the right side of the object once the position of the front view is established. With CAD, the right side view is created by looking down the X axis from the right (in the negative X viewing direction), perpendicular to the Z and Y axes.

The **left side view** shows what becomes the left side of the object once the position of the front view is established. The left side view is a mirror image of the right side view, except that hidden lines may be different. With CAD, the left side view is created by looking down the X axis from the left (in the positive X viewing direction), perpendicular to the Z and Y axes.

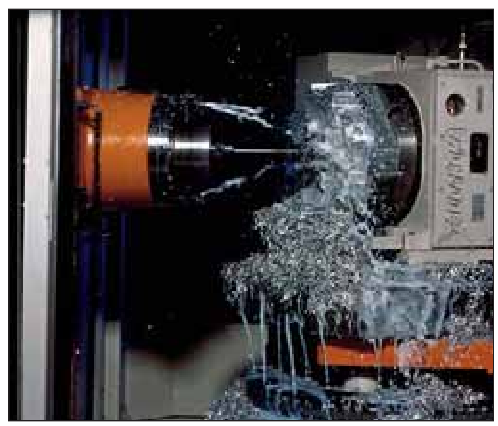


Figure 5.16

CAD data used directly by machine tool

This computer-numeric-control (CNC) machine tool can interpret and process 3-D CAD data for use in manufacturing to create dimensionally accurate parts.

(Courtesy of Intergraph Corporation.)

The **rear view** shows what becomes the rear of the object once the front view is established. The rear view is at 90 degrees to the left side view and is a mirror image of the front view, except that hidden lines may be different. With CAD, the rear view is created by looking down the Z axis from behind the object (in the positive Z viewing direction), perpendicular to the Y and X axes.

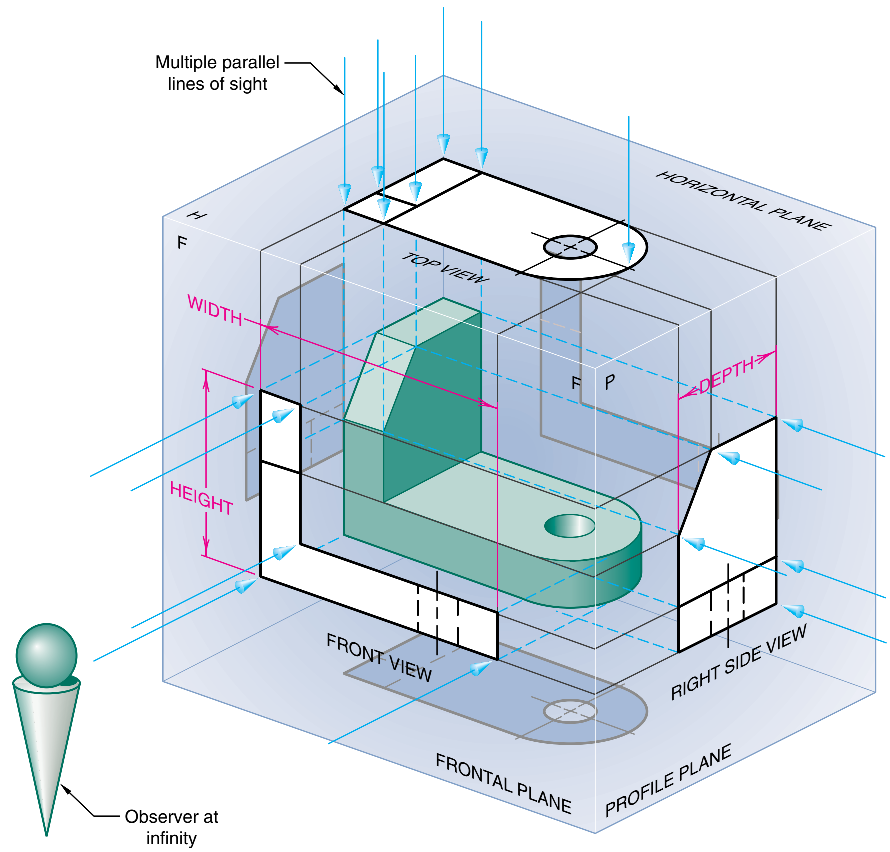


Figure 5.17

Object suspended in a glass box, producing the six principal views
Each view is perpendicular to and aligned with the adjacent views.

The **bottom view** shows what becomes the bottom of the object once the front view is established. The bottom view is a mirror image of the top view, except that hidden lines may be different. With CAD, the bottom view is created by looking down the Y axis from below the object (positive Y viewing direction), perpendicular to the Z and X axes.

The concept of laying the views flat by "unfolding the glass box," as shown in Figure 5.18, forms the basis for two important multiview drawing standards:

1. Alignment of views.
2. Fold lines.

The top, front, and bottom views are all aligned vertically and share the same width dimension. The rear, left side, front, and right side views are all aligned horizontally and share the same height dimension.

Fold lines are the imaginary hinged edges of the glass box. The fold line between the top and front views is labeled *H/F,* for horizontal/frontal projection planes; and the fold line between the front and each profile view is labeled *F/P,* for frontal/profile projection planes. The distance from a point in a side view to the F/P fold line is the same as the distance from the corresponding point in the top view to the H/F fold line. Conceptually, then, the fold lines are edge-on views of reference planes. Normally, fold lines or reference planes are not shown in engineering drawings. However, they are very important for auxiliary views and spatial geometry construction.

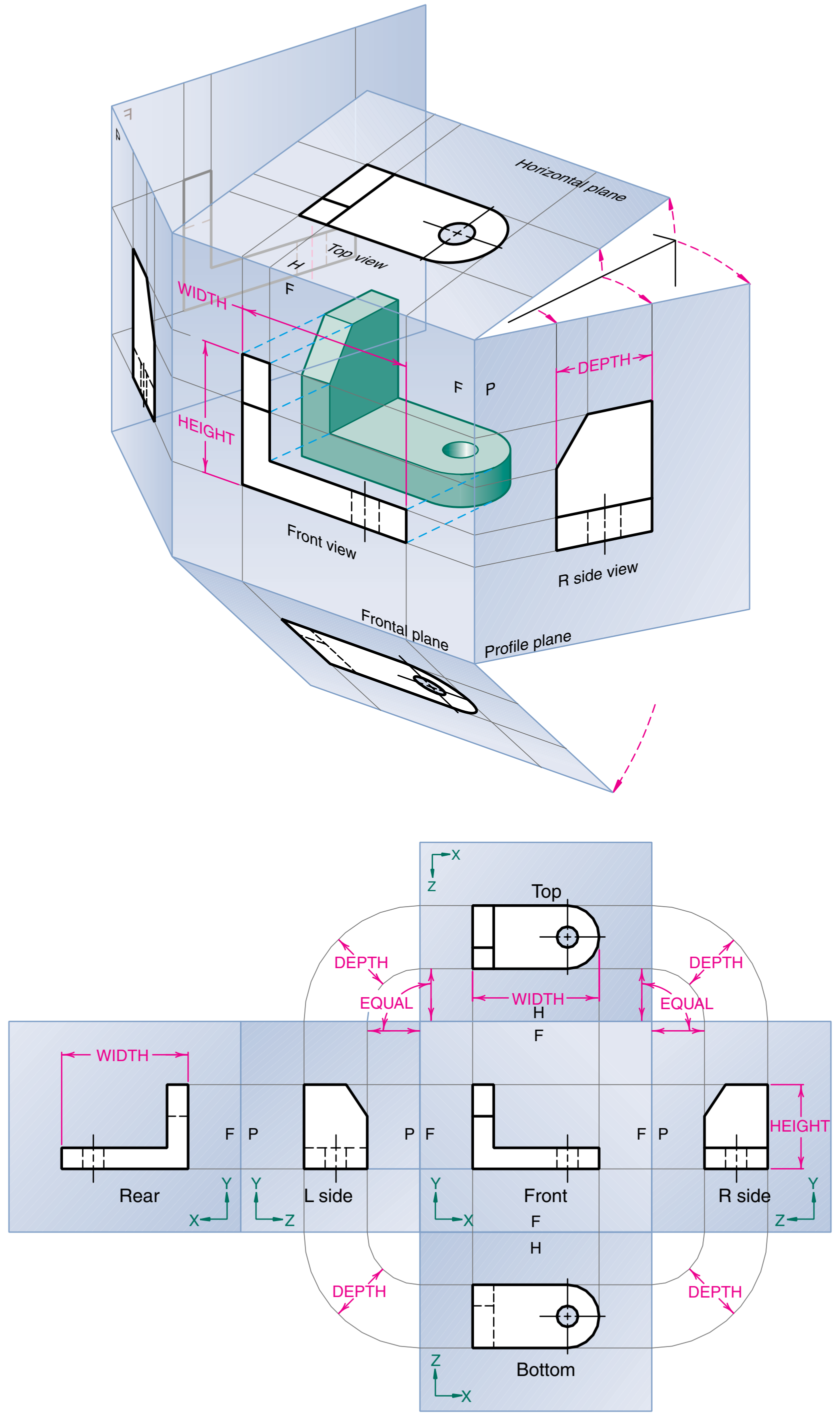


Figure 5.18

Unfolding the glass box to produce a six-view drawing

Historical Highlight

Multiview Drawings

Rudimentary plan views of buildings have been used since ancient times. See Figure 1.15. However, elevations or multiviews of buildings would take many more years before they were in common use. Albrecht Dürer (1471–1528) is known mainly for his beautiful engravings (Figure 1.17) but he demonstrated the principles of multiview drawings in a book

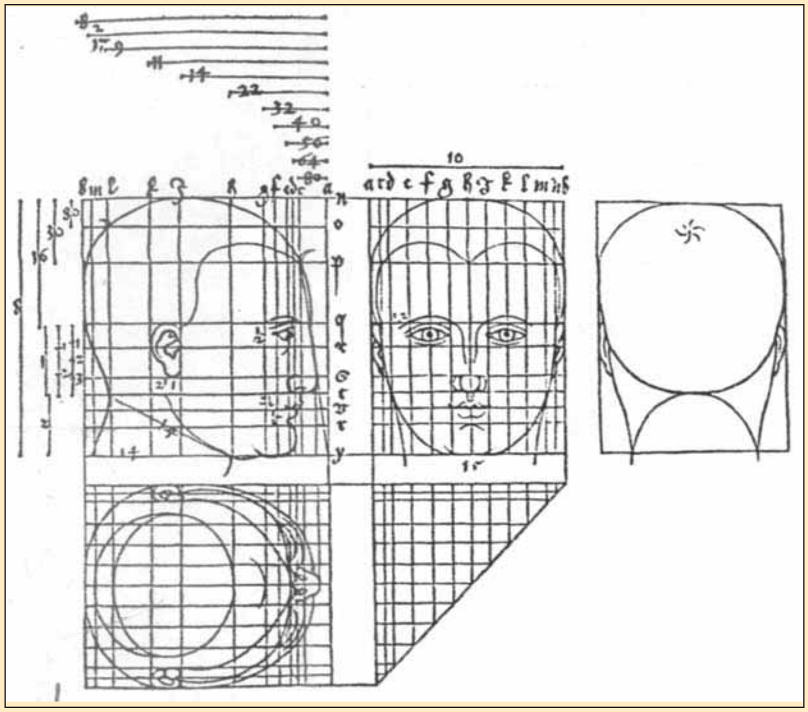


Figure 1

(A) Dürer's systematic use of orthographic projection to define the human head and its features' proportions. Most of the dimensions given should be read as their reciprocals, taking the whole man's height as unity.

Practice Exercise 5.1

Hold an object at arm's length or lay it on a flat surface. Close one eye, then view the object such that your line of sight is perpendicular to a major feature, such as a flat side. Concentrate on the outside edges of the object and sketch what you see. Move your line of sight 90 degrees, or rotate the object 90 degrees, and sketch what you see. This process will show you the basic procedure necessary to create the six principal views.

5.4.1 Conventional View Placement

The three-view multiview drawing is the standard used in engineering and technology because many times the other three principal views are mirror images and do not add to the knowledge about the object. The standard views used in a three-view drawing are the *top, front,* and *right side* views, arranged as shown in Figure 5.19. The width dimensions are aligned between the front and top views, using vertical projection lines. The height dimensions are aligned between the front and profile views, using horizontal projection lines. Because of the relative positioning of the three views, the depth dimension cannot be aligned using projection lines. Instead, the depth dimension is measured in either the top or right side view and transferred to the other view, using either a scale, miter line, compass, or dividers (Figure 5.19).

The arrangement of the views may only vary as shown in Figure 5.20. The right side view can be placed adjacent to the top view because both views share the depth dimension. Note that the side view is rotated so that the depth dimension in the two views is aligned.

that did not have much appeal to those who would have benefited most from his work. Toward the end of his life he wrote a book on geometry that was mainly a summary of what was already known but did contain some interesting drawings. In this book were elementary drawings such as sections through cones and the principles of orthographic projection.

Dürer began another series of books on geometry titled *The Four Books on Human Proportions,* published posthumously in 1528. For this book he made careful measurements of the proportions of human figures, then averaged them before recording his findings. The problem he faced was how to graphically represent these human proportions. Dürer chose to use orthogonal multiview drawings to represent human proportions as shown in Figure 1. His drawings bear a lot of similarity to multiview drawings used today, but it was very new at his time. Although Dürer demonstrated the usefulness of orthogonal multiview drawings, they were not widely practiced until Gaspard Monge refined this projection system in 1795.

Excerpted from *The History of Engineering Drawing,* by Jeffrey Booker, Chatto & Windus, London, England, 1963.

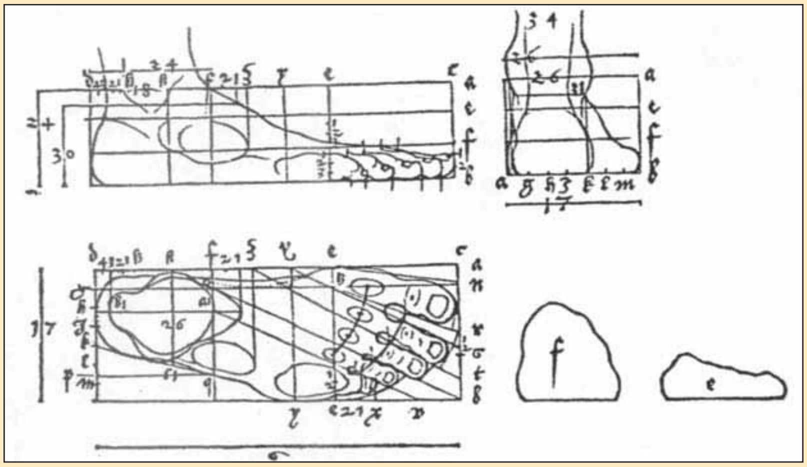


Figure 1 Continued

(B) A foot defined in terms of its three orthographic projections systematically arranged. Notice that Dürer arranged these in "first angle" while his heads in (A) are in "third angle." The two shapes "f" and "e" to the right are vertical sections through the foot at *f* and *e* in the elevation and plan.

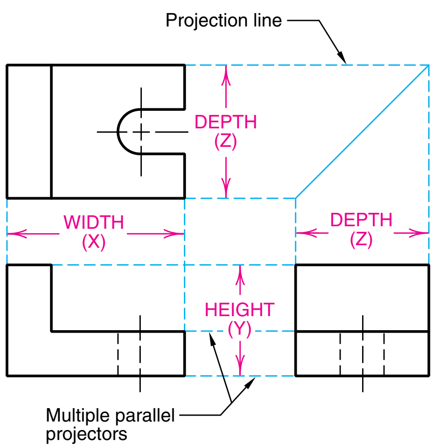


Figure 5.19

Three space dimensions

The three space dimensions are width, height, and depth. A single view on a multiview drawing will only reveal two of the three space dimensions. The 3-D CAD systems use X, Y, and Z to represent the three dimensions.

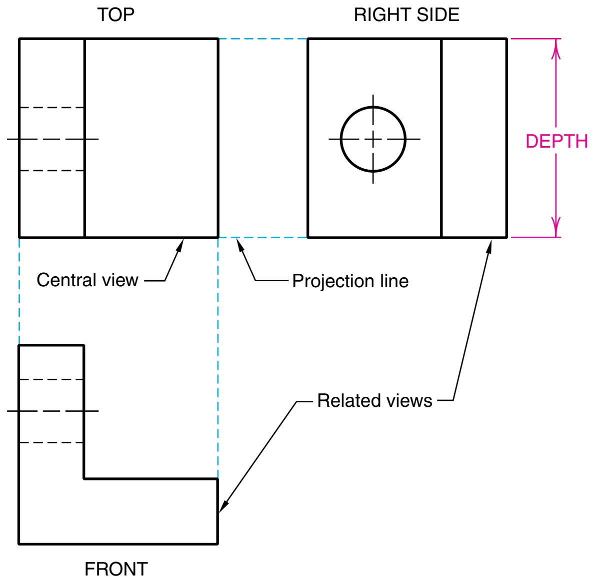
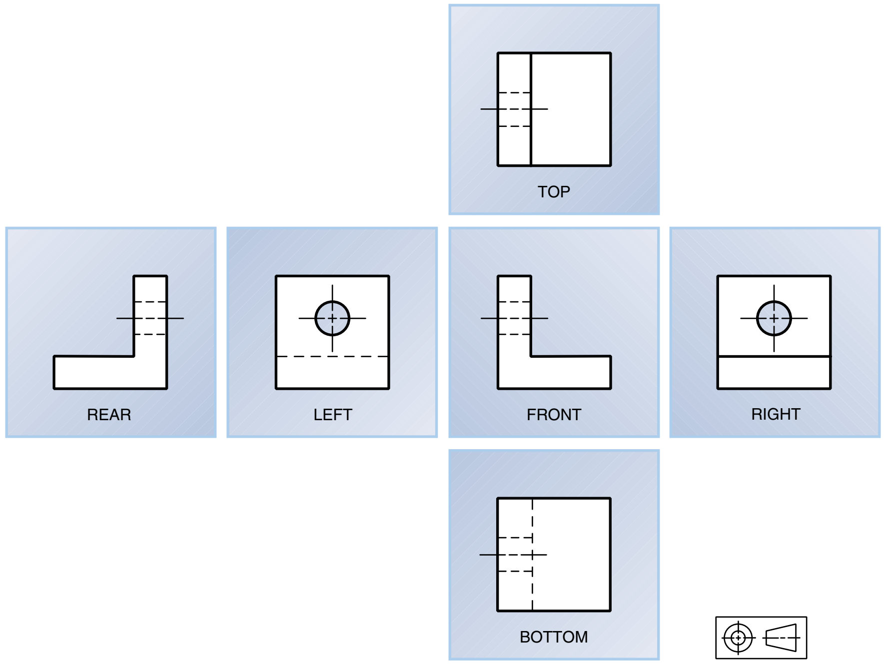


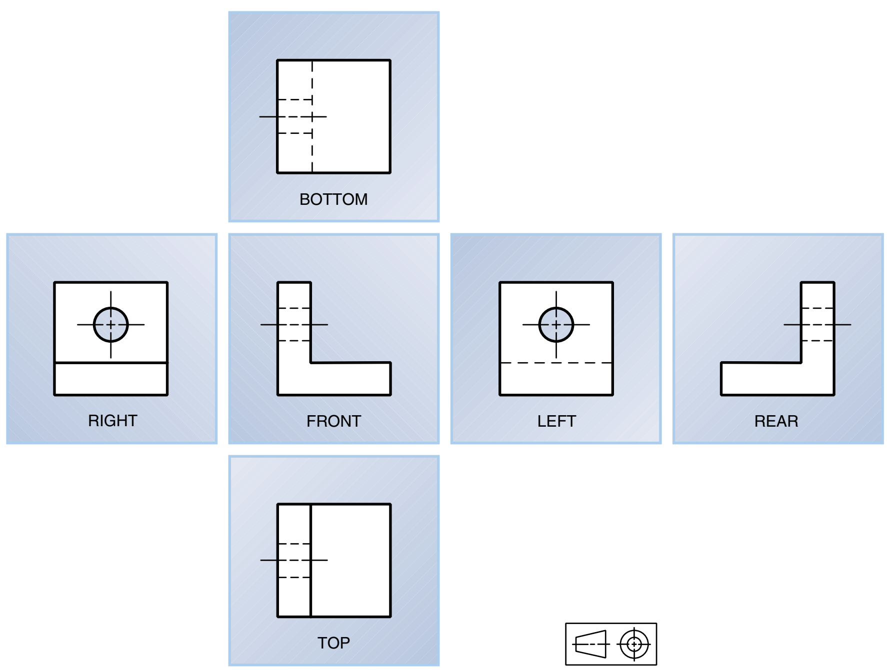
Figure 5.20

Alternate view arrangement

In this view arrangement, the top view is considered the central view.



(A) U.S. Standard Third Angle Projection



(B) ISO Standard First Angle Projection

Figure 5.21

Standard arrangement of the six principal views for third- and first-angle projection

Third- and first-angle drawings are designated by the standard symbol shown in the lower right corner of parts (A) and (B). The symbol represents how the front and right-side views of a truncated cone would appear in each standard.

5.4.2 First- and Third-Angle Projection

Figure 5.21A shows the standard arrangement of all six views of an object, as practiced in the United States and Canada. The ANSI standard third-angle symbol shown in the figure commonly appears on technical drawings to denote that the drawing was done following **third-angle projection** conventions. Europe and some other countries use the **first-angle projection** and a different symbol, as shown in Figure 6.21B. To understand the difference between first- and third-angle projection, refer to Figure 5.22, which shows the *orthogonal planes*. Orthographic projection can be described using these planes. If the first quadrant is used for a multiview drawing, the results will be very different from those of the third quadrant (Figure 5.23). Familiarity with both first- and third-angle projection is valuable because of the global nature of business in our era. As an example, Figure 5.24 shows an engineering drawing produced in the United States for a German-owned company, using first-angle projection.

5.4.3 Adjacent Views

Adjacent views are two orthographic views placed next to each other such that the dimension they share in common is aligned, using parallel projectors. The top and front views share the width dimension; therefore, the top view is placed directly above the front view, and vertical parallel projectors are used to ensure alignment of the shared width dimension. The right side and front views share the height dimension; therefore, the right side view is placed directly to the right of the front view, and horizontal parallel projectors are used to ensure alignment of the shared height dimension.

The manner in which adjacent views are positioned illustrates the first rule of orthographic projection: Every point or feature in one view must be aligned on a parallel projector in any adjacent view. In Figure 5.25, the hole in the block is an example of a feature shown in one view and aligned on parallel projectors in the adjacent view.

Principles of Orthographic Projection Rule 1:
Alignment of Features
Every point or feature in one view must be aligned on a parallel projector in any adjacent view.

The distance *between* the views is not fixed, and it can vary according to the space available on the paper and the number of dimensions to be shown.

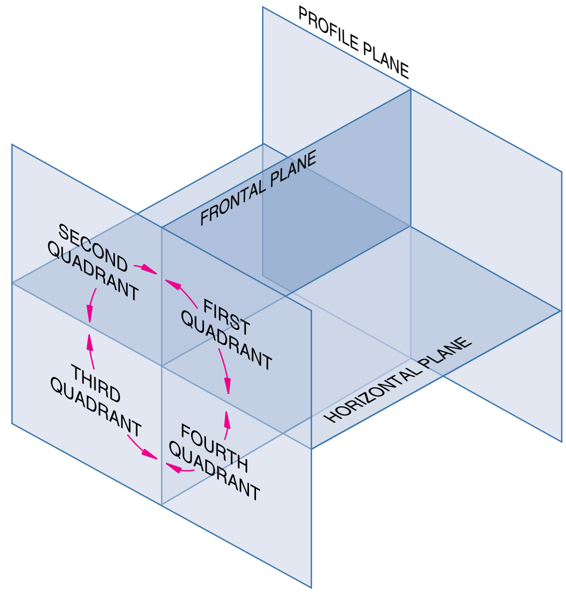


Figure 5.22

The principal projection planes and quadrants used to create first- and third-angle projection drawings
These planes are used to create the six principal views of first- and third-angle projection drawings.

5.4.4 Related Views

Two views that are adjacent to the same view are called **related views;** in related views, distances between common features are equal. In Figure 5.25, for example, the distance between surface 1 and surface 2 is the same in the top view as it is in the right side view; therefore, the top and right side views are related views. The front and right side views in the figure are also related views, relative to the top view.

Principles of Orthographic Projection Rule 2:
Distances in Related Views
Distances between any two points of a feature in related views must be equal.

5.4.5 Central View

The view from which adjacent views are aligned is the **central view.** In Figure 5.25, the front view is the central view. In Figure 5.20, the top view is the central view. Distances and features are projected or measured from the central view to the adjacent views.

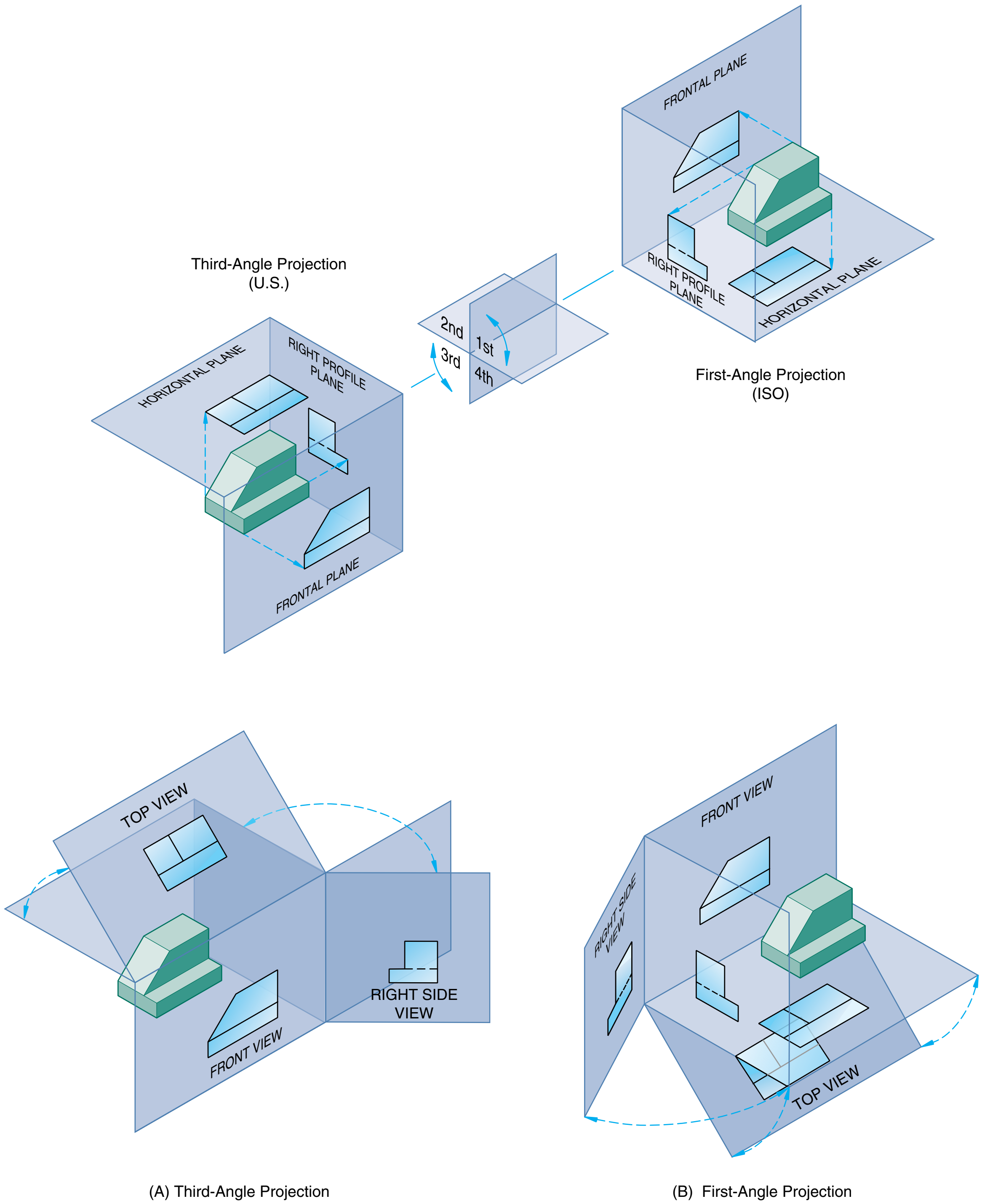


Figure 5.23

Pictorial comparison between first- and third-angle projection techniques

Placing the object in the third quadrant puts the projection planes between the viewer and the object. When placed in the first quadrant, the object is between the viewer and the projection planes.

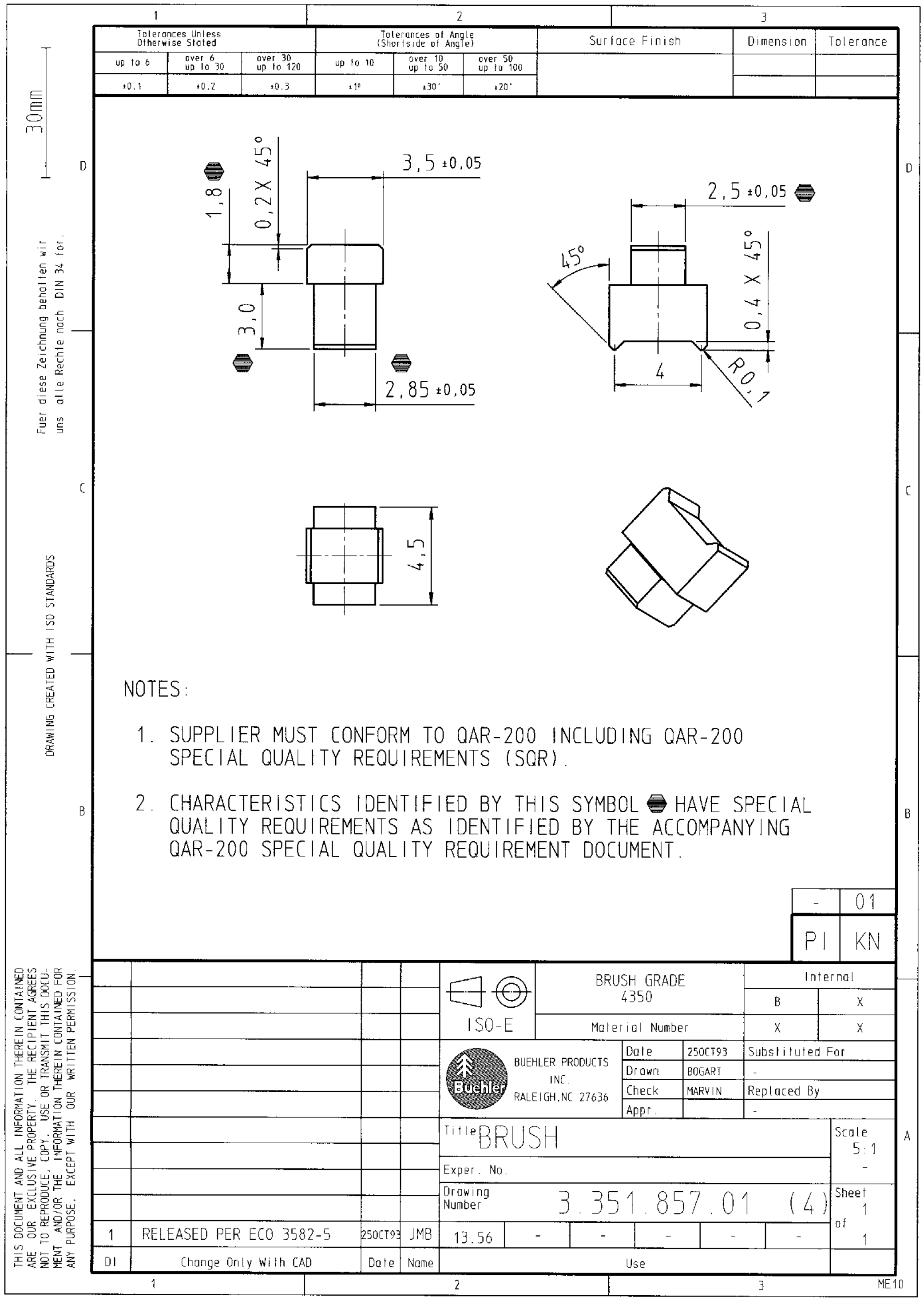


Figure 5.24

First-angle projection engineering drawing produced in the United States for a European company

(Courtesy of Buehler Products, Inc.)

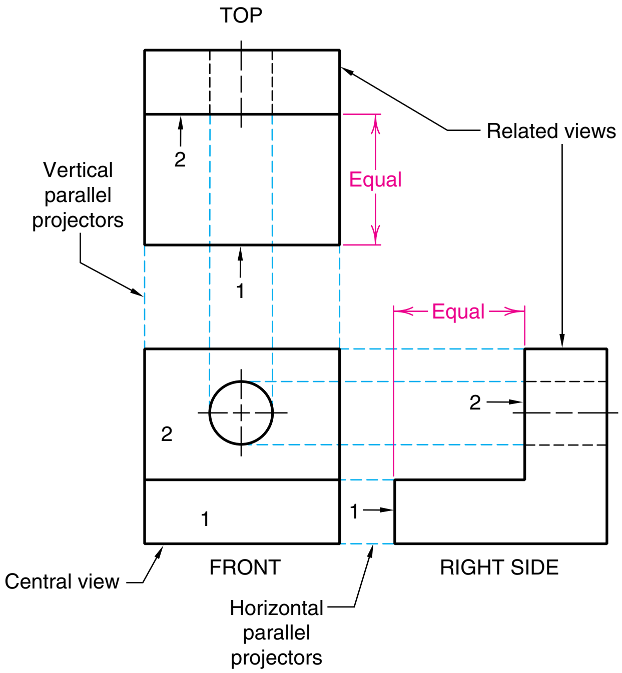


Figure 5.25

Alignment of views

Three-view drawings are aligned horizontally and vertically on engineering drawings. In this view arrangement, the front view is the central view. Also notice that surfaces 1 and 2 are the same distance apart in the related views: top and right side.

5.4.6 Line Conventions

The **alphabet of lines** is discussed and illustrated in detail in Chapter 1, Section 1.6, "Alphabet of Lines."

Because hidden lines and center lines are critical elements in multiview drawings, they are briefly discussed again in the sections that follow.

Hidden Lines In multiview drawings, hidden features are represented as dashed lines, using ANSI standard line types (see Figure 5.26).

Dashed lines are used to represent such hidden features as:

Holes—to locate the limiting elements.
Surfaces—to locate the edge view of the surface.
Change of planes—to locate the position of the change of plane or corner.

For example, Figure 5.27 shows dashed lines representing hidden features in the front and top views. The dashed parallel lines in the top and front views represent the limiting elements of the hole drilled through the object but not visible in these views. The hole is visible in the right side view. The single vertical dashed line in the front view represents the hidden edge view of surface C. Surface C is visible in the side view and is on edge in the top and front views.

Most CAD systems do not follow a standard practice for representing hidden lines. The user must decide if the drawn hidden lines effectively communicate the desired information.

Center Lines Center lines are alternating long and short thin dashes and are used for the axes of symmetrical parts and features, such as cylinders and drilled holes (Figure 5.28), for bolt circles (Figure 5.29D), and for paths of motion (Figure 5.29E). Center lines should not terminate at another line or extend between views (Figure 5.29C). Very short, unbroken center lines may be used to represent the axes of very small holes (Figure5.29C).

Some CAD systems have difficulty representing center lines using standard practices. This is especially true of the center lines for circles. Other CAD systems automatically draw the center lines to standards.

One- and Two-View Drawings Some objects can be adequately described with only one view (Figure 5.30). A sphere can be drawn with one view because all views will be a circle. A cylinder or cube can be described with one view if a note is added to describe the missing feature or dimension. Other applications include a thin gasket or a printed circuit board. One-view drawings are used in electrical, civil, and construction engineering.

Other objects can be adequately described with two views. Cylindrical, conical, and pyramidal shapes are examples of such objects. For example, a cone can be described with a front and a top view. A profile view would be the same as the front view (Figure 5.31).

5.5 Multiview Sketches

Multiview drawings can have from one to three or more views of an object. However, multiview sketches rarely have more than three views.

Multiview sketches are important in that they provide more accurate geometric information than a pictorial sketch, without requiring the time that a formal multiview drawing would take. If dimensions are provided, they are usually only for a particular feature(s) and are often only approximations, since these sketches are used early in the design process before final specifications have been made.

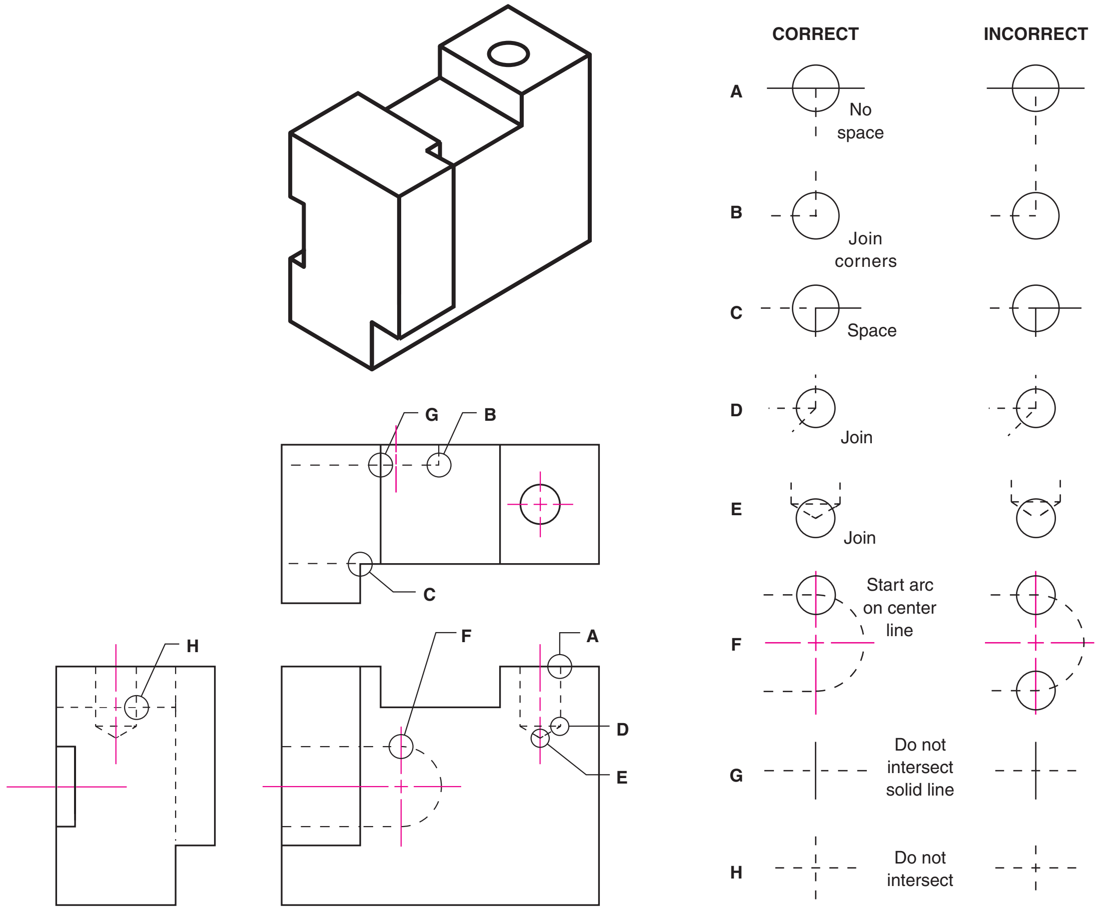


Figure 5.26

Drawing conventions for hidden lines

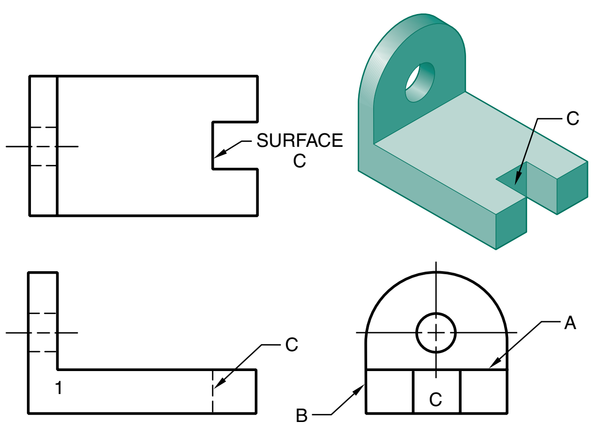


Figure 5.27

Hidden features

The dashed lines on this drawing indicate hidden features. The vertical dashed line in the front view shows the location of plane C. The horizontal dashed lines in the front and top views show the location of the hole.

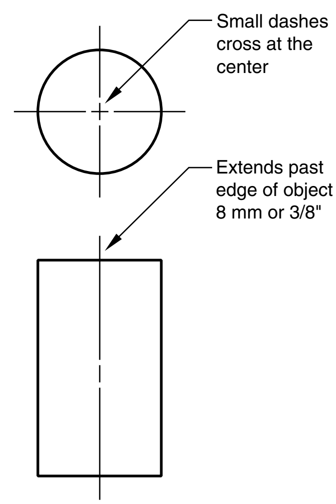


Figure 5.28

Center lines

Center lines are used for symmetrical objects, such as cylinders. Center lines should extend past the edge of the object by 8 mm or $\frac{3}{8}''$.

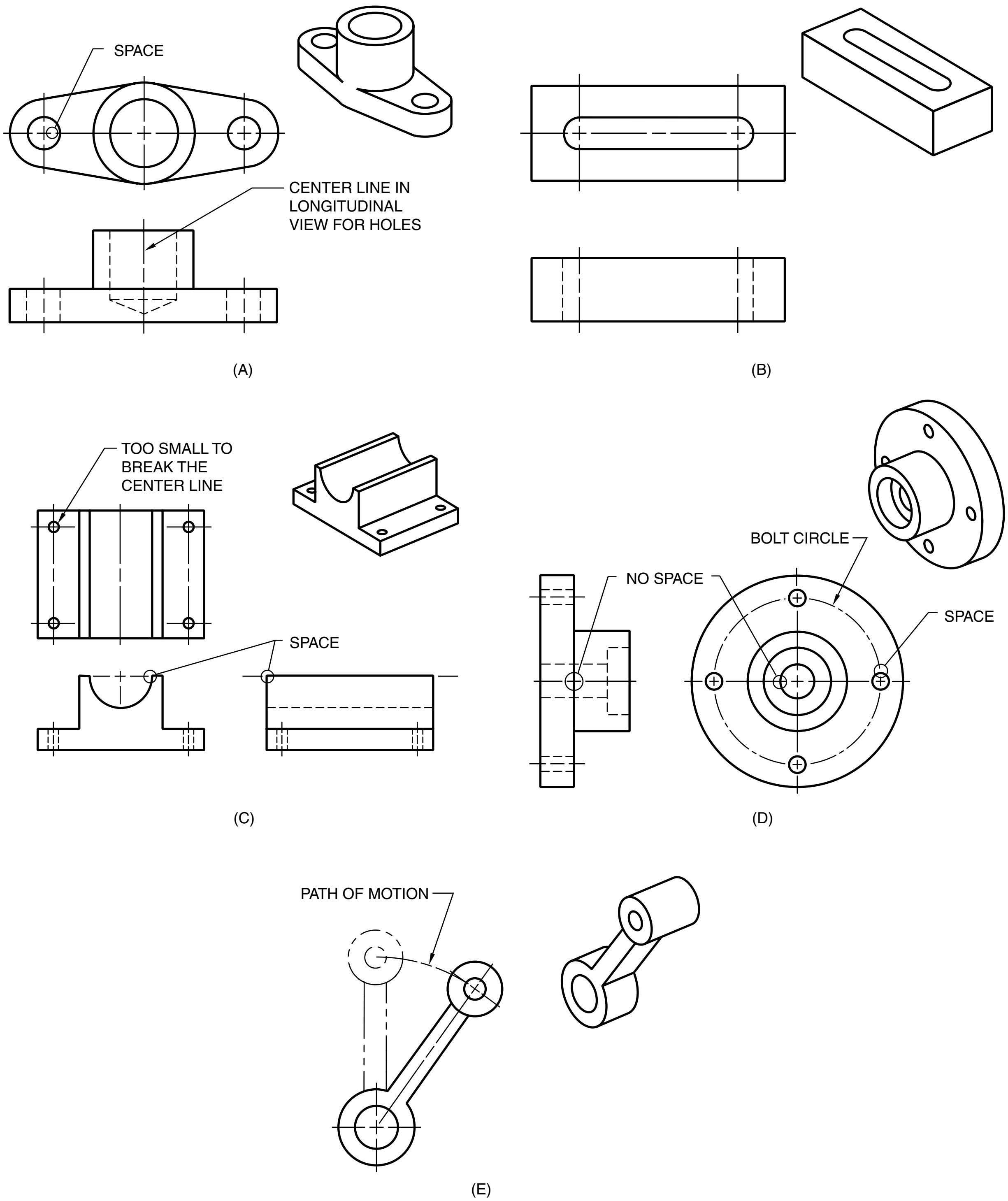


Figure 5.29

Standard center line drawing practices for various applications

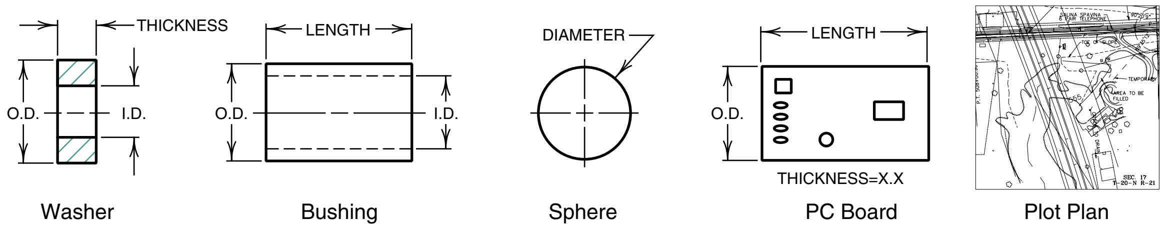


Figure 5.30

One-view drawings

Applications for one-view drawings include some simple cylindrical shapes, spheres, thin parts, and map drawings.

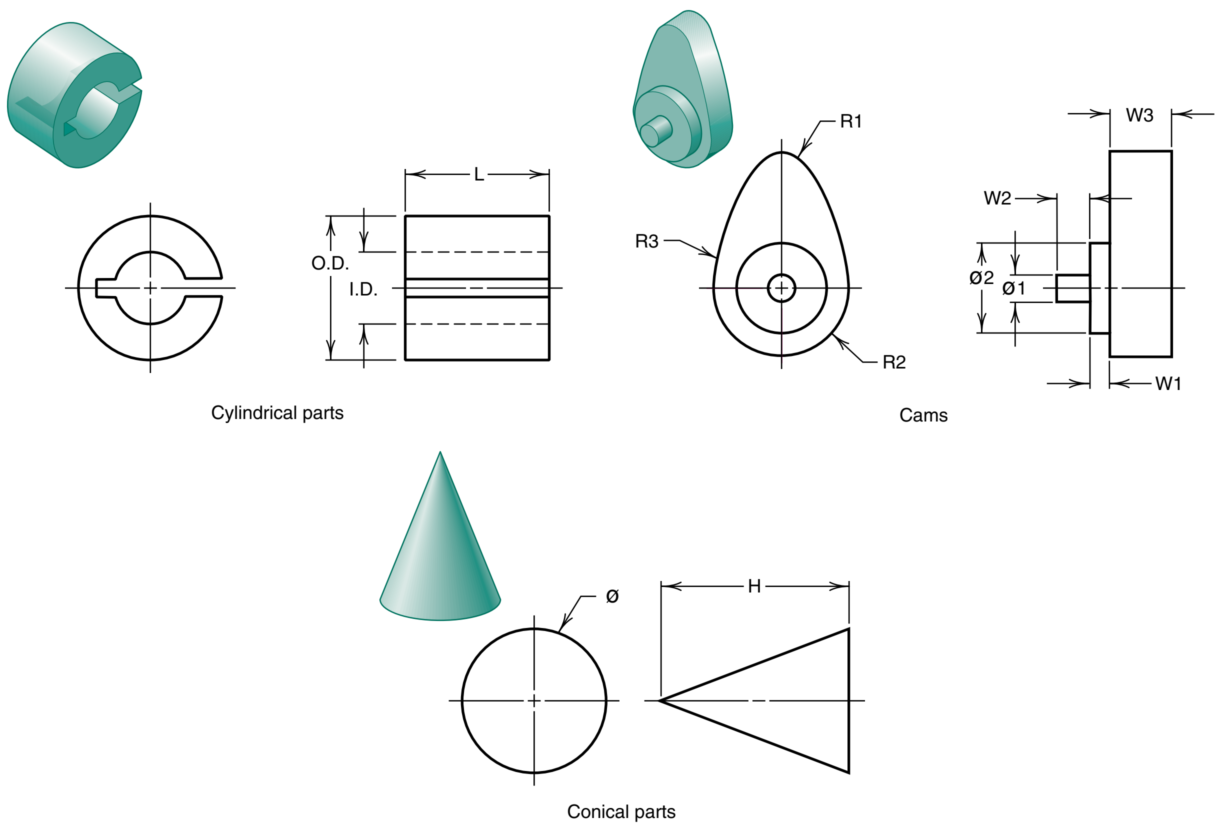


Figure 5.31

Two-view drawings

Applications for two-view drawings include cylindrical and conical shapes.

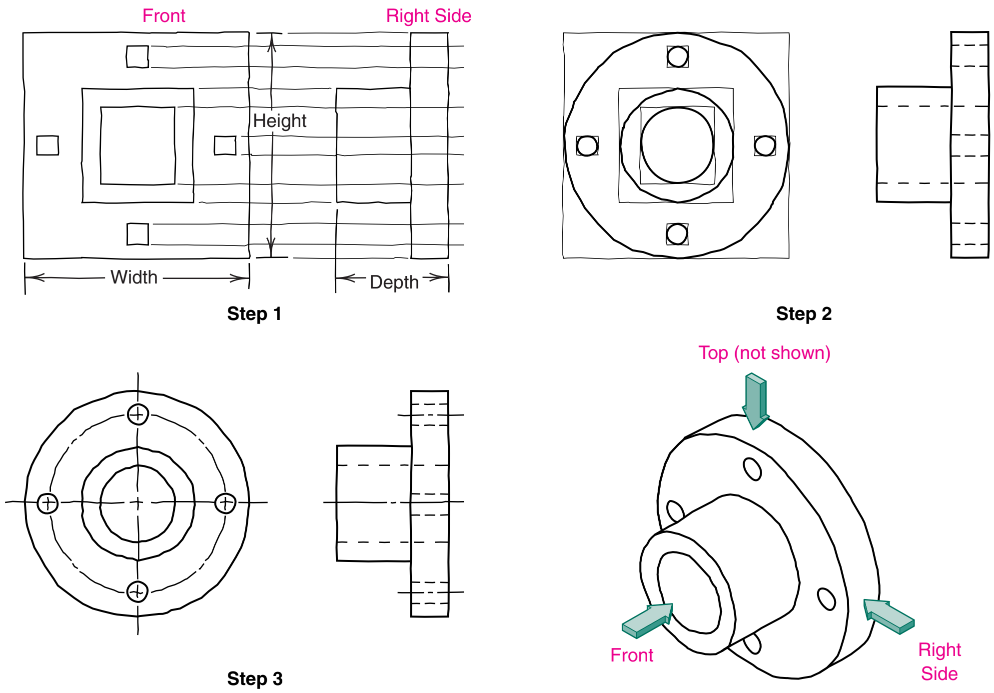


Figure 5.32

Creating a two-view sketch

A two-view sketch is created by blocking in the details, then adding center lines, circles, arcs, and hidden lines.

As is the goal with all sketches, multiview sketches should be done quickly and clearly. Straightedges, such as triangles and T-squares, should be avoided since they will only slow you down and will compel you toward a level of finish that is inappropriate in sketches. In addition, you should draw only as many views as are necessary to show the features accurately. An initial analysis of the features should tell you if one, two, or three views are needed to clearly show the elements of interest.

5.5.1 One-View Sketches

The simplest multiview sketch represents just the front view of an object. Though not truly a *multiview,* it is still meant to represent only two dimensions of the object, which is the basic concept of multiview drawings. This sketch can be produced using the techniques shown in Chapter 2.

5.5.2 Two-View Sketches

Occasionally, an object can be completely described using only two views. As an example, Figure 5.32 shows a symmetrical part that can be described using two views. If the front view is as shown in the pictorial, the top and side views would be the same. Nothing would be gained by drawing both the top and side views, so only one of these views is sketched.

Step by Step: Creating a Two-View Sketch

Figure 5.32 and the following steps describe how to create a two-view sketch.

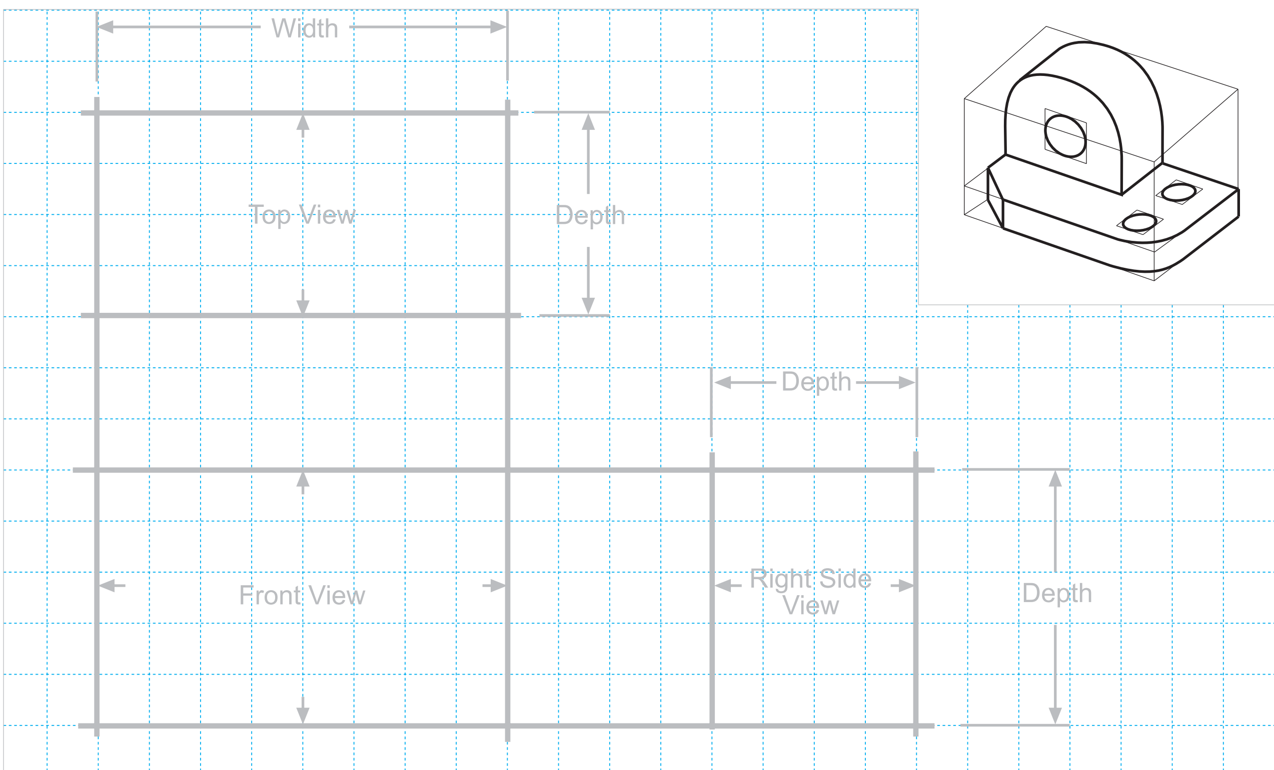
Step 1. In the front view, block in the squares with sides equal to the diameters of the circles. Since both the front and right side views show the height dimension, construction lines can be used to project the height of the squares onto the right side view. Block in the rectangles representing the details for the side view.

Step 2. Using the squares and center lines as guides, sketch the circles for each hole and the cylinder, in the front view. Using the construction lines as guides, sketch the hidden lines for the holes, in the side view.

Step 3. Darken all visible, center, and hidden lines.

Practice Problem 5.1

Create a three-view sketch of the object using the grid. The front, top, and right side views have been blocked in for you.



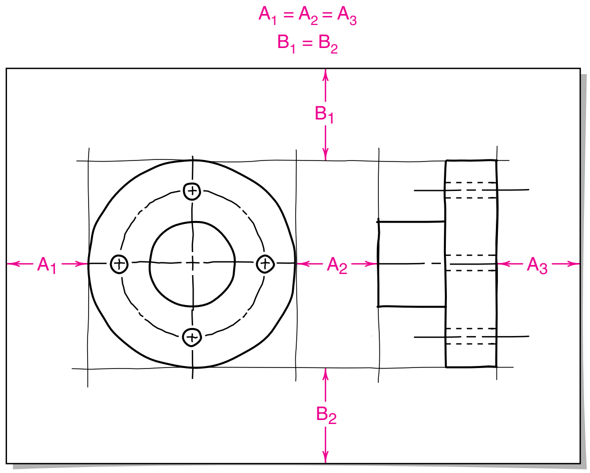


Figure 5.33

Centering a two-view sketch

A two-view sketch is centered on a sheet of paper by equally dividing the areas between and around the views.

Scale and locate the views on the drawing so that there is approximately equal spacing between the two views and between each view and the edge of the paper (Figure 5.33). Normally, if the front and right side views are used, the paper is oriented so that the long dimension runs horizontally; if the front and top views are used, the long dimension of the paper runs vertically. There are exceptions to this if the object has particularly extreme proportions. Remember that the top view is *always* aligned with and placed above the front view, and the right side view is *always* aligned with and placed to the right of the front view. *Do not* rearrange the views just to fit them on the paper.

5.5.3 Three-View Sketches

When an object is more complex, three views are needed. The object used in Figure 5.34 was chosen because it has many of the most common features you will be sketching, such as holes, arcs, lines, and planes.

Step by Step: Creating a Three-View Sketch

Figure 5.34 and the following steps show how to create a three-view sketch.

Step 1. Begin by blocking in the front, top, and right side views of the object, using the overall width, height, and depth. Sketch the front view first, then use construction lines to project the width dimension from the front view to the top view. Also, use construction lines to project the height dimension from the front view to the right side view. Leave room between the views so the sketch does not look crowded; there should be room to add text for notes and dimensions. The spaces between views should be approximately the same. Make sure the depth dimension is equal in the top and side views by measuring the distance using a scale or dividers.

Step 2. Lightly block in the major features seen in each view. For example, the drilled holes are blocked in on the views where they look round. The angled edge and the rounded corner are most clearly seen in the top view. Begin darkening these major features.

Step 3. Quite often, features will appear in two and sometimes all three of the views, and construction lines can be used to project the location or size of a feature from one view to another. Remember that each view always shares one dimension with an adjoining view. The depth dimension can be shared between the top and right side view with a special construction line called a **miter line.** The miter line is drawn at a 45-degree angle and is used as a point of intersection for lines coming to and from the right side and top views. For example, the width of a hole in the top view can be projected down to the front view. Then the location of the hole can be passed across the miter line to the right side view.

Step 4. Finish adding the rest of the final lines. Be careful to do all hidden lines and center lines for the holes. Darken all final lines.

5.5.4 Multiviews from 3-D CAD Models

The computer screen can be used as a projection plane displaying the 2-D image of a 3-D CAD model. The user can control the line of sight and the type of projection (parallel or perspective). Most 3-D CAD software programs have automated the task of creating multiview drawings from 3-D models. With these CAD systems, the 3-D model of the object is created first. Most CAD programs have predefined viewpoints that correspond to the six principal views (Figure 5.35). The views that will best represent the object in multiview are selected, the viewpoint is changed, a CAD command converts the projection of the 3-D model into a 2-D drawing, and the first view is created (Figure 5.36). This view is then saved as a block or symbol. The second view is created by changing the viewpoint again and then converting the new projection to a 2-D drawing

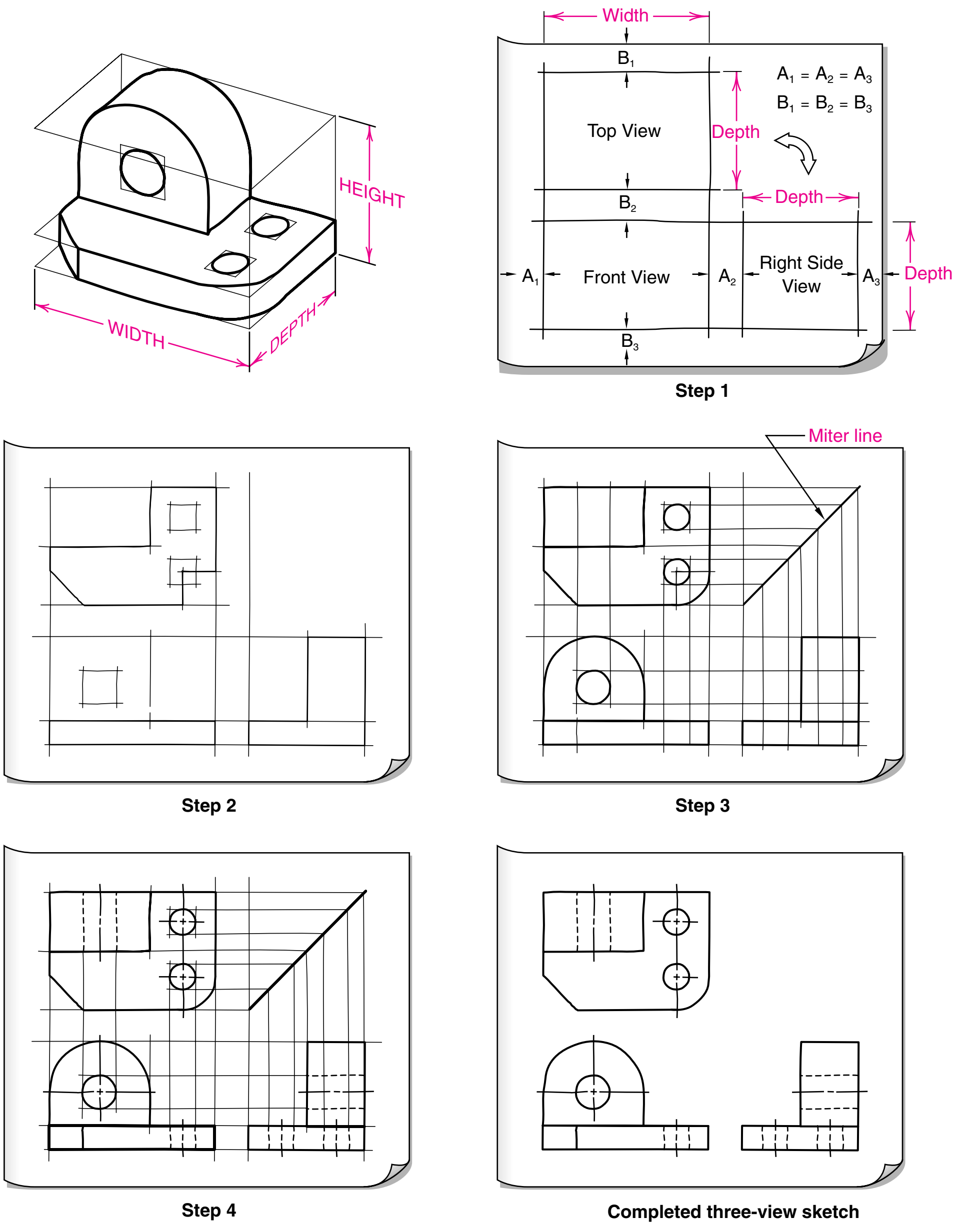


Figure 5.34

Creating a three-view sketch

A three-view sketch is created by blocking in the overall width, height, and depth dimensions for each view, then blocking in the details, using a miter line to transfer depth dimensions between the top and side views, and then adding the final details, such as circles, arcs, center lines, and hidden lines.

of the object (Figure 5.37). These steps are repeated for as many views as are necessary for the multiview drawing.

After the required number of 2-D views are created, the views are arranged on a new drawing by retrieving the blocks or symbols created earlier. Care must be taken to bring the views in at the proper scale and correct alignment. The views must then be edited to change solid lines to hidden lines and to add center lines. Other changes may be required so that the views are drawn to accepted standards (Figure 5.38).

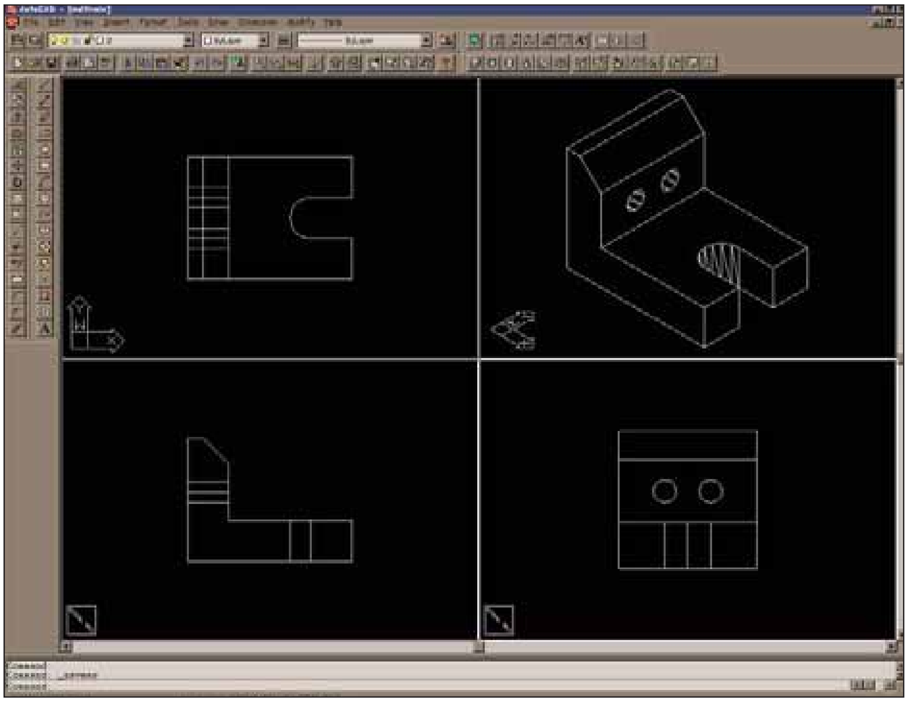


Figure 5.35

Predefined multiviews on a CAD system

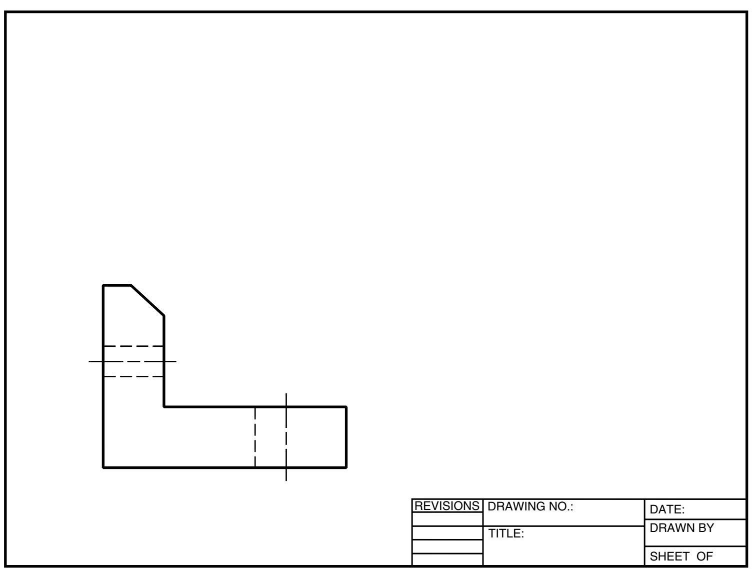


Figure 5.36

Changing the viewpoint on a 3-D CAD model to create a front view

This view is captured, then placed in a title block and border line.

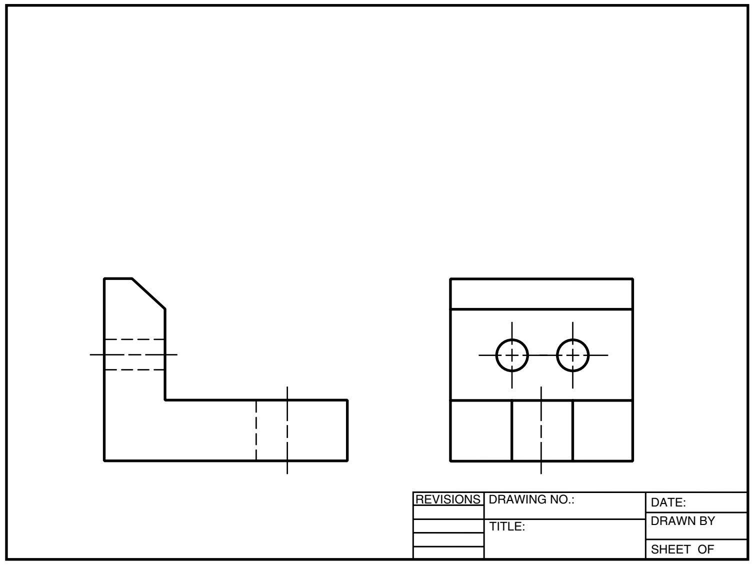


Figure 5.37

Changing the viewpoint on the 3-D model to create a right side view
This view is captured, then placed in a title block and border line.

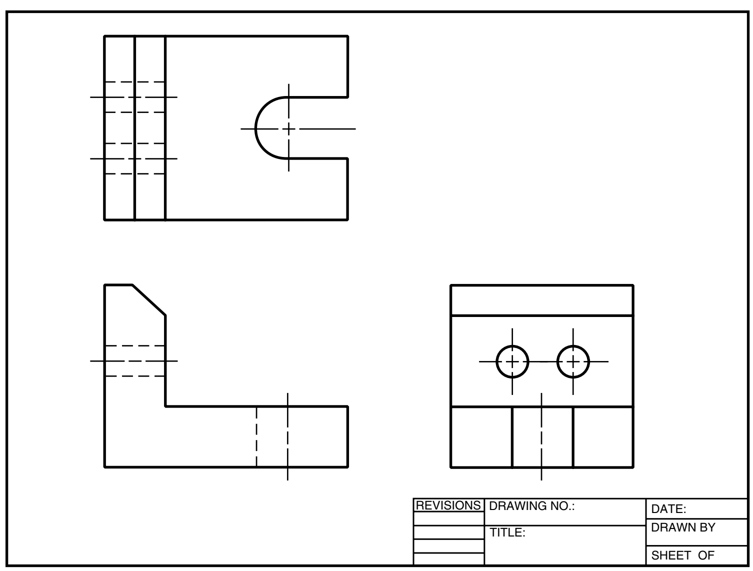


Figure 5.38

Creating a multiview drawing of the 3-D model
The previously captured views are brought together with a standard border and title block to create the final drawing.

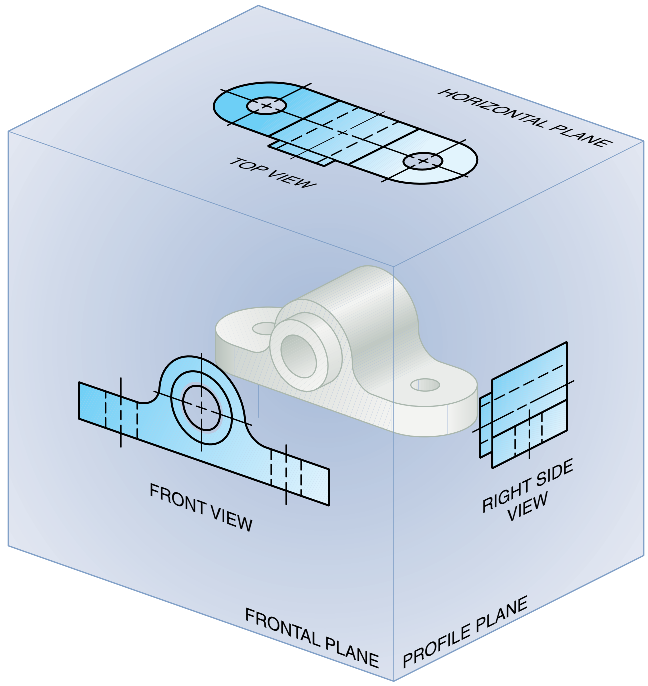


Figure 5.39

Good orientation

Suspend the object in the glass box so that major surfaces are parallel or perpendicular to the sides of the box (projection planes).

5.6 View Selection

Before a multiview drawing is created, the views must be selected. Four basic decisions must be made to determine the best views.

1. Determine the best position of the object. The object must be positioned within the imaginary glass box such that the surfaces of major features are either perpendicular or parallel to the glass planes (Figure 5.39). This will create views with a minimum number of hidden lines. Figure 5.40 shows an example of poor positioning: the surfaces of the object are not parallel to the glass planes, resulting in many more hidden lines.
2. Define the front view. The front view should show the object in its natural or assembled state (Figure 5.41). For example, the front view of an automobile would show the automobile in its natural position, on its wheels.
3. Determine the minimum number of views needed to completely describe the object so it can be produced. For our example, three views are required to completely describe the object (Figure 5.42).
4. Once the front view is selected, determine which other views will have the fewest number of hidden lines. In Figure 5.43, the right side view is selected over the left side view because it has fewer hidden lines.

Practice Exercise 5.2

Using any of the objects in Figure 5.122 in the back of this chapter, generate three multiview sketches. Each sketch should use a different view of the object as the front view. What features of the object become hidden or visible as you change the front view?

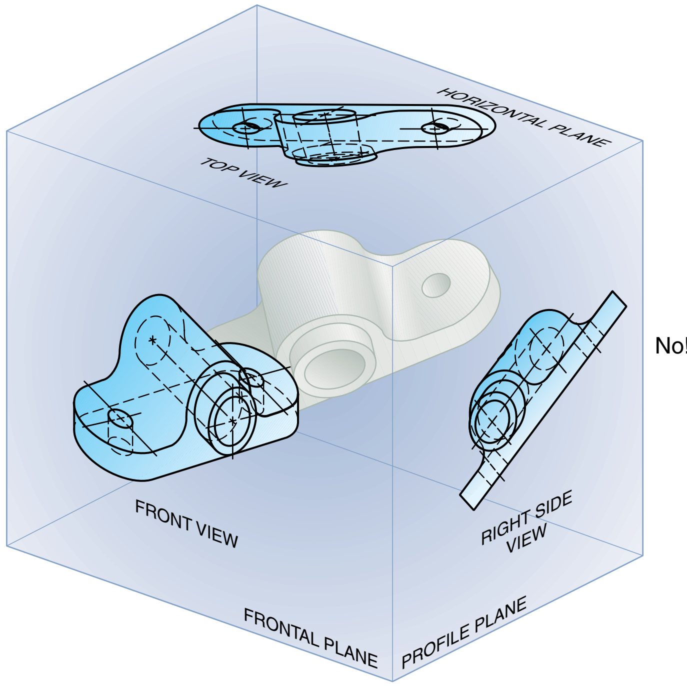


Figure 5.40

Poor orientation

Suspending the object so that surfaces are not parallel to the sides of the glass box produces views with many hidden lines.

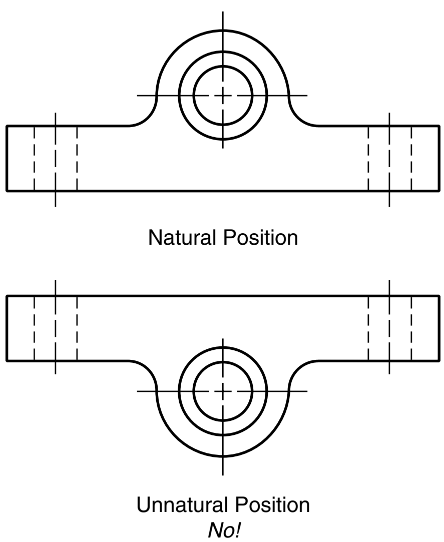


Figure 5.41

Natural position

Always try to draw objects in their natural position.

5.7 Fundamental Views of Edges and Planes for Visualization

In multiview drawings, there are *fundamental views* for edges and planes. These fundamental views show the edges or planes in true size, not foreshortened, so that true measurements of distances, angles, and areas can be made.

5.7.1 Edges (Lines)

An **edge,** or *corner,* is the intersection of two planes, and is represented as a line on multiview drawings. A **normal line,** or **true-length line,** is an edge that is parallel to a plane of projection and thus perpendicular to the line of sight. In Figure 5.44, edge 1–2 in the top and right side views is a normal edge.

> Principles of Orthographic Projection Rule 3:
> ***True Length and Size***
> Features are true length or true size when the lines of sight are perpendicular to the feature.

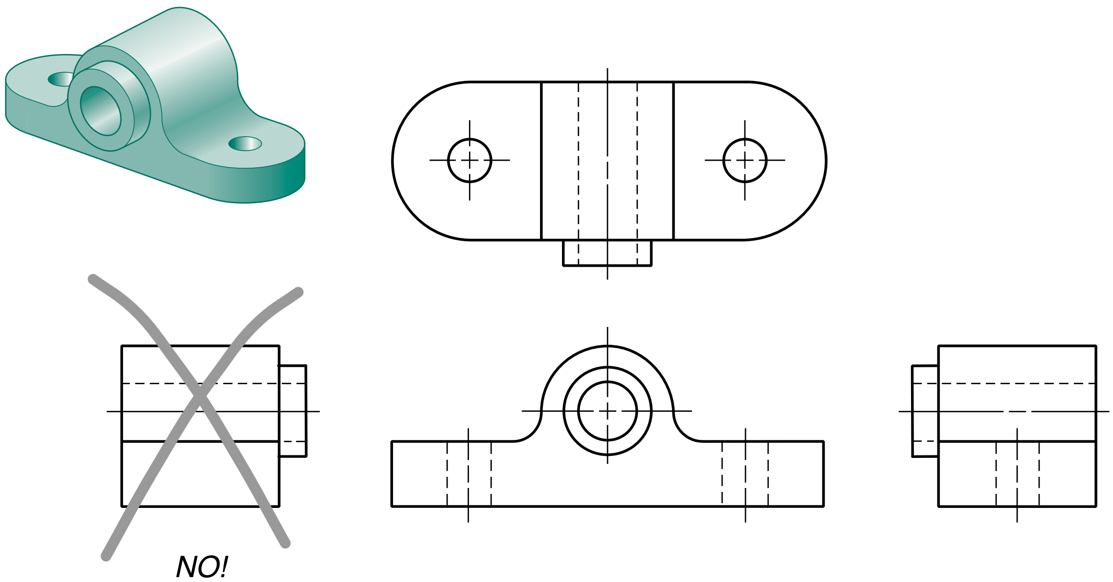


Figure 5.42

Minimum number of views

Select the minimum number of views needed to completely describe an object. Eliminate views that are mirror images of other views.

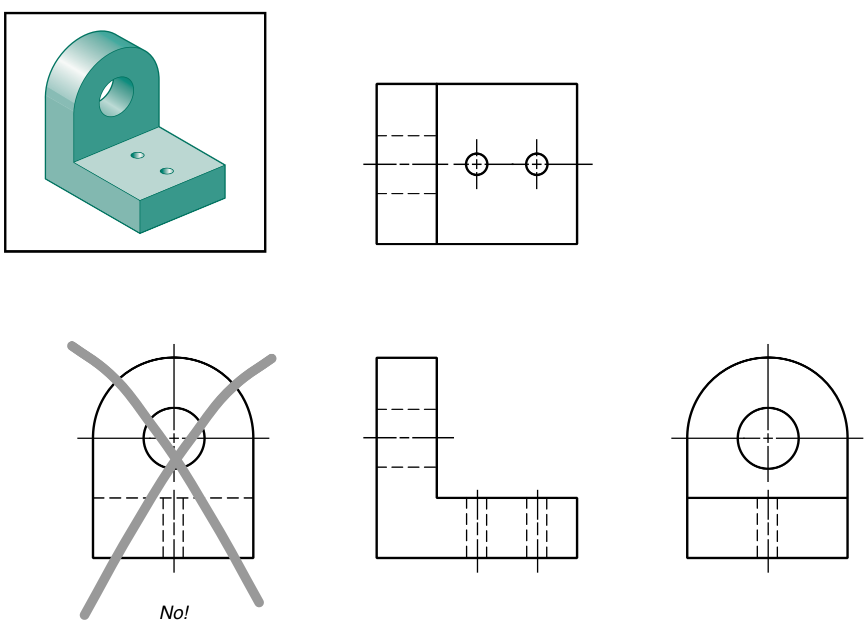


Figure 5.43

Most descriptive views

Select those views that are the most descriptive and have the fewest hidden lines. In this example, the right side view has fewer hidden lines than the left side view.

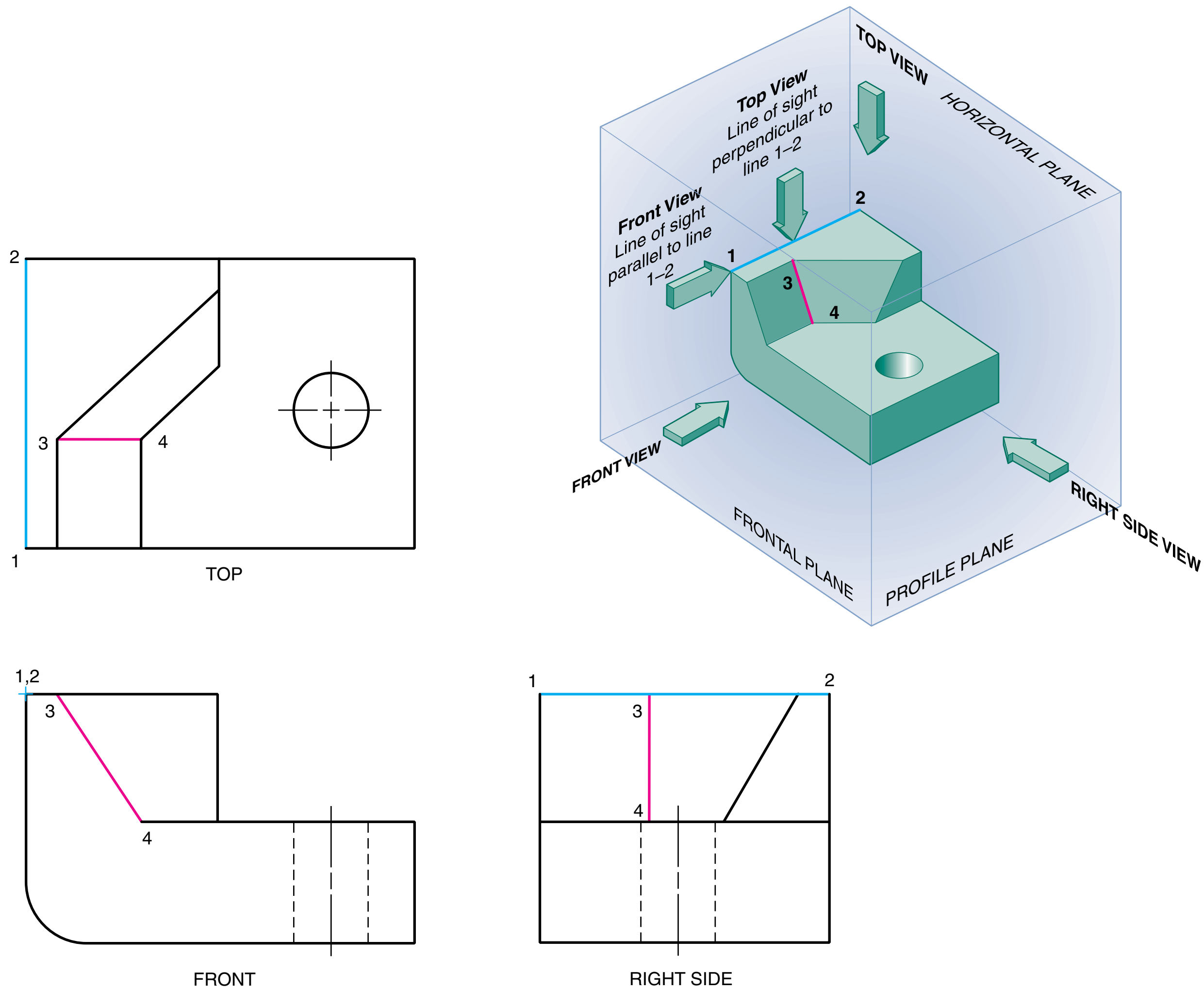


Figure 5.44

Fundamental views of edges

Determine the fundamental views of edges on a multiview drawing by the position of the object relative to the current line of sight and the relationship of the object to the planes of the glass box.

An edge appears as a point in a plane of projection to which it is perpendicular. Edge 1–2 is a point in the front view of Figure 5.44. The edge appears as a point because it is parallel to the line of sight used to create the front view.

An **inclined line** is parallel to a plane of projection, but inclined to the adjacent planes, and it appears foreshortened in the adjacent planes. In Figure 5.44, line 3–4 is inclined and foreshortened in the top and right side views, but true length in the front view, because it is parallel to the frontal plane of projection.

An **oblique line** is not parallel to any principal plane of projection; therefore, it never appears as a point or in true length in any of the six principal views. Instead, an oblique edge will be foreshortened in every view and will always appear as an inclined line. Line 1–2 in Figure 5.45 is an oblique edge.

Principles of Orthographic Projection Rule 4:
Foreshortening
Features are foreshortened when the lines of sight are not perpendicular to the feature.

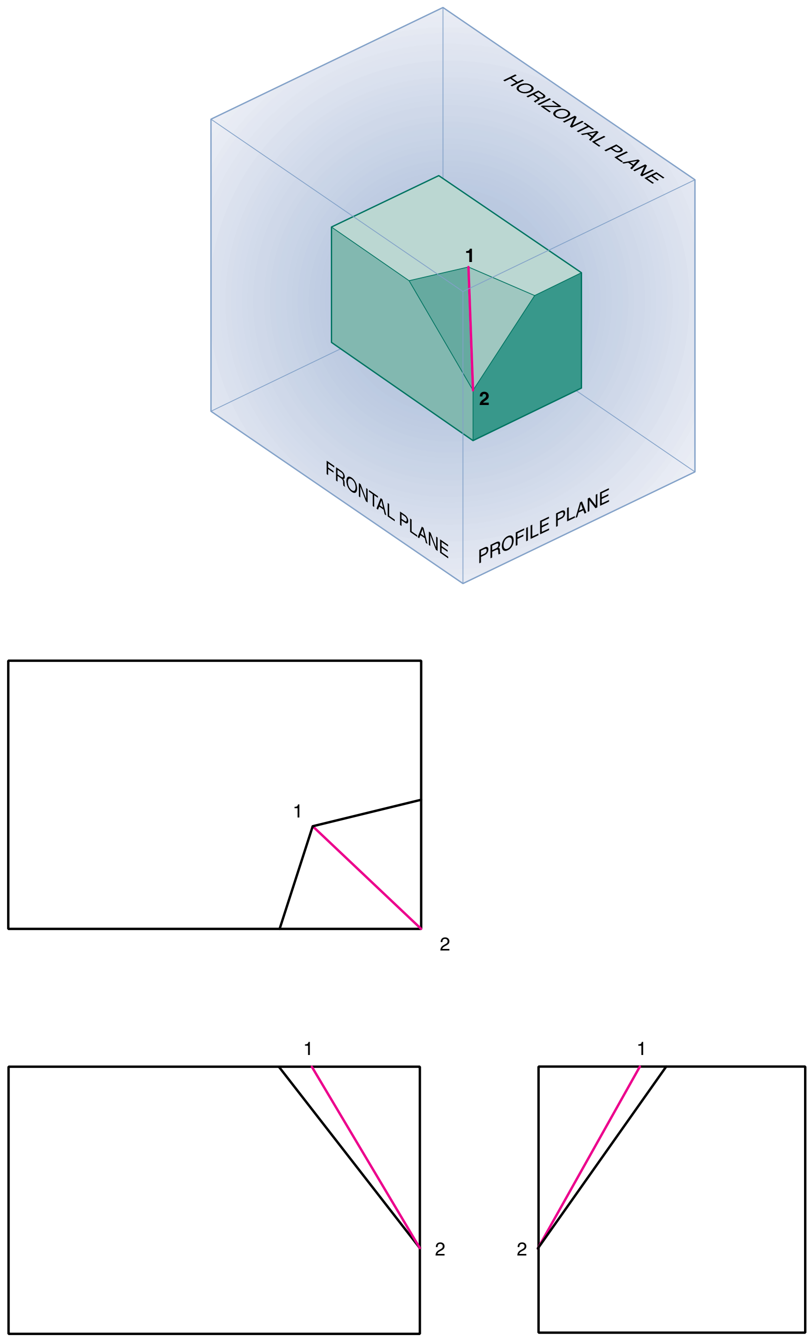


Figure 5.45

Oblique line

Oblique line 1-2 is not parallel to any of the principal planes of projection of the glass box.

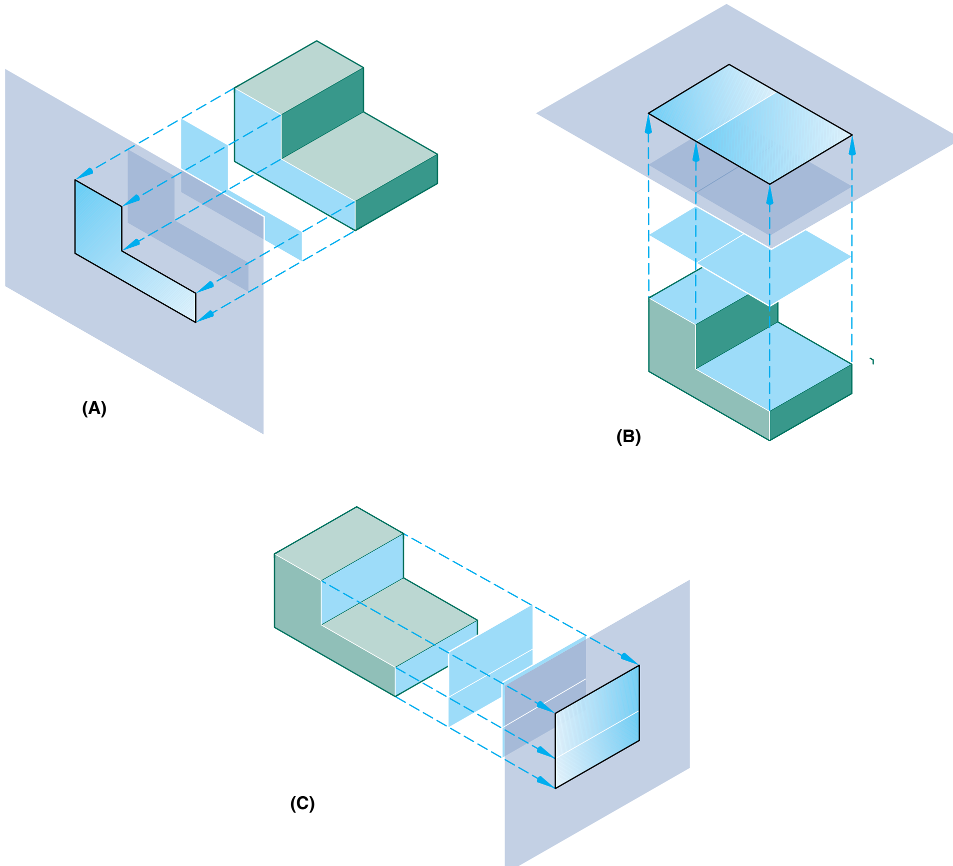


Figure 5.46

Normal faces

Projection of normal faces onto the image plane.

5.7.2 Principal Planes

A **principal plane** is parallel to one of the principal planes of projection and is therefore perpendicular to the line of sight. A principal plane or surface will be true size and shape in the view where it is parallel to the projection plane, and it will appear as a horizontal or vertical line in the adjacent views. In Figure 5.46A, the surface is parallel to the frontal projection plane and is therefore a principal plane. Because the surface appears true size and shape in the front view, it is sometimes referred to as a **normal plane.** This surface also appears as a horizontal edge in the top view and as a vertical edge in the right side view (Figure 5.47). This edge representation is an important characteristic in multiview drawings (Figure 5.48). Principal planes are categorized by the view in which the plane appears true size and shape: frontal, horizontal, or profile (Figure 5.49).

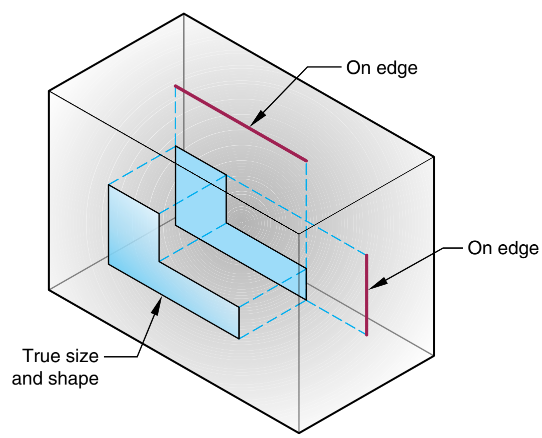


Figure 5.47

Normal face projection

A normal face projects on all three principal image planes. On one image plane, the face appears true size and shape. In the other two, the face appears on edge and is represented as a line.

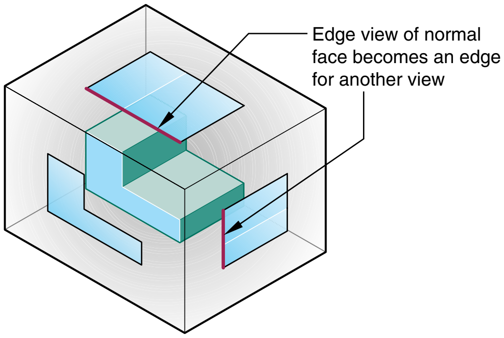


Figure 5.48

Edge views of normal face

In a multiview projection, edge views of a normal face become the outlines of another face.

Practice Exercise 5.3

Replace the object on the other side of your image plane with a stiff sheet of cardboard representing a single face of an object. Align the cardboard sheet so that it is parallel to the image plane. Ask a second person to hold the cardboard sheet, if necessary. Change your viewing direction, but don't move the cardboard sheet, and look at the sheet as an edge view. Do the same by holding the image plane still and rotating the cardboard sheet. Rotate the cardboard less than 90 degrees about either the horizontal or vertical axis to create an inclined face. Move the image plane around until you can identify the two standard views where the inclined face is visible. Find the view where the face is seen as an edge. How does the amount of rotation affect the size of the projection seen in the image plane? Rotate the cardboard so that it is almost normal to the image plane. How does it look from the three principal views? Do the same tests with the cardboard sheet rotated about both the vertical and horizontal axes, creating an oblique face.

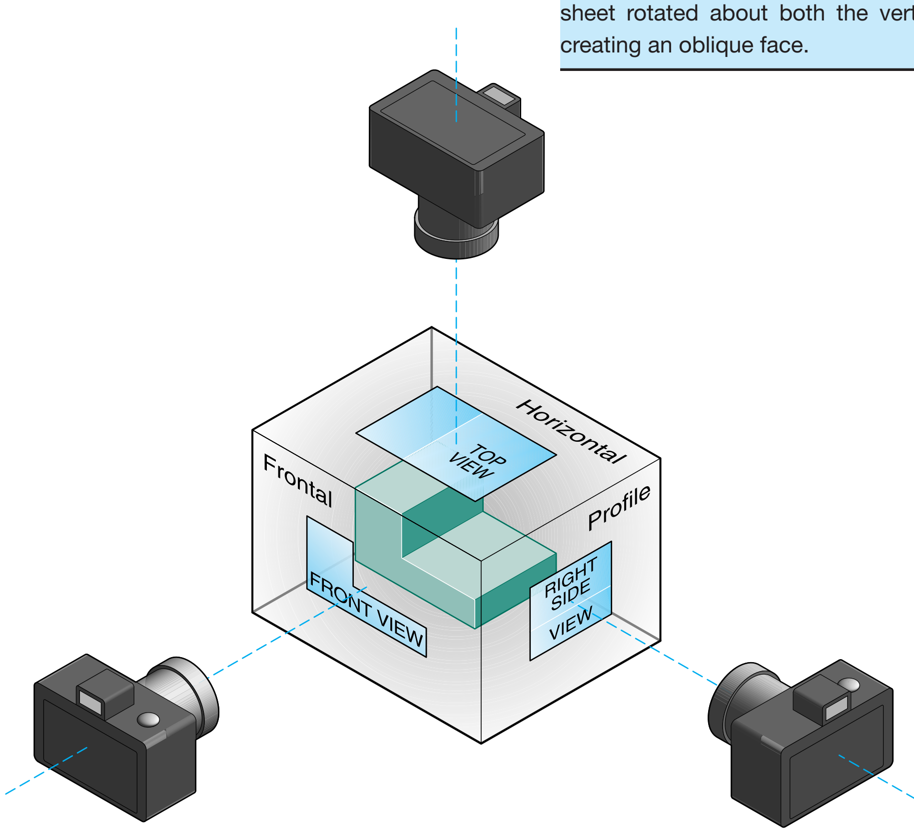


Figure 5.49

Camera metaphor

The metaphor of cameras can be used to describe capturing three principal views of the object—front, top, and right side—through the three image planes.

Practice Exercise 5.4

Two ways to demonstrate an image plane are as follows:

1. Using a camera, take pictures of simple objects under good light. (If you use an instant camera, the exercise can be done immediately.) Look at the object from exactly the same viewpoint as that used when the picture was taken. Make sure the lighting is also the same. On the photograph, highlight the contours of the object, using water-based markers. Identify different faces of the object by using different colors. Study the results, then use a damp cloth to wipe the picture clean, to be used again.
2. Alternatively, place a 12″ × 12″ sheet of rigid clear plastic or a cardboard frame with a transparency acetate between you and a well-lit object. Brace the plastic so that you don't have to hold it and draw the contours of the object, using water-based markers. When done, study the results, then use a damp cloth to wipe the plastic clean.

Using each of these techniques, look at the objects from a number of different viewpoints, either by moving yourself or by rotating the object. From which viewpoints can you see the greatest number of contours? Which viewpoints afford the fewest number of contours? What happens when you get closer or farther away?

Practice Exercise 5.5

Use the same setup of object and image plane as you used in the previous exercise. However, instead of drawing directly on the plastic sheet, use it to "frame" your view of the object and draw what you see on a piece of paper. (If you do not have a sheet of clear plastic, make a cardboard frame.) Instead of drawing the edges in perspective, as you see them, draw them in parallel projection (i.e., all edges that are parallel on the object are parallel in the sketch).

Practice Exercise 5.6

Place a 12″ × 12″ sheet of rigid, clear plastic between you and the object. Rotate the object 360 degrees about each of the three axes. Which faces are revealed by each rotation? Are faces always seen in their true size and shape?

A **frontal plane** is parallel to the front plane of projection and is true size and shape in the front view. A frontal plane appears as a horizontal edge in the top view and a vertical edge in the profile views. In Figure 5.46A, the surface is a frontal plane.

A **horizontal plane** is parallel to the horizontal planes of projection and is true size and shape in the top (and bottom) view. A horizontal plane appears as a horizontal edge in the front and side views. In Figure 5.46B, the surface is a horizontal plane.

A **profile plane** is parallel to the profile (right or left side) planes of projection and is true size and shape in the profile views. A profile plane appears as a vertical edge in the front and top views. In Figure 5.46C, the surface is a profile plane.

5.7.3 Inclined Planes

An **inclined plane** is perpendicular to one plane of projection and inclined to adjacent planes, and it cannot be viewed in true size and shape in any of the principal views. An inclined plane appears as an edge in the view where it is perpendicular to the projection plane and as a foreshortened surface in the adjacent views (Figure 5.50). To view an inclined plane in its true size and shape, create an auxiliary view, as described in Chapter 6.

5.7.4 Oblique Planes

An **oblique plane** is not parallel to any of the principal planes of projection (Figure 5.51). An oblique surface does not appear in its true size and shape, or as an edge, in any of the principal views; instead, an oblique plane always appears as a foreshortened plane in the principal views. A secondary auxiliary view must be constructed, or the object must be rotated, in order to create a normal view of an oblique plane.

Of course, most objects will contain a combination of principal (normal), inclined, and oblique surfaces. Figure 5.52 shows an example of an object with a combination of all of these types of surfaces. By carefully tracking a surface between all three principal views, you can identify whether it is projected in true size, foreshortened, or as an edge. In this way, you can determine what type of surface it is.

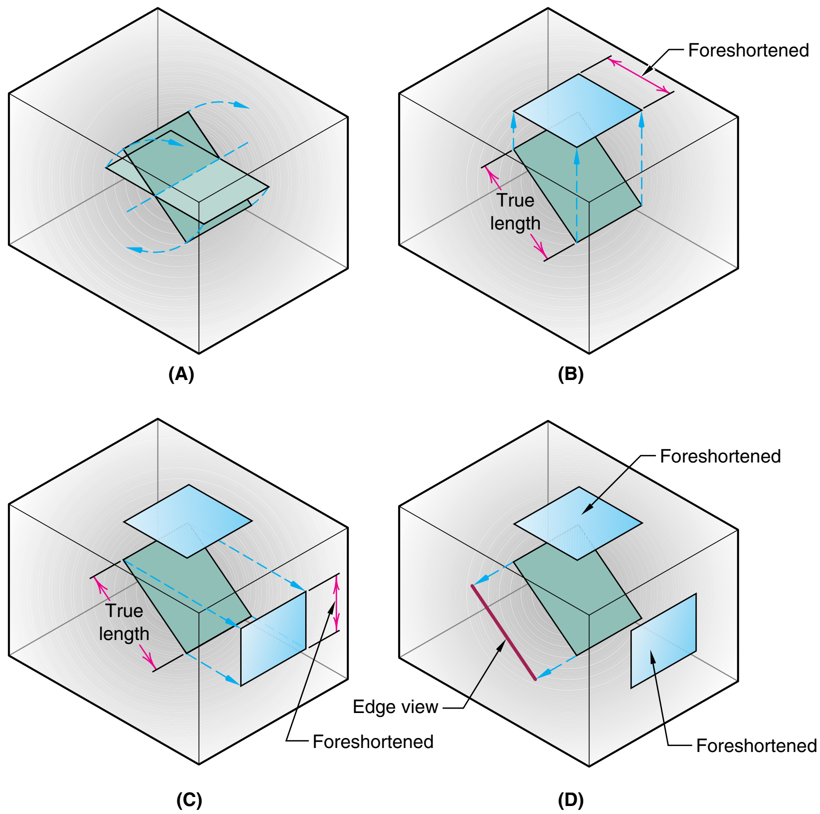


Figure 5.50

Inclined face projection

An inclined face is oriented so that it is not parallel to any of the principal image planes. The inclined face is foreshortened in two views and is an edge in one view.

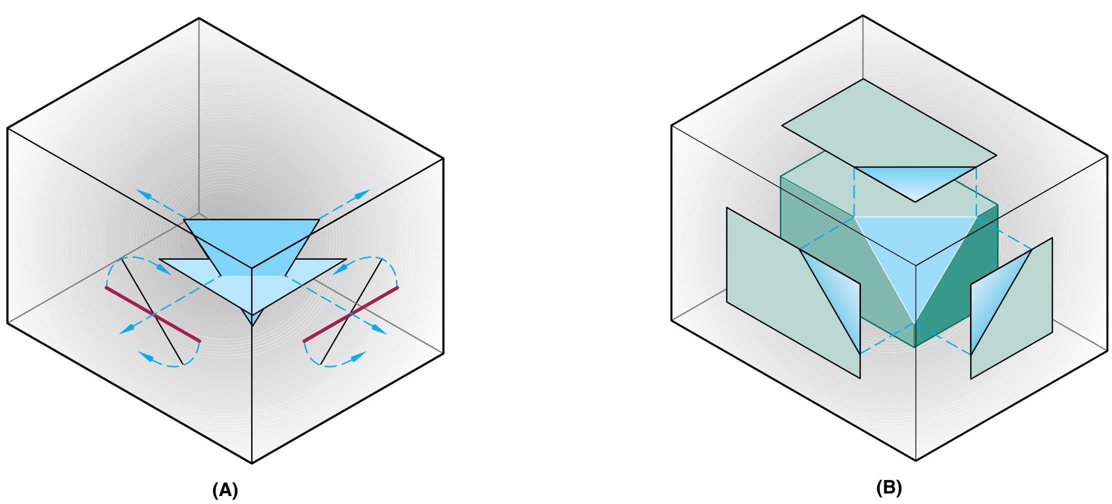


Figure 5.51

Oblique face projection

The projection of an oblique face is foreshortened in all three principal image planes.

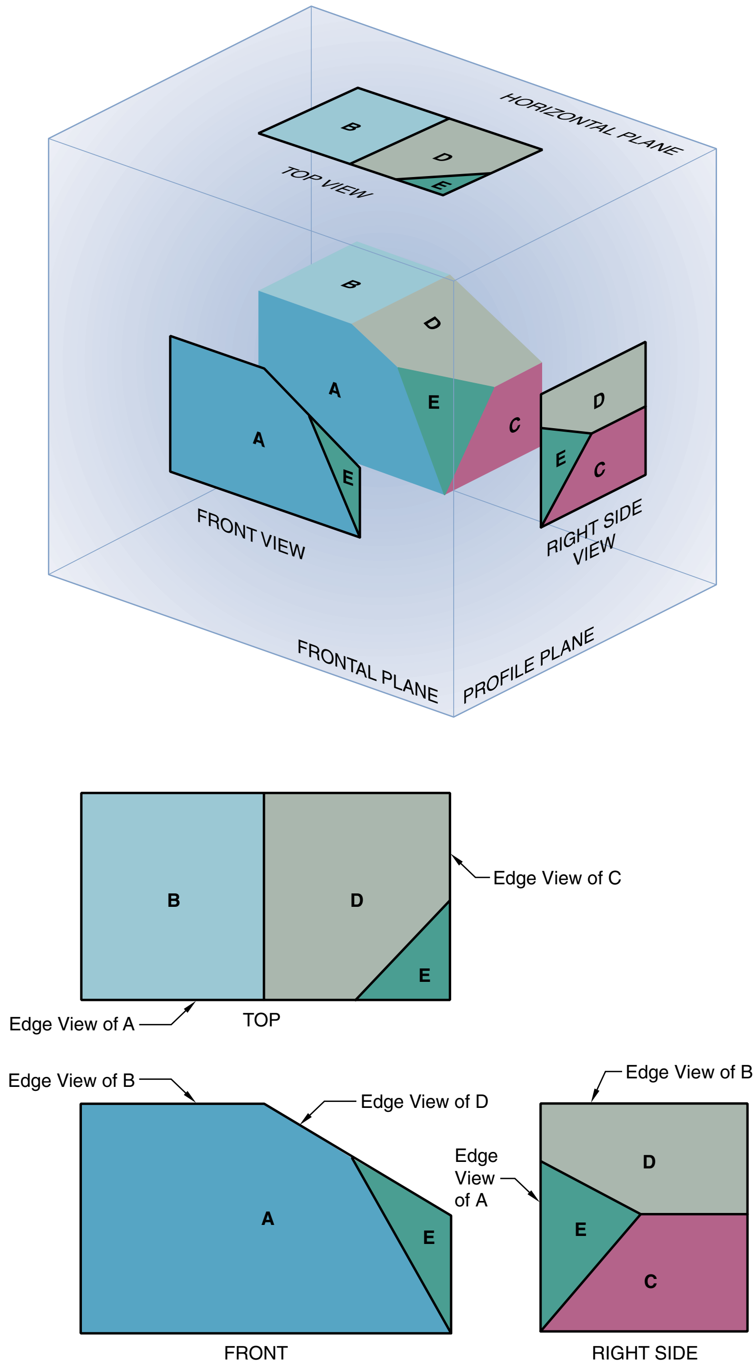


Figure 5.52

Fundamental views of surfaces

Surface A is parallel to the frontal plane of projection. Surface B is parallel to the horizontal plane of projection. Surface C is parallel to the profile plane of projection. Surface D is an inclined plane and is on edge in one of the principal views (the front view). Surface E is an oblique plane and is neither parallel nor on edge in any of the principal planes of projection.

Practice Exercise 5.7

Using stiff cardboard, cut out the following shapes:

- Rectangle
- Circle
- Trapezoid
- Irregular shape with at least six sides, at least two of which are parallel to each other

Sketch the following multiviews of each shape:

- The line of sight perpendicular to the face
- Rotated 45 degrees about the vertical axis
- Rotated 90 degrees about the vertical axis
- Rotated 45 degrees about the horizontal axis
- Rotated 90 degrees about the horizontal axis
- Rotated 45 degrees about both the vertical and horizontal axes

Which views represent true-size projections of the surface? In what views is the surface inclined, oblique, or on edge? What is the shape of a circle when it is foreshortened? For the inclined projections, how many primary dimensions of the surface appear smaller than they are in true-size projection? What is the relationship between the foreshortened dimension and the axis of rotation? Identify the parallel edges of the surface in the true-size projection. Do these edges stay parallel in the other views? Are these edges always seen in true length?

5.8 Multiview Representations for Sketches

Three-dimensional solid objects are represented on 2-D media as points, lines, and planes. The solid geometric primitives are transformed into 2-D geometric primitives. Being able to identify 2-D primitives and the 3-D primitive solids they represent is important in visualizing and creating multiview drawings. Figure 5.53 shows multiview drawings of common geometric solids.

5.8.1 Points

A **point** represents a specific position in space and has no width, height, or depth. A point can represent:

The *end view of a line*.
The *intersection of two lines*.
A *specific position in space*.

Even though a point does not have width, height, or depth, its position must still be marked. On technical drawings, a point marker is a small, symmetrical cross. (See Chapter 3, "Engineering Geometry.")

5.8.2 Planes

A plane can be viewed from an infinite number of vantage points. A plane surface will always project as either a line or an area. Areas are represented either in true size or foreshortened, and they will always be similar in configuration (same number of vertices and edges) from one view to another, unless viewed on edge. For example, surface B in Figure 5.54 is always an irregular four-sided polygon with two parallel sides (a trapezoid) in all the principal views. Since surface B is seen as a foreshortened area in the three views, it is an oblique plane.

> Principles of Orthographic Projection Rule 5:
> ***Configuration of Planes***
> Areas that are the same feature will always be similar in configuration from one view to the next, unless viewed on edge.

In contrast, area C in Figure 5.54 is similar in shape in two of the orthographic views and is on edge in the third. Surface C is a regular rectangle, with parallel sides labeled 3, 4, 5, and 6. Sides 3–6 and 4–5 are parallel in both the top view and the right side view. Also, lines 3–4 and 5–6 are parallel in both views. Parallel features will always be parallel, regardless of the viewpoint.

> Principles of Orthographic Projection Rule 6:
> ***Parallel Features***
> Parallel features will always appear parallel in all views.

A plane appears as an **edge view** or *line* when it is parallel to the line of sight in the current view. In the front view of Figure 5.54, surfaces A and D are shown as edges.

> Principles of Orthographic Projection Rule 7:
> ***Edge Views***
> Surfaces that are parallel to the lines of sight will appear on edge and be represented as lines.

A **foreshortened plane** is neither parallel nor perpendicular to the line of sight. There are two types of foreshortened planes, oblique and inclined, as described in Sections 5.7.3 and 5.7.4. Surface B is foreshortened in all views of Figure 5.54.

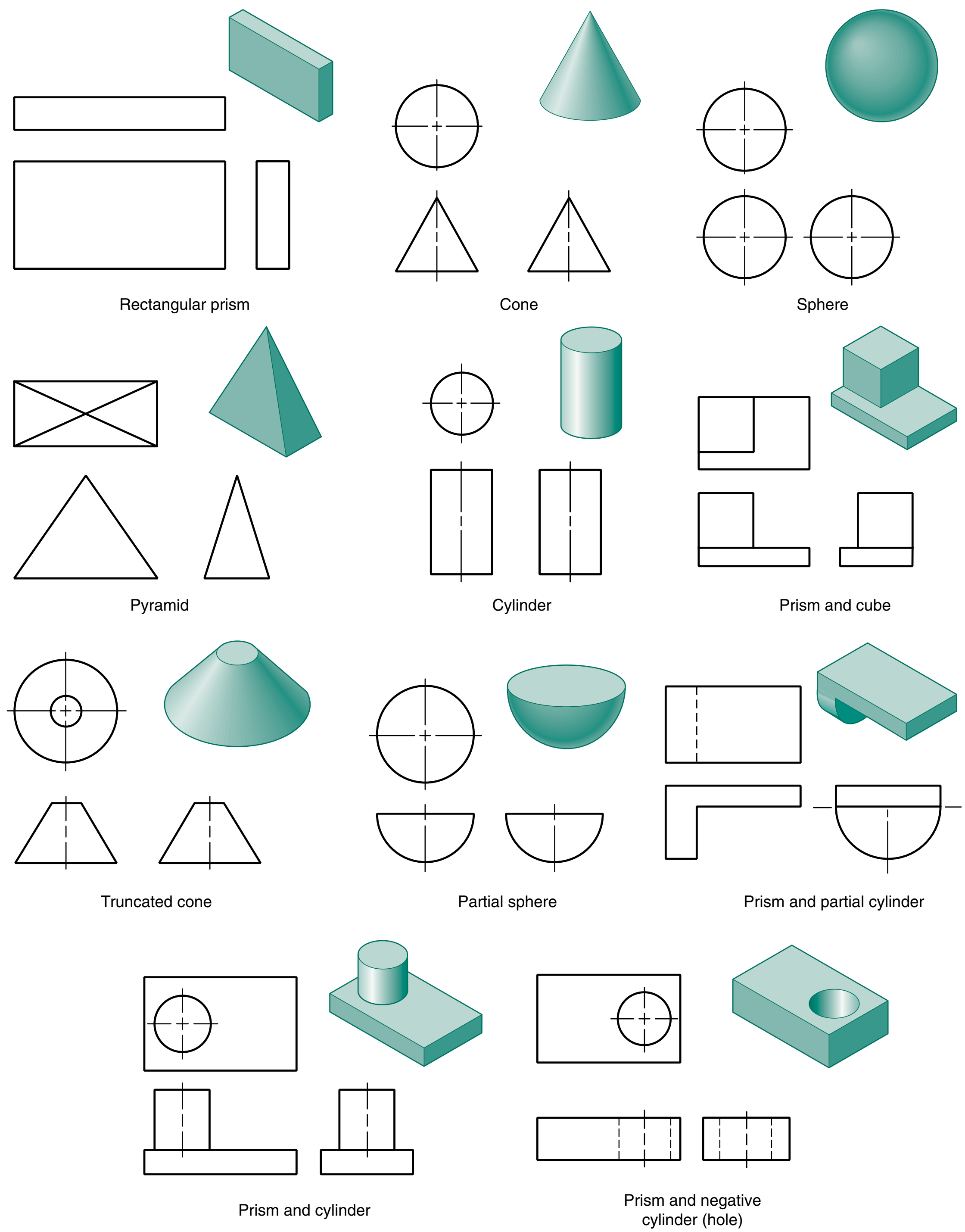


Figure 5.53

Multiview drawings of solid primitive shapes

Understanding and recognizing these shapes will help you to understand their application in technical drawings. Notice that the cone, sphere, and cylinder are adequately represented with fewer than three views.

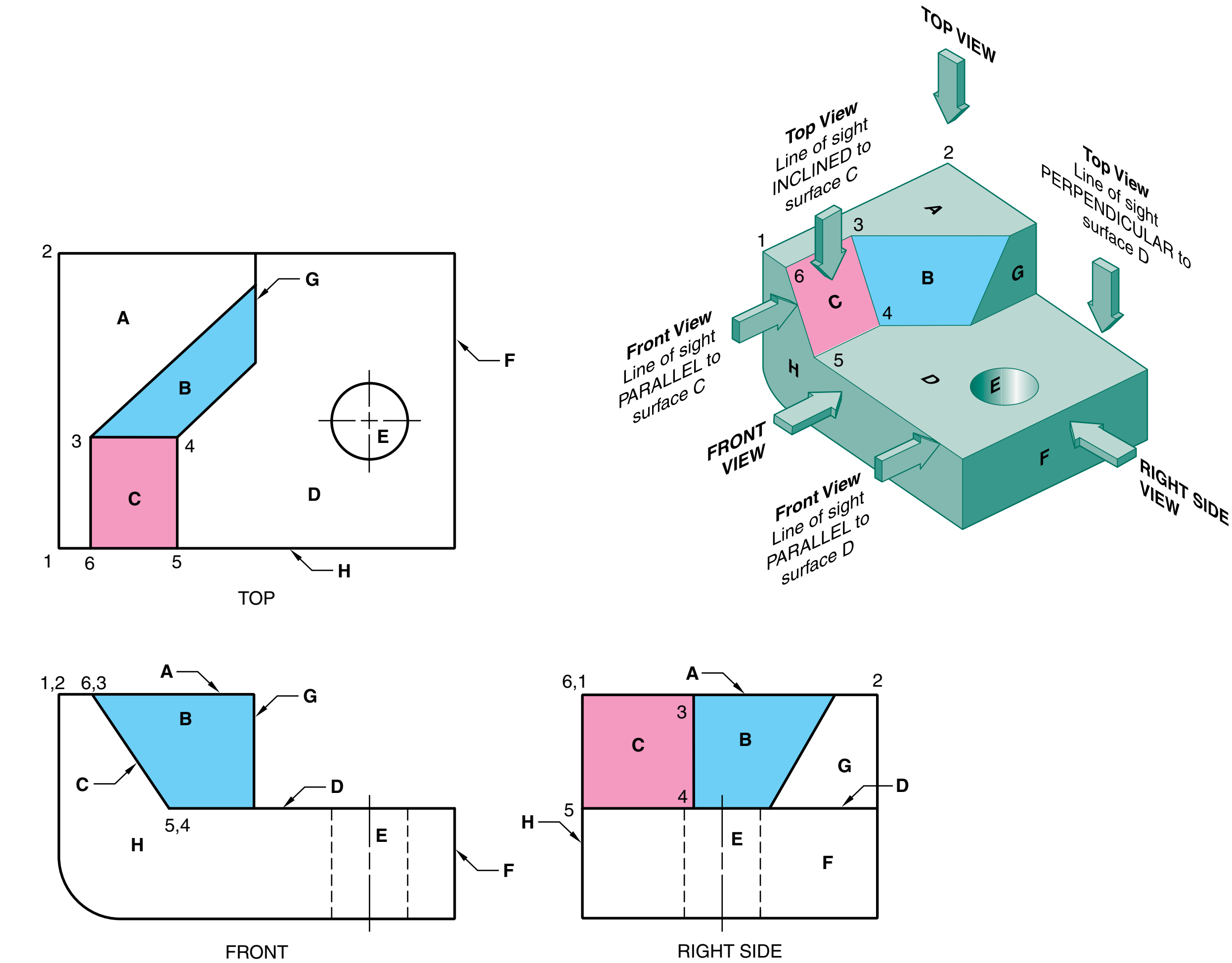


Figure 5.54

Rule of configuration of planes

Surface B is an example of the Rule of Configuration of Planes. The edges of surface C, 3-4 and 5-6, are examples of the Rule of Parallel Features.

Practice Exercise 5.8

Hold an object that has at least one flat surface (plane) at arm's length. Close one eye and rotate the object so that your line of sight is perpendicular to the flat surface. What you see is a true-size view of the plane. Slowly rotate the object while focusing on the flat plane. Notice that the flat plane begins to foreshorten. As you continue to rotate the object slowly, the plane will become more foreshortened until it disappears from your line of sight and appears as a line or edge. This exercise demonstrates how a flat plane can be represented on paper in true size, foreshortened, or as a line.

5.8.3 Change of Planes (Edge)

A **change of planes,** or **corner,** occurs when two nonparallel surfaces meet, forming an edge (Figure 5.54, Line 3–4). Whenever there is a change in plane, a line must be drawn to represent that change. The lines are drawn as solid or continuous if visible in the current view, or dashed if they are hidden.

5.8.4 Angles

An angle is represented in true size when it is in a normal plane. If an angle is not in a normal plane, then the angle

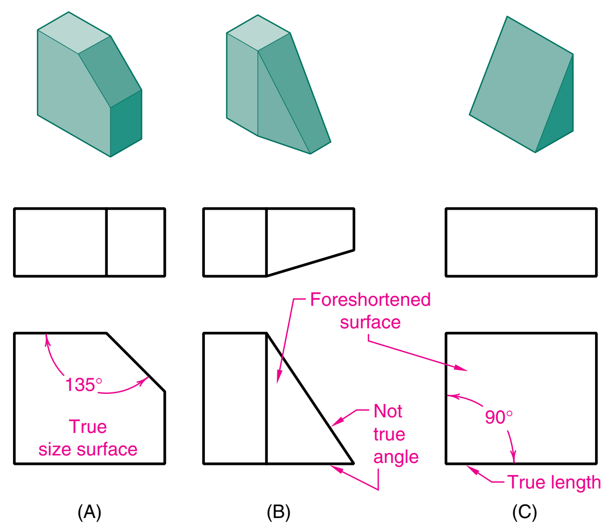


Figure 5.55

Angles

Angles other than 90 degrees can only be measured in views where the surface that contains the angle is perpendicular to the line of sight. A 90-degree angle can be measured in a foreshortened surface if one edge is true length.

will appear either larger or smaller than true size. For example, in Figure 5.55A, the 135-degree angle is measured as 135 degrees in the front view, which is parallel to the plane containing the angle. In Figure 5.55B, the angle is measured as less than true size in the front view because the plane containing the angle is not parallel to the frontal plane and is foreshortened. Right angles can be measured as 90 degrees in a foreshortened plane if one line is true length (Figure 5.55C).

5.8.5 Curved Surfaces

Curved surfaces are used to round the ends of parts and to show drilled holes and cylindrical features. Cones, cylinders, and spheres are examples of geometric primitives that are represented as curved surfaces on technical drawings.

Only the far outside boundary, or limiting element, of a curved surface is represented in multiview drawings. For example, the curved surfaces of the cone and cylinder in Figure 5.56 are represented as lines in the front and side views. Note that the bases of the cone and cylinder are represented as circles when they are positioned perpendicular to the line of sight.

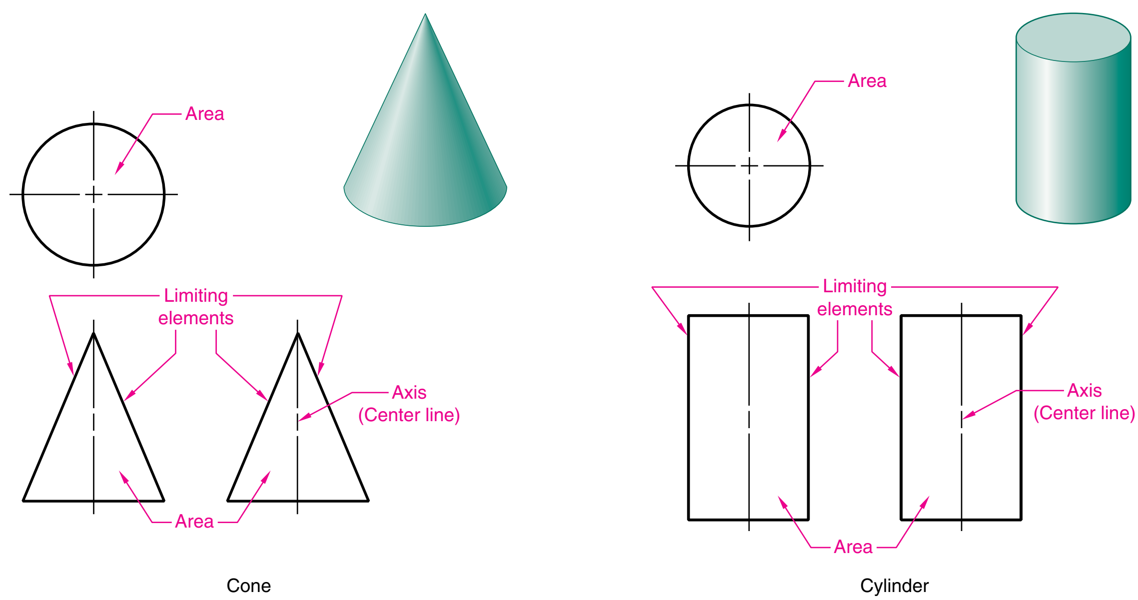


Figure 5.56

Limiting elements

In technical drawings, a cone is represented as a circle in one view and a triangle in the other. The sides of the triangle represent limiting elements of the cone. A cylinder is represented as a circle in one view and a rectangle in the other.

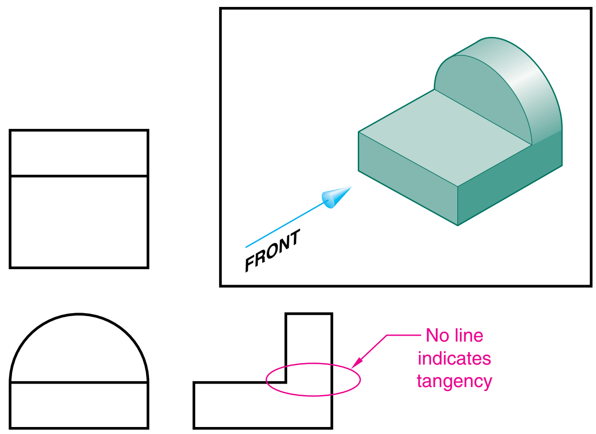


Figure 5.57

Tangent partial cylinder

A rounded end, or partial cylinder, is represented as an arc when the line of sight is parallel to the axis of the partial cylinder. No line is drawn at the place where the partial cylinder becomes tangent to another feature, such as the vertical face of the side.

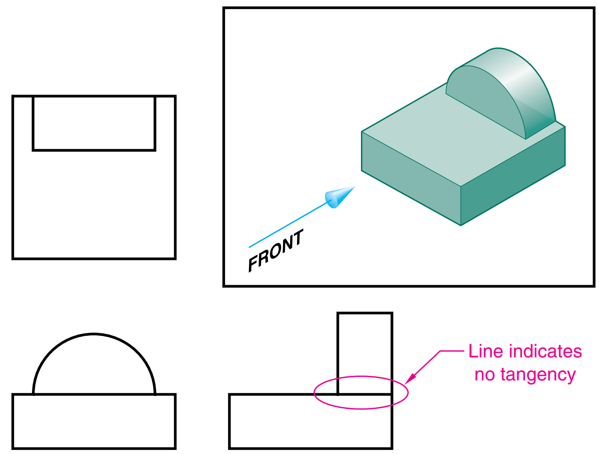


Figure 5.58

Nontangent partial cylinder

When the transition of a rounded end to another feature is not tangent, a line is used at the point of intersection.

Practice Exercise 5.9

Hold a 12-ounce can of soda at arm's length so that your line of sight is perpendicular to the axis of the can. Close one eye; the outline of the view should be a rectangle. The two short sides are edge views of the circles representing the top and bottom of the can. The two long sides represent the limiting elements of the curved surface. Hold the can at arm's length such that your line of sight is perpendicular to the top or bottom. Close one eye; the outline should look like a circle.

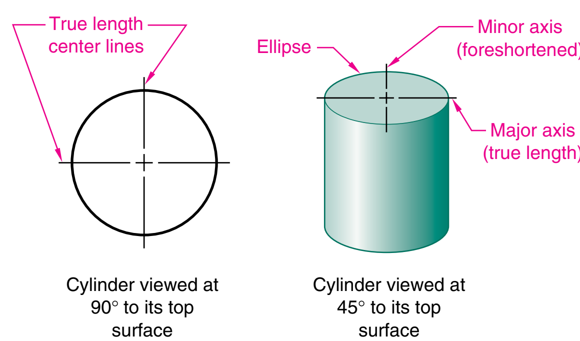


Figure 5.59

Elliptical representation of a circle

An elliptical view of a circle is created when the circle is viewed at an oblique angle.

Partial cylinders result in other types of multiview representations. For example, the rounded end of the object in Figure 5.57 is represented as an arc in the front view. In the adjacent views, it is a rectangle, because the curve is tangent to the sides of the object. If the curve were not tangent to the sides, then a line representing a change of planes would be needed in the profile and top views (Figure 5.58).

An ellipse is used to represent a hole or circular feature that is viewed at an angle other than perpendicular or parallel. Such features include handles, wheels, clock faces, and ends of cans and bottles. Figure 5.59 shows the end of a cylinder, viewed first with a perpendicular line of sight and then with a line of sight at 45 degrees. For the perpendicular view, the center lines are true length, and the figure is represented as a circle (Figure 5.60). However, when the view is tilted, one of the center lines is foreshortened and becomes the minor axis of an ellipse. The center line that remains true length becomes the major axis of the ellipse. As the viewing angle relative to the circle increases, the length of the minor axis is further foreshortened (Figure 5.60).

5.8.6 Holes

Figure 5.61 shows how to represent most types of machined holes. A **through hole,** that is, a hole that goes all the way through an object, is represented in one view

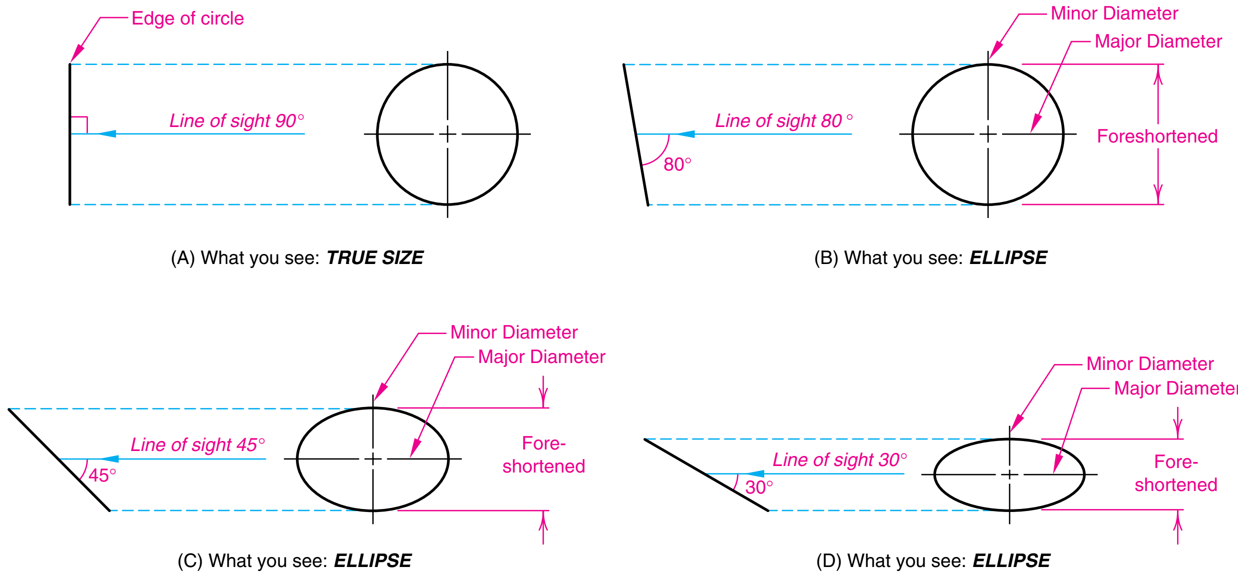


Figure 5.60

Viewing angles for ellipses

The size or exposure of an ellipse is determined by the angle of the line of sight relative to the circle.

as two parallel hidden lines for the limiting elements and is shown as a circle in the adjacent view (Figure 5.61A). A **blind hole,** that is, one that is not drilled all the way through the material, is represented as shown in Figure 5.61B. The bottom of a drilled hole is pointed, because all drills used to make such holes are pointed. The depth of the blind hole is measured to the flat, as shown, then 30-degree lines are added to represent the drill tip.

A drilled and counterbored hole is shown in Figure 5.61C. **Counterbored holes** are used to allow the heads of bolts to be flush with or below the surface of the part. A drilled and **countersunk hole** is shown in Figure 5.61D. Countersunk holes are commonly used for flathead fasteners. Normally, the countersink is represented by drawing 45-degree lines. A **spotfaced hole** is shown in Figure 5.61E. A spotfaced hole provides a place for the heads of fasteners to rest, to create a smooth surface on cast parts. For countersunk, counterbored, and spotfaced holes, a line must be drawn to represent the change of planes that occurs between the large diameter and the small diameter of the hole. Figure 5.61F shows a threaded hole, with two hidden lines in the front view and a solid and a hidden line in the top view.

5.8.7 Fillets, Rounds, Finished Surfaces, and Chamfers

A **fillet** is a rounded *interior* corner, normally found on cast, forged, or plastic parts. A **round** is a rounded *exterior* corner, normally found on cast, forged, or plastic parts. A fillet or round can indicate that both intersecting surfaces are not machine finished (Figure 5.62). A fillet or round is shown as a small arc.

With CAD, corners are initially drawn square, then fillets and rounds are added using a FILLET command.

Fillets and rounds eliminate sharp corners on objects; therefore, there is no true change of planes at these places on the object. However, on technical drawings, only corners, edge views of planes, and limiting elements are represented. Therefore, at times it is necessary to add lines to represent rounded corners for a clearer representation of an object (Figure 5.63). In adjacent views, lines are added to the filleted and rounded corners by projecting from the place where the two surfaces would intersect if the fillets or rounds were not used (Figure 5.64). This is a conventional practice used to give more realistic representation of the object in a multiview drawing.

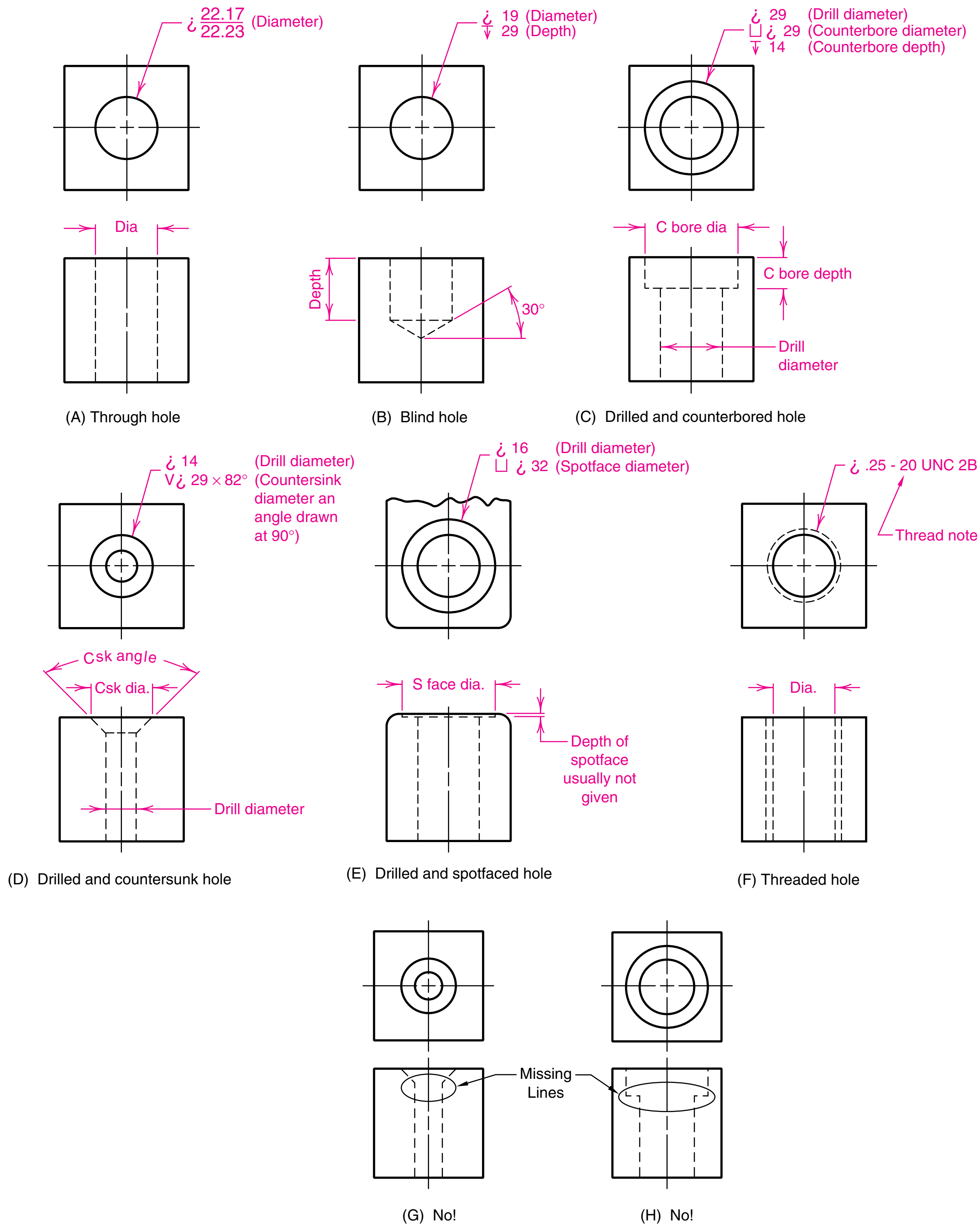


Figure 5.61

Representation of various types of machined holes

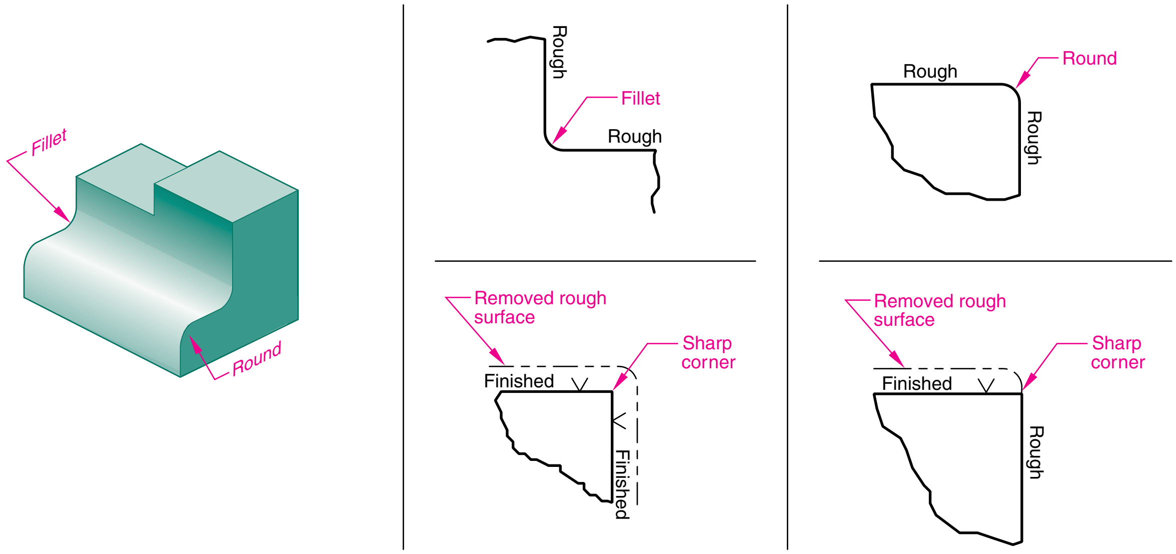


Figure 5.62

Representation of fillets and rounds

Fillets and rounds indicate that surfaces of metal objects have not been machine finished; therefore, there are rounded corners.

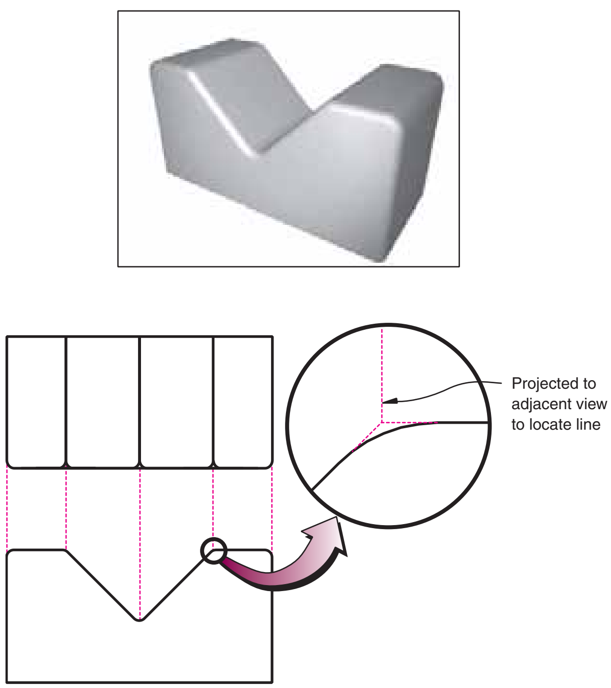


Figure 5.63

Representing fillet and rounded corners

Lines tangent to a fillet or round are constructed and then extended, to create a sharp corner. The location of the sharp corner is projected to the adjacent view, to determine where to place representative lines indicating a change of planes.

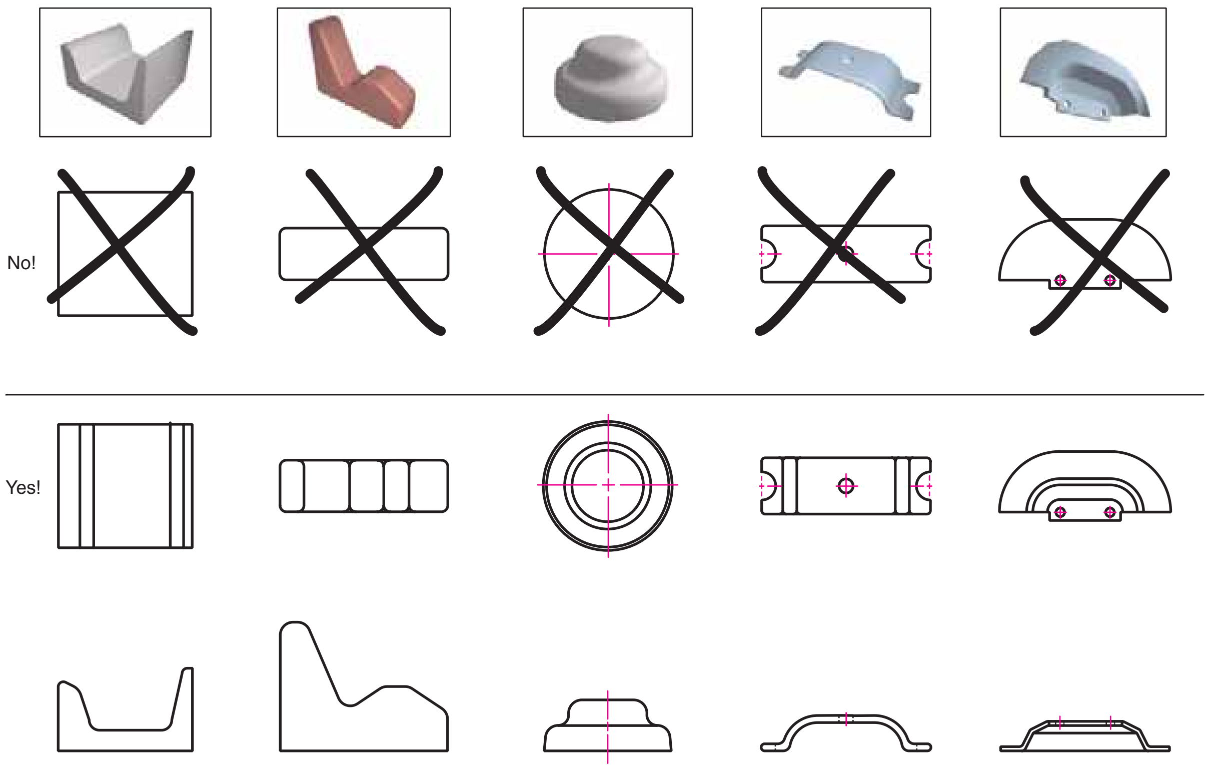


Figure 5.64

Examples of representing filleted and rounded corners

Lines are added to parts with fillets and rounds, for clarity. Lines are used in the top views of these parts to represent changes of planes that have fillets or rounds at the corners.

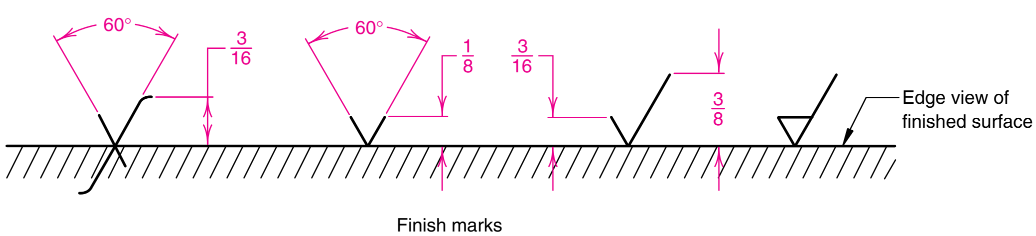


Figure 5.65

Finish mark symbols

Finish marks are placed on engineering drawings to indicate machine-finished surfaces.

When a surface is to be machined to a finish, a **finish mark** in the form of a small V is drawn on the edge view of the surface to be machined, that is, the *finished surface*. Figure 5.65 shows different methods of representing finish marks and the dimensions used to draw them.

A **chamfer** is a beveled corner used on the openings of holes and the ends of cylindrical parts to eliminate sharp corners (Figure 5.66). Chamfers are represented as lines or circles to show the change of plane. Chamfers can be internal or external and are specified by a linear and an

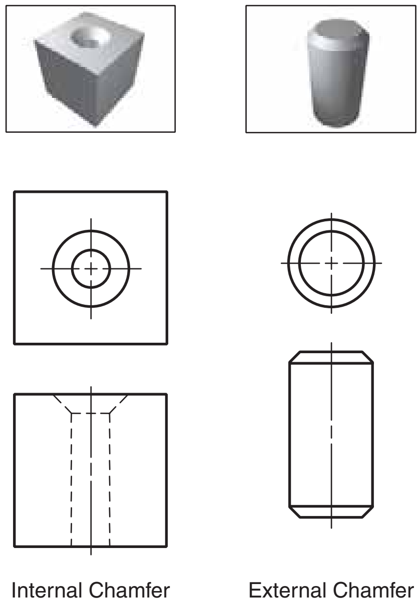


Figure 5.66

Examples of internal and external chamfers

Chamfers are used to break sharp corners on ends of cylinders and holes.

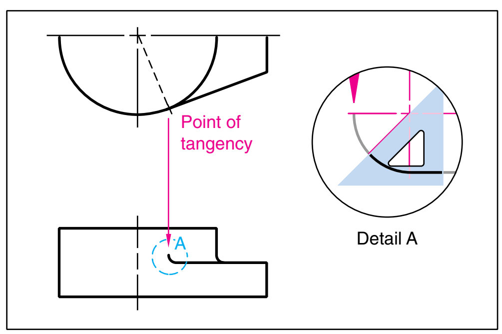
angular dimension. With CAD, chamfers are added automatically to square corners using a CHAMFER command.

5.8.8 Runouts

A **runout** is a special method of representing filleted surfaces that are tangent to cylinders (Figure 5.67). A runout is drawn starting at the point of tangency, using a radius equal to that of the filleted surface, with a curvature of approximately one-eighth the circumference of a circle. Examples of runout uses in technical drawings are shown in Figure 5.68. If a very small round intersects a cylindrical surface, the runouts curve *away* from each other (Figure 5.68A). If a large round intersects a cylindrical surface, the runouts curve *toward* each other (Figure 5.68C).

5.8.9 Intersecting Cylinders

When two dissimilar shapes meet, a line of intersection usually results. The conventional practices for representing



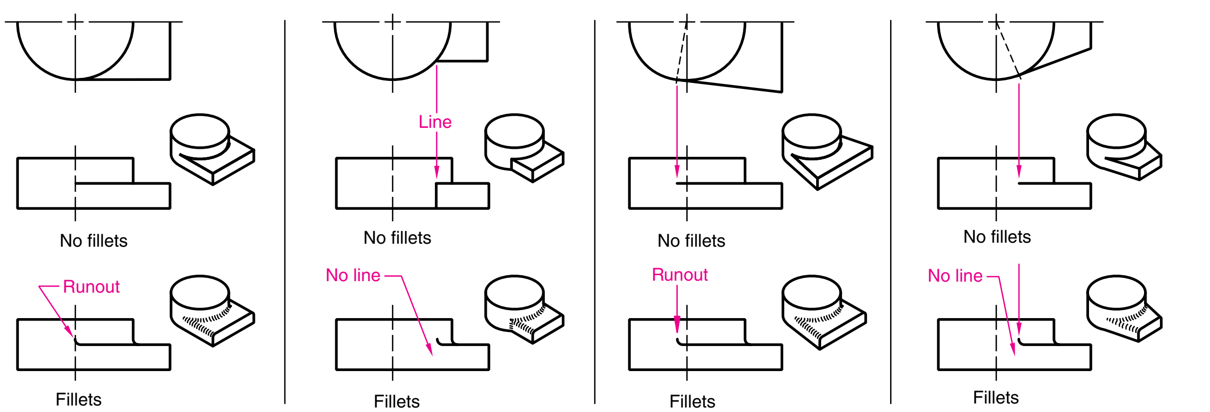


Figure 5.67

Runouts

Runouts are used to represent corners with fillets that intersect cylinders. Notice the difference in the point of tangency with and without the fillets.

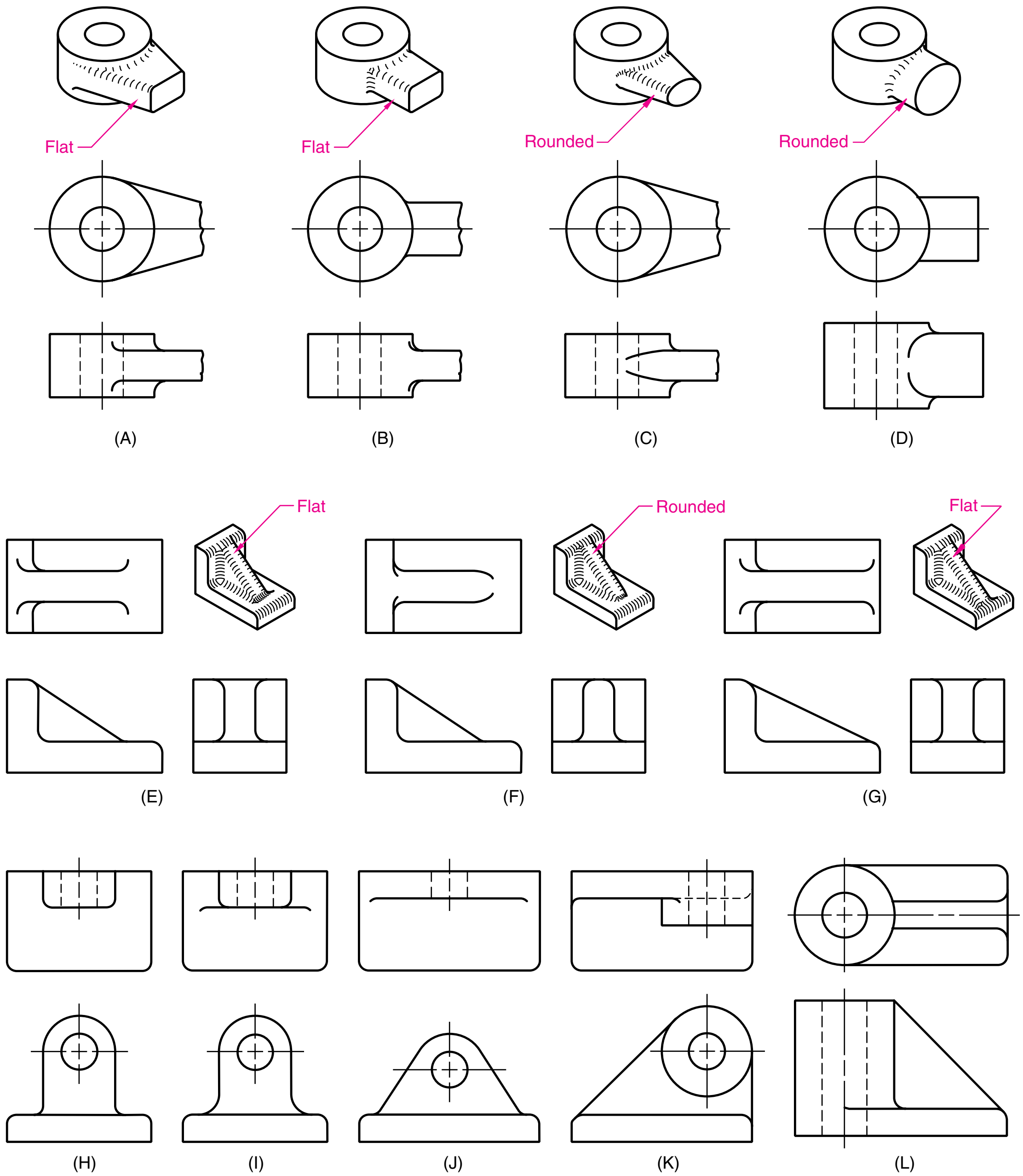


Figure 5.68

Examples of runouts in multiview drawings

intersecting surfaces on multiview drawings are demonstrated in Figure 5.69, which shows two cylinders intersecting. When one of the intersecting cylinders is small, true projection is disregarded (Figure 5.69A). When one cylinder is slightly smaller than the other, some construction is required (Figure 5.69B). When both cylinders are of the same diameter, the intersecting surface is drawn as straight lines (Figure 5.69C).

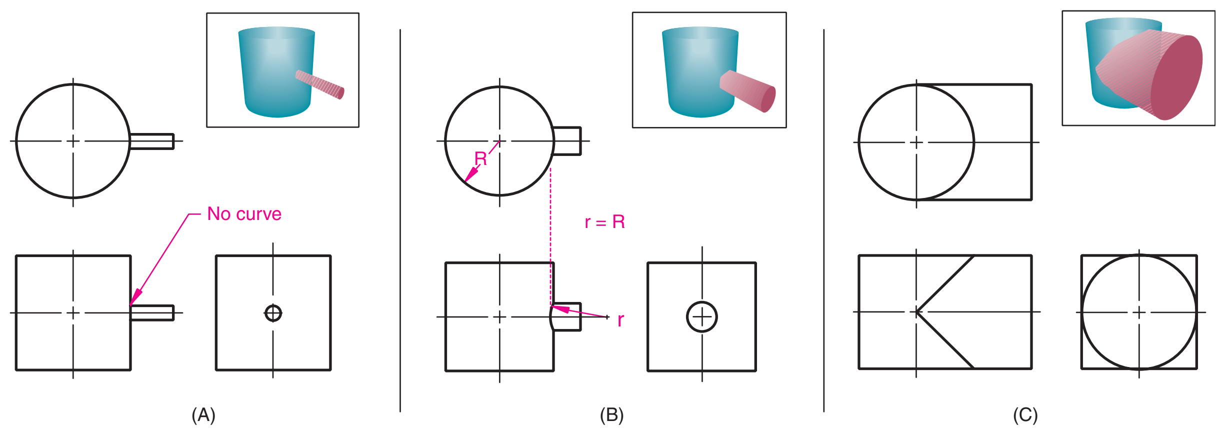


Figure 5.69

Representing the intersection of two cylinders
Representation of the intersection of two cylinders varies according to the relative sizes of the cylinders.

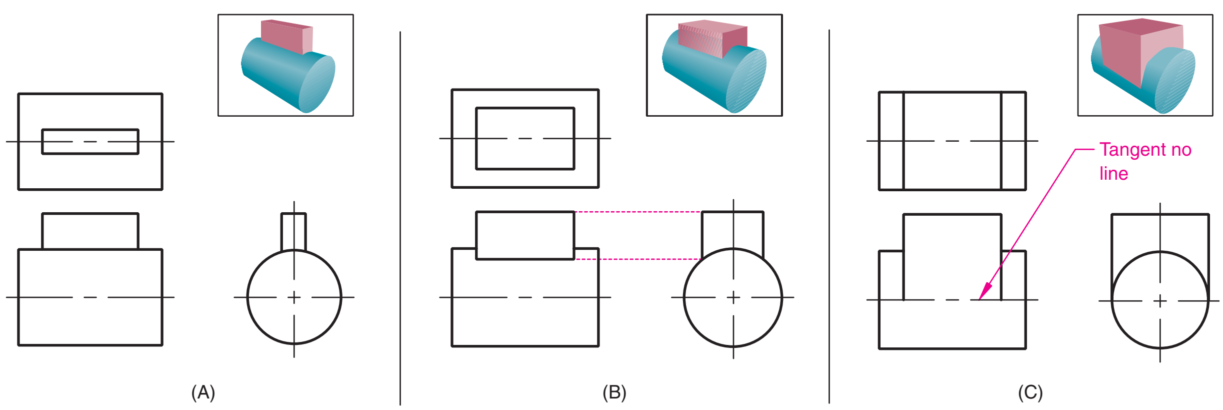


Figure 5.70

Representing the intersection between a cylinder and a prism
Representation of the intersection between a cylinder and a prism depends on the size of the prism relative to the cylinder.

5.8.10 Cylinders Intersecting Prisms and Holes

Figure 5.70 shows cylinders intersecting with prisms. Large prisms are represented using true projection (Figure 5.70B and C); small prisms are not (Figure 5.70A). Figure 5.71 shows cylinders intersected with piercing holes. Large holes and slots are represented using true projection (Figure 5.71B and D); small holes and slots are not (Figure 5.71A and C).

5.9 ANSI Standards for Multiview Drawings and Sketches

Standards form the common language used by engineers and technologists for communicating information. The standard view representations developed by ANSI for multiview drawings are described in the following paragraphs.

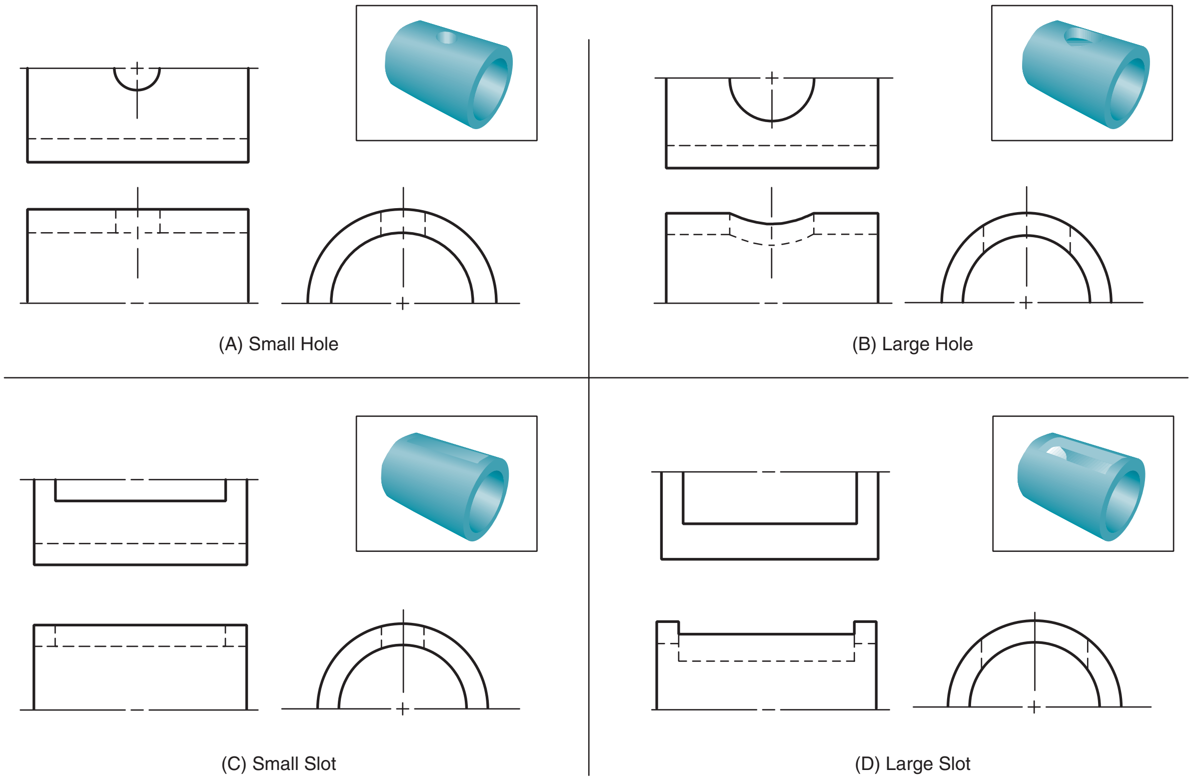


Figure 5.71

Representing the intersection between a cylinder and a hole

Representation of the intersection between a cylinder and a hole or slot depends on the size of the hole or slot relative to the cylinder.

5.9.1 Partial Views

A **partial view** shows only what is necessary to completely describe the object. Partial views are used for symmetrical objects, for some types of auxiliary views, and for saving time when creating some types of multiview drawings. A break line (shown as a jagged line) or center line for symmetrical objects may be used to limit the partial view (Figure 5.72). If a break line is used, it is placed where it will not coincide with a visible or hidden line.

Partial views are used to eliminate excessive hidden lines that would make reading and visualizing a drawing difficult. At times it may be necessary to supplement a partial view with another view. For example, in Figure 5.73, two partial profile views are used to describe the object better. What has been left off in the profile views are details located behind the views.

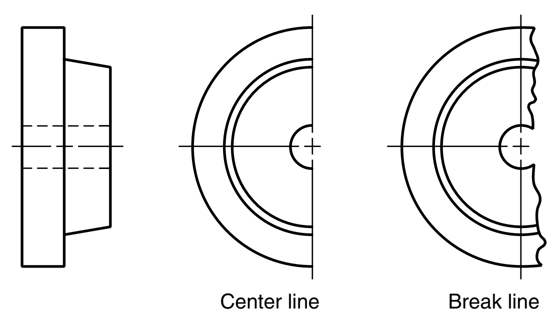


Figure 5.72

A partial view used on a symmetrical object

The partial view is created along a center line or a break line.

Figure 5.73

The use of two partial profile views to describe an object and eliminate hidden lines

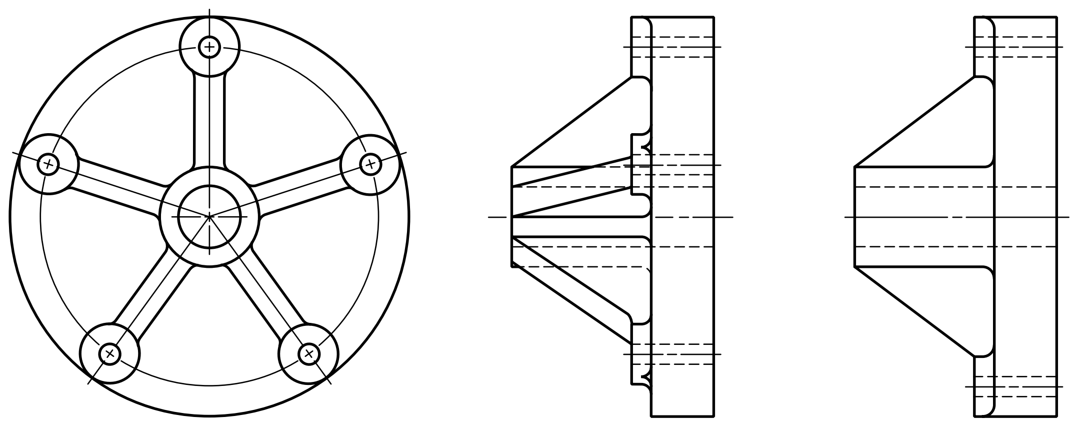


Figure 5.74

Revolution conventions used to simplify the representation of ribs and webs

5.9.2 Revolution Conventions

At times, a normal multiview drawing will result in views that are difficult to visualize and read. This is especially true of objects with ribs, arms, or holes that are not aligned with horizontal and vertical center lines. Figure 5.74 shows an object with ribs and holes that are equally spaced, with the two bottom holes not aligned with the center line of the object. True projection produces an awkward profile view that is difficult to draw because all but one rib are foreshortened (Figure 5.74A). ANSI standard **revolution conventions** allow the profile view to be drawn as shown in Figure 5.74B. You must visualize the object as if the ribs are revolved into alignment with the vertical center line in the front view. This will produce a profile view that is easier to visualize and draw.

Revolution conventions can also be used on parts that have *bolt circles*. Figure 5.75 shows the true projection of

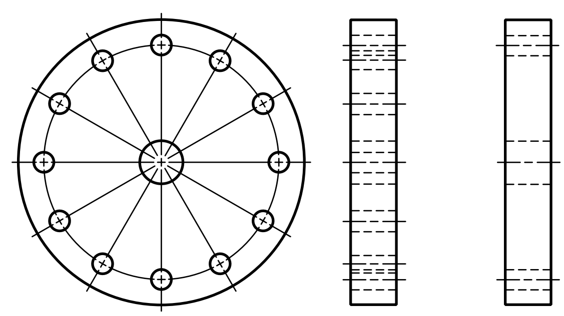


Figure 5.75

Revolution conventions used on objects with bolt circles to eliminate hidden lines and improve visualization

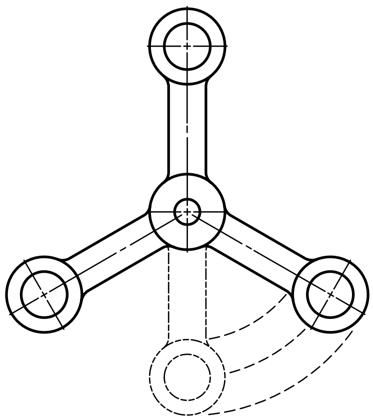


Figure 5.76

Revolution conventions used to simplify the representation of arms

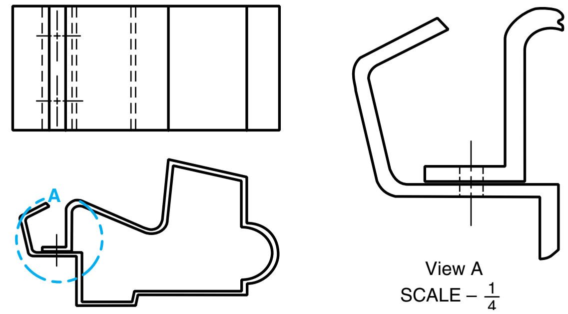


Figure 5.77

A scaled removed view (view A)

a plate with a bolt circle. Notice that the profile view becomes difficult to read because of so many hidden lines. As shown in Figure 5,75, revolution conventions dictate that only two of the bolt circle holes must be represented in the profile view. These two bolt circle holes are aligned with the vertical center line in the front view and are then represented in that position in the profile view.

Figure 5.76 shows another example of revolution conventions. The inclined arms in the figure result in a foreshortened profile view, which is difficult and time-consuming to draw. Revolution conventions allow the arms to be shown in alignment with the vertical center line of the front view, to create the profile view shown in the figure.

Objects similar to those described in the preceding paragraphs are frequently represented as section views. When revolution techniques are used with section views, the drawings are called *aligned sections*. (See Chapter 8, "Section Views.")

Revolution conventions were developed before CAD. With the advent of 3-D CAD and the ability to extract views automatically, it is possible to create a true-projection view, like that shown in Figure 5.76, quickly and easily. You are cautioned that, even though a view can be automatically produced by a CAD system, this does not necessarily mean that the view will be easy to visualize by the user.

Practice Exercise 5.10

In Figures 5.74 through 5.76, a new revolved view was created to replace a true projection in the profile view. This was done in order to represent the features of the object more clearly. Sketch new front views as if the new profile views represented true projections.

5.9.3 Removed Views

At times, it is important to highlight or enlarge part of a multiview. A new view is drawn that is not in alignment with one of the principal views, but is removed and placed at a convenient location on the drawing sheet. A **removed view** is a complete or partial orthographic view that shows some details more clearly. A new viewing plane is used to define the line of sight used to create the removed view, and both the viewing plane and the removed view are labeled, as shown in Figure 5.77.

5.10 Visualization for Design

Previous sections of this chapter provided information on how to document and visualize objects as two-dimensional views in a multiview drawing. Sections 5.10 through 5.12 provide a more general introduction to 3-D visualization and its role in the engineering, science, and technology fields. Section 5.13 describes additional approaches to visualizing 3-D objects as multiview projections.

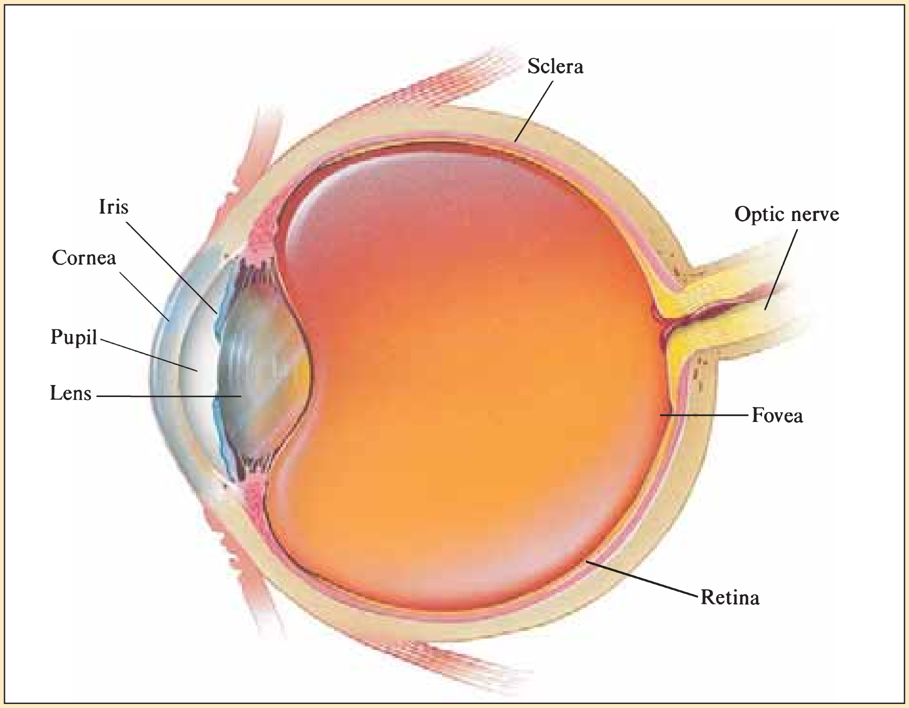
Vision

Light travels in straight lines, so visual information can be used to determine both the direction and distance of an object. No other human stimulus provides as much detail as the human eye. **Vision,** the perception of light, is carried out through the eye, which contains receptors that detect photons of light. The eye is organized similar to a camera. The receptors are located in the back of the eye and are categorized as either rods, which are receptors for black and white vision, or cones, which are receptors for color. There are three different kinds of cones, cells that absorb either red, green, or blue wavelengths of light to give humans color vision. The field of receptors that line the back of the eye is called the retina. The retina contains approximately three million cones and one billion rods. Most of the cones are located in the central region of the retina called the fovea. The eye forms a sharp image in the central fovea region of the retina.

The light rays are focused onto the receptors by the lens of the eye. Light first passes through a transparent layer called the cornea, which begins to focus light onto the rear of the eye. Light then passes through the lens, which is a structure that completes the focusing. Muscles attached to the lens contract and change the shape of the lens to change the point of focus on the rear of the eye. The amount of light entering the eye is controlled by a shutter, called the iris, which is located between the cornea and the lens. The iris reduces the size of the transparent zone, or pupil, of the eye through which light passes.

The optic nerve transmits visual stimuli more or less directly to the brain in the region called the visual cortex. Visual impulses are processed in the brain to determine intensity, color, and point-to-point images.

Having two eyes looking at the same object or scene causes each eye to see slightly different images because they are viewed from slightly different angles. This slight displacement of the images, called parallax, permits very sensitive depth perception. By comparing the differences between the images provided by each eye with the physical distance to specific objects, humans learn to interpret distance through stereoscopic vision. We are not born with the ability to perceive distance; it is a learned trait. Stereoscopic vision develops in babies over a period of months.



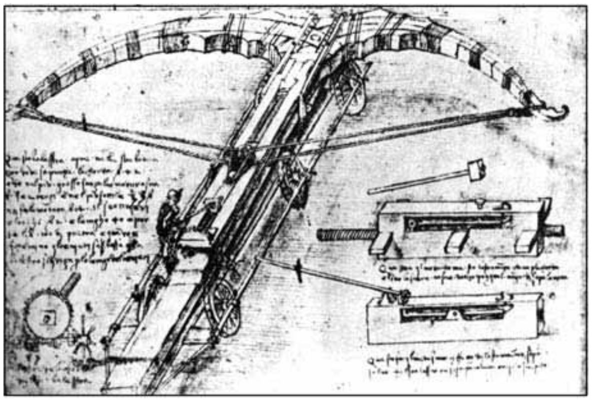


Figure 5.78

Design visualization
Leonardo da Vinci used drawings as a means of visualizing his designs.
(© Art Resource.)

The brain has an amazing ability to process visual information. Unconsciously, your brain is managing the navigation as you walk through the house or drive down the street. Your brain's desire to organize the visual information around you allows you to look at the clouds or the stars and see the shapes of animals, objects, or people. This natural visualization ability can be put to work in more structured ways by engineers, scientists, and technologists to solve problems.

Nikola Tesla, one of the great inventors in electronics, was said to be able to design exclusively with images in his head. Leonardo da Vinci, a great inventor of an earlier generation, used drawings as an integral part of his design process (Figure 5.78). The famous scientist Albert Einstein used visual imagery to solve complex problems in physics. Einstein once said: "The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which serve as elements of thought are certain signs and more or less clear images which can be voluntarily reproduced and combined."

We all have the ability to use imagery to solve problems that are spatial in nature. What you may not have is Tesla's ability to do complete designs from beginning to end in your head. You will find, however, that transforming your ideas into tangible graphic images serves both as a permanent record of those ideas and as a means of encouraging further creative thinking. Though sketching is a primary method for visualization, the current computer graphics hardware and software systems are a great equalizer for those who do not have a natural ability to express their ideas visually (Figure 5.79).

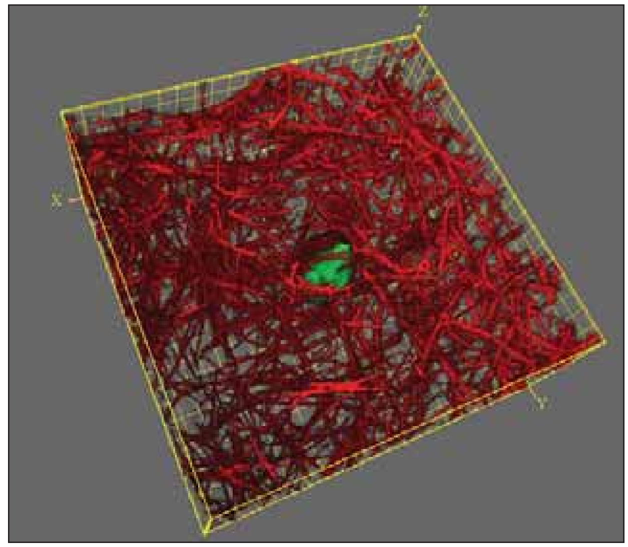


Figure 5.79

Computer-generated scientific visualization
Cancer cell in liver tissue.
(Courtesy of Paul Robinson and Bartek Rajwa, Purdue University.)

To effectively use graphics as a vehicle for visualizing design ideas, you must understand that the two-dimensional graphics you draw—whether on paper or a computer screen—are a *representation* of information existing in another form. Exercises at the end of this chapter focus on drawing exactly what you see, as though there was a direct connection between your hand and the object being drawn (Figure 5.80). In fact, the mind and the information it receives visually play a critical role in guiding what the pencil draws on the paper (Figure 5.81).

5.10.1 Problem Solving

Visualization is important and integral to the engineering design process. Using either the computer or the drafting board, engineers and technologists must have the ability to document their completed designs, based on well-defined technical graphics standards. They must also have the ability to understand, at a deeper level, the three-dimensional forms they are documenting.

The ability to visualize forms in your mind enhances your ability to understand both existing objects and objects that may not yet have been manufactured. Visualizing three-dimensional forms allows you to play *what-if games* in the early stages of the design process, before there are physical models. The ability to visualize also allows you to spatially analyze more detailed problems later on.

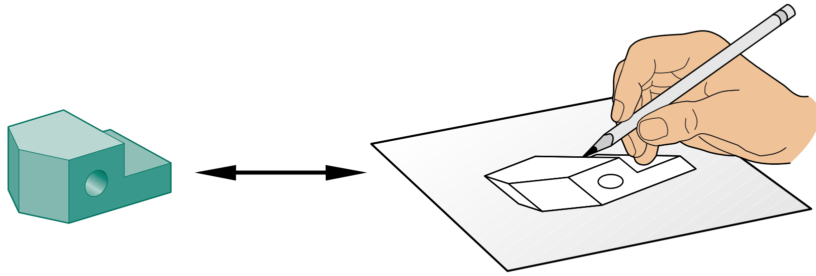


Figure 5.80

Hand/eye connection

The hand/eye connection is important when sketching.

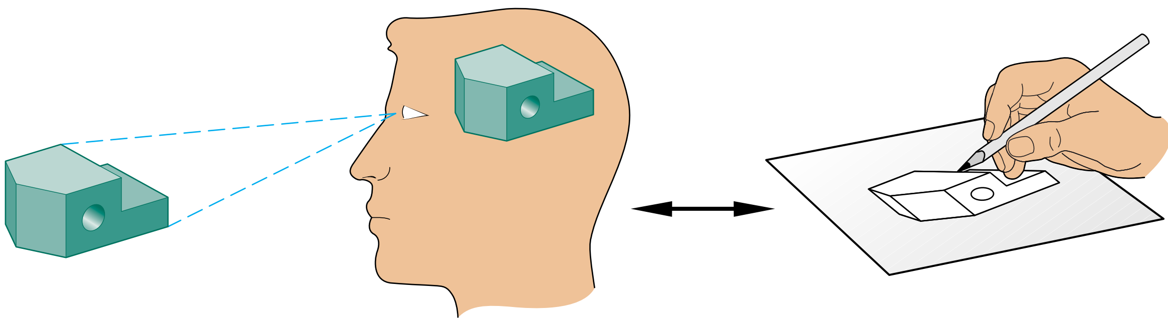


Figure 5.81

Hand/eye/mind connection

The hand/eye/mind connection more accurately describes the processes used to make sketches. The mind forms a mental picture of existing or nonexisting objects, which can then be sketched. The feedback loop between the mind and the hand is so powerful that the object need not exist.

As an engineer or technologist, much of what you will do professionally will involve solving problems. The problem drawing may start out as a flowchart (Figure 5.82), but it should soon evolve into an image of an object (Figure 5.83).

Now you can begin the what-if games: "What if I move this part over to the other side?" "What if I lower the height by half and make it a bit deeper?" You may perform some of these what-if games as mental images, but eventually there will be too much detail and/or too many variations of the design to keep in your head. Put them down on paper as *ideation* sketches.

Eventually you will use your sketching abilities to create problem-solving ideation sketches; at first, however, you will use those abilities to understand a 3-D object as it exists. Before you can evolve a design, you must first understand fully how it exists initially. By reviewing what you know about an image of an object, mentally building and synthesizing that information, and drawing the results of this mental effort, you can visualize a 3-D object and its future possibilities (Figure 5.81). However, the process does not stop there; what you have drawn becomes a graphics image for starting the whole process all over again.

5.11 Solid Object Features

The first visualization technique treats objects as you would normally see and feel them. A closer look at a solid object reveals features, or attributes, which help you visualize the object's current form. These attributes are also useful for transforming the object into something new, either on paper or in your mind. Figure 5.84 contains two simple, primitive objects, one a *brick* or rectangular

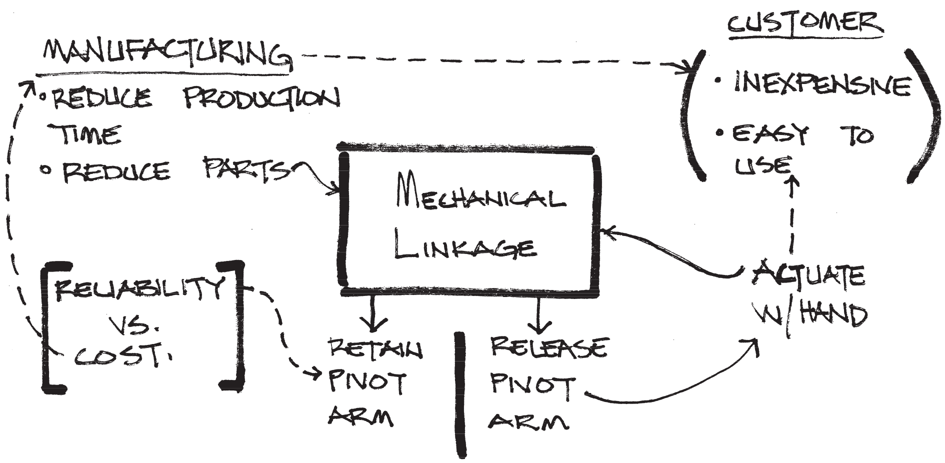


Figure 5.82

Flowchart

This flowchart is used to identify requirements of the design.

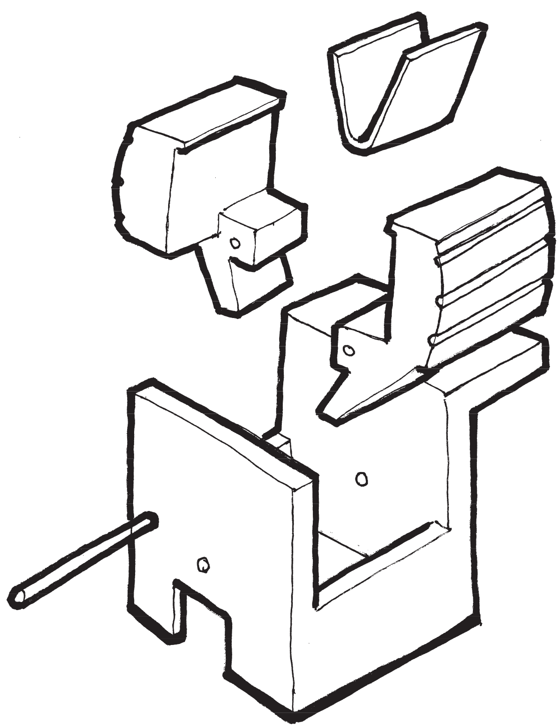


Figure 5.83

Ideation sketch

An exploded assembly sketch is used to visualize a possible design solution.

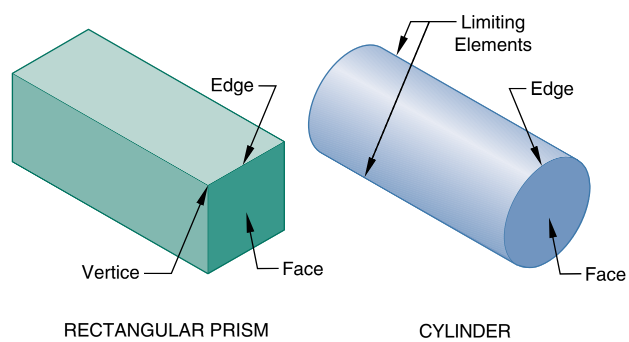


Figure 5.84

Solid object features

These rectangular prism and cylinder primitives show important features: edge, face, vertex, and limiting element.

prism, and the other a *cylinder*. These two primitives clearly demonstrate several important characteristics, or attributes, of objects.

Practice Exercise 5.11

Put various objects under a strong, directed light. Identify the edges on the object by looking at them and then feel them with your hand. Does the gradation of light on various parts of the object correspond to the "sharpness" of the corners?

Edges are the lines that represent the boundary between two faces of an object. On real objects, edges exist at a sharp break in light or dark levels on a surface (see Figure 5.84). **Faces** are areas of uniform or gradually changing lightness and are always bounded by edges. This is an important rule! Both edges and faces can be curved. For instance, as you follow around the curved face of the cylinder, there is gradual change in the lightness of the surface. Only when you go to the front of the cylinder is there an abrupt change in lightness, signaling an edge.

Another important attribute demonstrated by the cylinder is the limiting element. A **limiting element** is a line that represents the farthest outside feature of the curved surface. It is the last visible part of the curved surface as it drops away from your line of sight. Even though it is not a boundary between faces, a line is used to represent the limiting element. The line is tangent to the curved edge at each end of the cylinder. If you examine the cylinder, you will note that, even with an ideal viewing position, a curved face that curves more than approximately 180 degrees will have some of its surface obscured; in other words, you have a face that is only partially visible. For the cylinder in Figure 5.84, its curved face is half hidden and one of its circular faces is completely hidden.

Another important attribute found on the brick is corners, or **vertices.** If an edge is the place where two faces meet, then vertices are places where more than two edges meet. By extension, this means that more than two faces also meet at this point. On the brick primitive seen in Figure 5.84, there are four vertices visible, each with three connecting edges. Can you see three faces connecting at all of these vertices?

Going back to the cylinder, does it have any vertices? The answer is no, because there is no point at which three edges or three faces come together.

Practice Exercise 5.12

Based on the brick (prism) and cylinder developments found in appendix pages A-51 and A-52, construct the brick and cylinder, using tape or glue to hold the paper forms together. After constructing the two primitive shapes, identify and label:

- The faces, edges, and vertices of the brick (prism).
- The faces and edges of the cylinder.

Hold the cylinder at arm's length and identify the limiting elements on each side of the curved surface. Change the position of the cylinder and notice: (a) the limiting elements change with the cylinder; and (b) you can never view more than 180 degrees of the 360-degree curved surface of the cylinder.

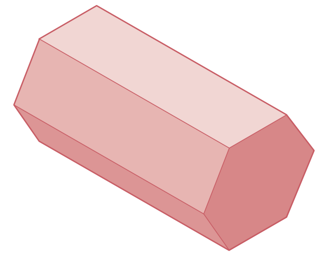


Figure 5.85

Object faces

This hexagonal prism has an end face attached to six other faces.

The basic rules of geometry that apply to 2-D shapes also apply to 3-D objects. Since faces are attached to each other at common edges, the **shape** of one face influences both the number of faces attached to it and the shapes of those other faces. For the brick primitive in Figure 5.84, all of the faces are either rectangles or squares, and the adjacent edges on each face are at 90 degrees to each other.

The shapes of 2-D faces can be used to interpret how a 3-D object is shaped. The square end face on the brick has four edges, which means there are four other faces attached to it. If the end face were a hexagon instead of a square (Figure 5.85), how many faces would be attached to it? What if the end face had one edge instead of four? Since one shape that has a single edge is a circle, the brick would become a cylinder and the end face would have only one curved face attached to it.

Practice Exercise 5.13

Have someone put various objects in a paper or cloth bag. Feel the objects without looking at them. Can you identify: (a) the edges, (b) the faces, and (c) the objects? Try sketching or describing the object based on what you feel when touching it.

5.12 Solid Object Visualization

5.12.1 Combinations and Negative Solids

Solid objects can be combined as if they were building blocks (Figures 5.86A and 5.86B). To be considered a true combination, a flat face of one object must join a flat face of the other object. This *face-to-face rule* guides the number of possible combinations you can make from two

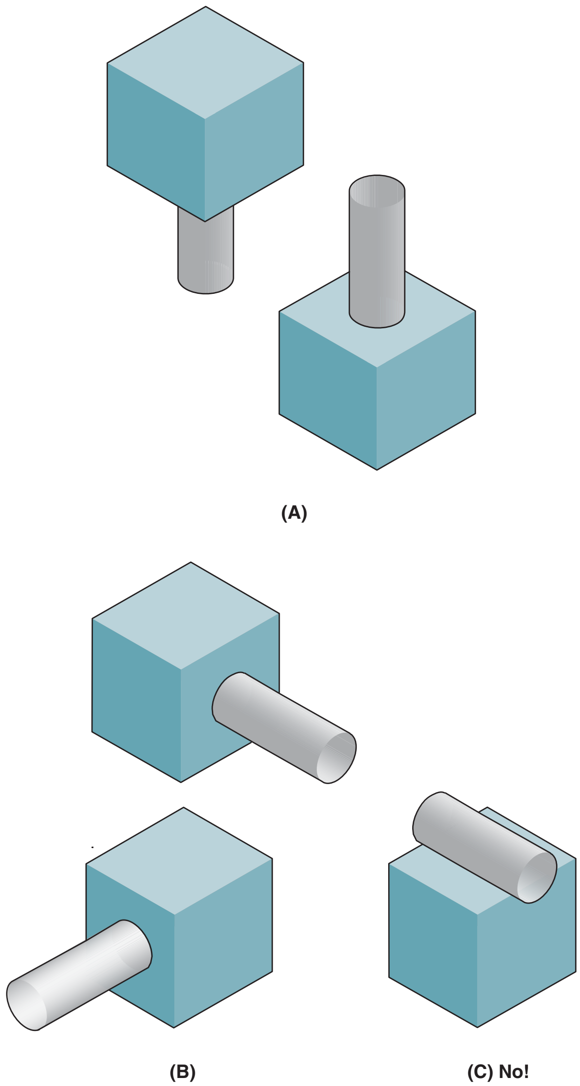


Figure 5.86

Combining solid objects

Additive combinations of primitives can be used to create new forms. This example shows acceptable (A and B) and unacceptable (C) ways a cylinder could be added to a cube to form a new object.

solid objects. A combination such as that shown in Figure 5.86C is not a true combination. For example, "a tire on a road" is thought of as two separate objects, not one.

Practice Exercise 5.14

Based on the cube development found at the end of this chapter, construct the cube, using tape or glue to hold the paper form together. Using either sketches or physical blocks shaped like those shown in Figure 5.86, explore all the possible combinations of these two objects. Are all of them unique?

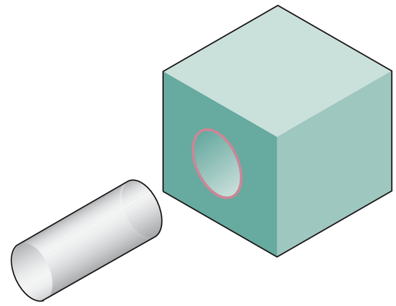


Figure 5.87

Removing solid objects

The cylinder subtracted from the cube is equal in volume and shape to the hole left in the cube.

Suppose, for example, that the cylinder is pushed through the cube and cube material comes out ahead of the cylinder, like a plug from a hole. The plug of removed cube material perfectly matches the *void* left in the cube (Figure 5.87). It is also a replica of the cylinder. There is a perfect negative/positive relationship between the void in the cube and the removed cylindrical plug. The plug can be thought of as a **negative solid.** If the plug is put back in the hole, it will fill the void perfectly, recreating the original cube.

If a smaller brick is removed instead of a cylindrical plug (Figure 5.88A), the effect would be similar, except the hole would have four straight sides, to match the four sides of the removed brick plug (Figure 5.88B).

Negative solids can also be taken off the corners, rather than from the middle. This *notching* produces several possibilities (Figure 5.89), especially when you expand beyond cylinders and bricks to wedges (Figure 5.90) and pyramids (Figure 5.91).

Practice Exercise 5.15

Using clay or Styrofoam, form a number of blocks approximating the brick primitive. Using a knife, remove various shaped primitives from your original brick, saving what you have cut off. The easiest shapes to remove are the ones coming off the corners. The difficult shapes to remove are the plugs from the middle of the brick. Observe that the new faces created on the original brick correspond to faces on the

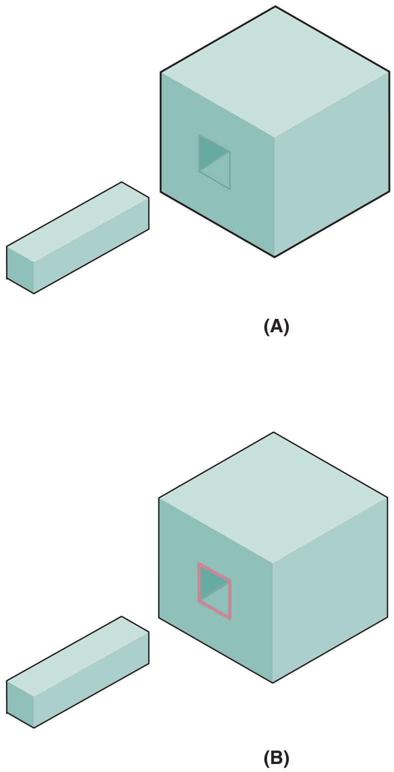


Figure 5.88

Subtracting a square prism

When a square prism is subtracted from the cube, the edges of the hole match the end face of the square prism.

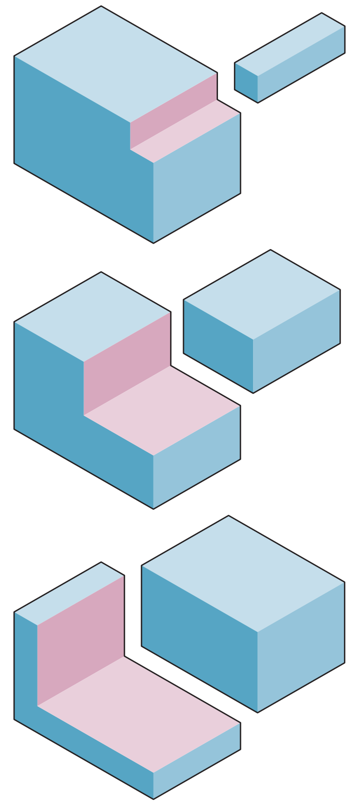


Figure 5.89

Subtracting progressively larger prisms

Subtraction of progressively larger prisms from the brick creates entirely different geometric forms.

removed shapes. The other faces on the removed shapes should form seamless surfaces with faces on the original brick when the shapes are put back. Pictorially sketch some of the new geometric forms you have created.

Instead of a physical model, use a 3-D CAD program that has primitives and Boolean operations. Create the brick as the base model, then subtract various primitive shapes, such as cubes, cylinders, and wedges, to create new geometric forms. Print pictorial views of some of the new forms.

To summarize, there are two fundamental techniques for combining solids: (1) the **additive** technique, in which one object is added to another to increase its volume; and (2) the **subtractive** technique, in which one object is removed from the other.

Used together, the two techniques for combining objects become a powerful tool for visualizing solids and creating complex geometric forms using a CAD solid modeling program. Complex objects (Figure 5.92A) can be "decomposed" into a combination of solid primitives. Starting with an initial primitive, new primitives can be either added or subtracted (Figure5.92B).

5.12.2 Planar Surfaces

Another tool that can be used for visualizing objects is planar surfaces. Such surfaces can interact with a solid object or can be used to represent the object itself.

Cutting Planes One planar surface that will be introduced later in this chapter is the **cutting plane.** For our purposes here, a cutting plane is *like a blade* that is flat, razor thin, and infinitely large. Two pieces of the object can be left together, instead of being separated, and the cutting plane can be thought of as having created a new surface inside the object (Figure 5.93).

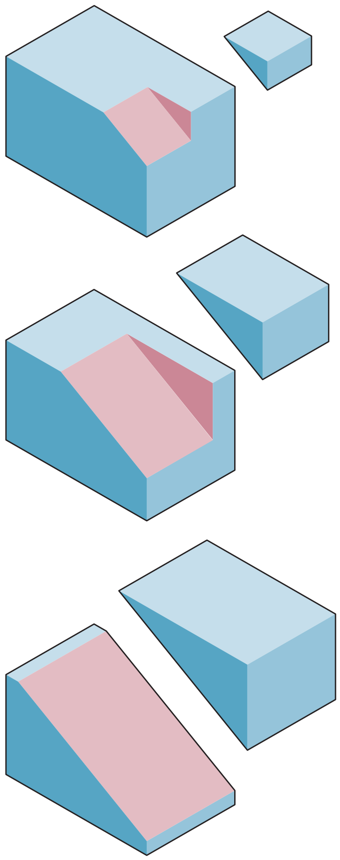


Figure 5.90

Subtracting progressively larger wedges
Subtraction of progressively larger wedges from the brick creates new geometric forms.

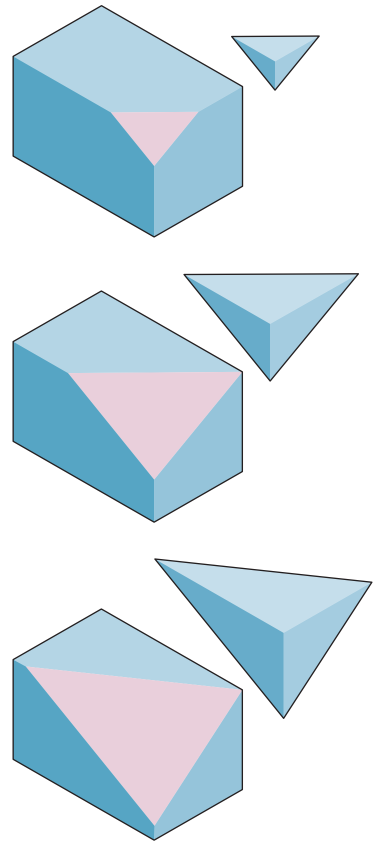
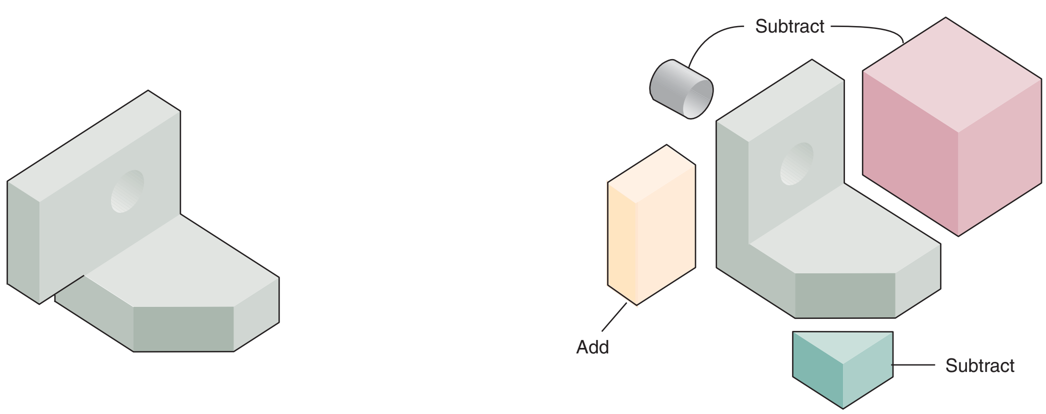


Figure 5.91

Subtracting progressively larger pyramids
Subtraction of progressively larger pyramids from the brick creates new geometric forms.



(A) (B)

Figure 5.92

Additive and subtractive techniques can be used to make a solid geometric form.

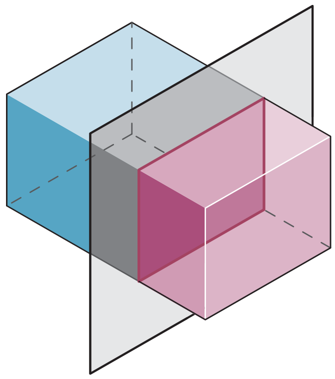


Figure 5.93

Normal cutting plane

A normal cutting plane in the brick will create a new surface called a normal face. This new surface is exactly the same as the end face.

In essence, the cutting plane is a 2-D plane that exists in a 3-D world. Now instead of combining two 3-D solids together, you can combine a 3-D solid with a 2-D plane. The orientation of the plane to the object determines what kind of cut is made; that is, the shape of the new face. For example, in Figure 5.93 the cutting plane is either perpendicular or parallel to all of the major faces on the primitive. This new face is called a **normal face** and is an exact replica of the end face of the primitive. If you rotate the cutting plane about one axis (Figure 5.94) (but less than 90 degrees) and cut all the way through the object, you create an **inclined face.** The inclined faces become longer and longer until the cutting plane is rotated 90 degrees. At this point, the plane is parallel to the top face of the object, and mirrors the shape of that face perfectly; the cutting plane has again become a normal face. If you rotate the cutting plane so that it is neither parallel nor perpendicular to any of the faces of the object, the face created by the cutting plane is called an **oblique face** (Figure 5.95).

When you rotate the cutting plane, the inclined face only lengthens along one of its two dimensions. This effect can be seen in both the brick primitive and the cylinder (Figure 5.96). In the cylinder, when the cutting plane is parallel to the end face, a normal face in the shape of a perfect circle is generated. As the plane rotates around the axis marked A, the dimension along axis A does not change; it stays the diameter of the circle. However, the dimension along axis B, which is perpendicular to axis A, gets longer and longer and the face becomes an *ellipse*.

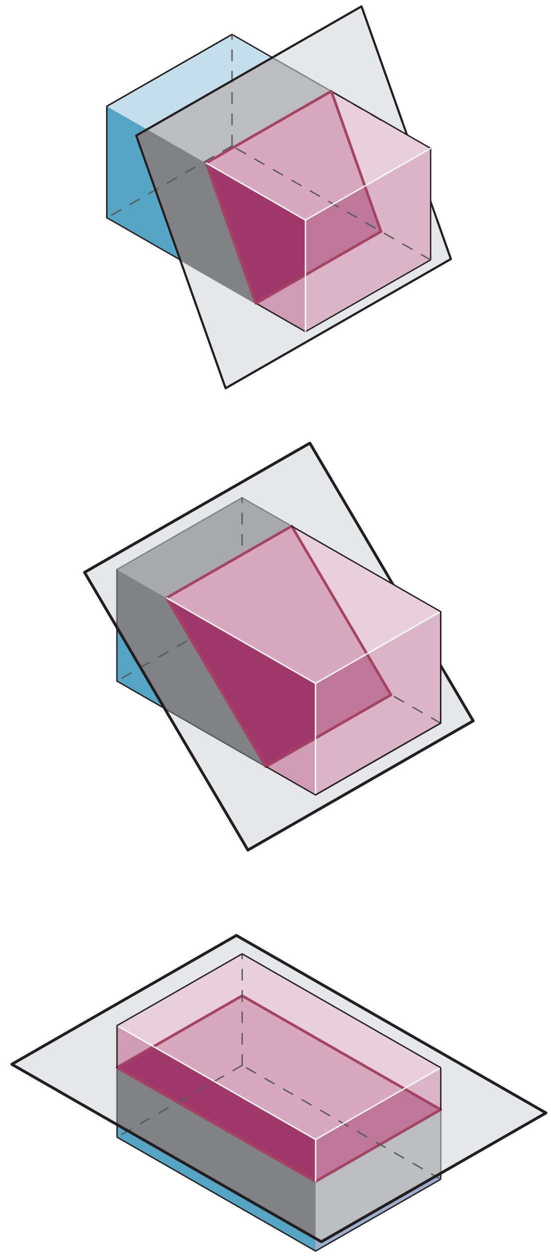


Figure 5.94

Cutting plane rotated about single axis

A cutting plane is rotated about a single axis in the brick. This creates inclined faces until the plane has rotated 90 degrees, creating a face normal to the top view.

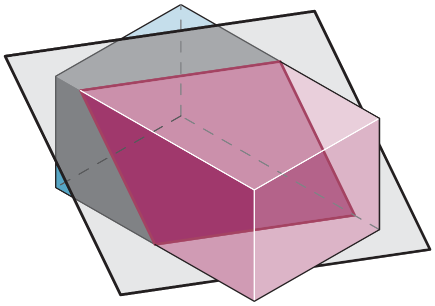


Figure 5.95

Cutting plane rotated about two axes

Rotating a cutting plane about two axes in the brick creates a new face called an oblique face.

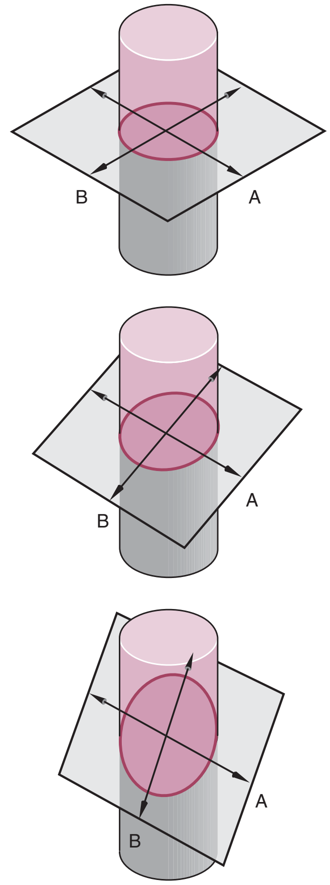


Figure 5.96

Cutting plane rotation

Rotating a cutting plane in a cylinder creates circular and elliptical faces.

Next, visualize the cutting plane actually cutting the object like a knife and making multiple slices along the long dimension. For a cylinder (Figure 5.97A) all of the slices are the same diameter. For a cone, however, (Figure 5.97B), the edges along the long dimension are not parallel to each other, and the slices from the point to the base of the cone get larger and larger, until the last slice equals the diameter of the base. For a sphere (Figure 5.97C), all of the edges are curved and the size of the slices is largest at the middle rather than at one end. These examples demonstrate that, on simpler objects, those edges running parallel to the cutting plane dictate the *shape* of the slices; those edges running in the direction that the cutting plane moves dictate the *size* of the slices.

Practice Exercise 5.16

Using clay or Styrofoam, form a number of blocks approximating various primitive objects, such as cones, cylinders, spheres, cubes, bricks, etc. Use a knife to cut each object into normal slices of uniform thickness. Lay the slices out in the order they came off the object. Compare their sizes and shapes and put them back together again, reforming each solid. What happens if you cut the slices at an incline to the end face of the solid? Do they differ from the normal slices? Do they vary from each other the same way the normal slices do? Do the *end* inclined slices differ from the others? Why?

5.12.3 Symmetry

Symmetry describes the relationship between the two halves of a solid object. For a symmetrical object, both halves are identical. If you rotate the cylinder 180 degrees so that the other circular face is toward you, the cylinder will look the same because both halves of the cylinder are identical.

One way to evaluate two halves of an object without rotating it is to bisect the object with a thin sheet, or cutting plane (Figure 5.98). If the plane acts as a mirror and the mirror reflection of one half looks identical to that of the other half, the halves are symmetrical. Objects can have more than one plane of symmetry. For example, the cylinder can be cut in half by a plane that goes through the center of the circular ends (Figure 5.98B).

Mentally rotating an object is one way to imagine planes of symmetry. For example, if you imagine rolling the cylinder like you would a log, you will see that it does not look any different when you roll it 90 degrees, or even 180 degrees. This demonstrates that there are multiple planes of symmetry passing through the long axis of the cylinder.

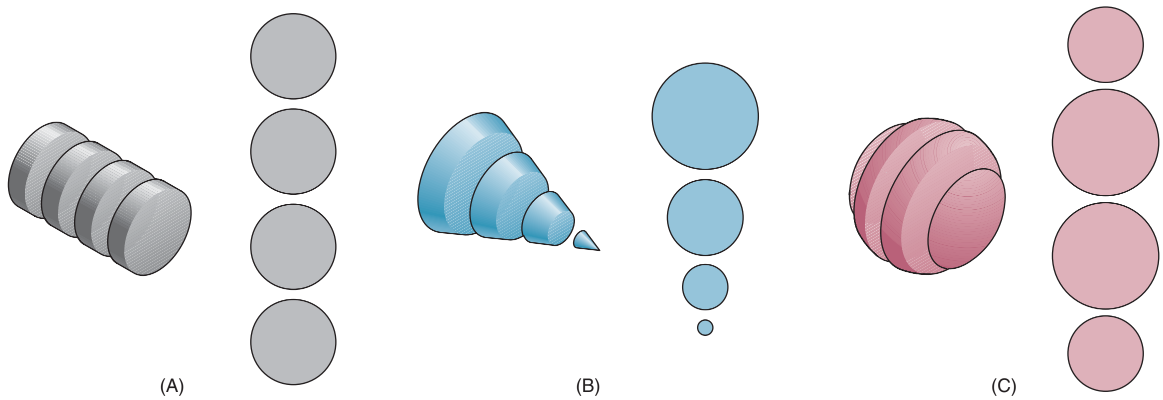


Figure 5.97

Progressive slicing of a cylinder, cone, and sphere

This creates different-sized progressions of circular faces for the three primitives.

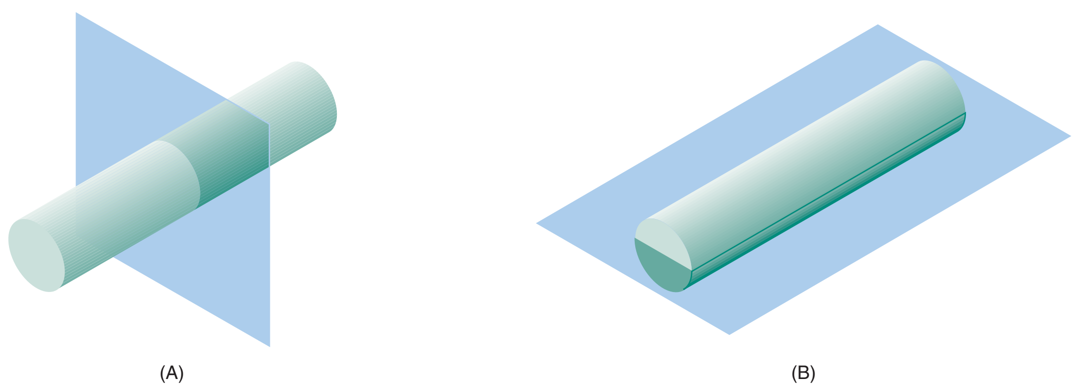


Figure 5.98

Planes of symmetry

Planes of symmetry for a cylinder are created by passing a plane through the midpoint of the cylinder (A) or by passing the plane through the centers of the circular ends (B).

Practice Exercise 5.17

Using physical objects, such as the brick and cylinder constructed in Practice Exercise 5.12, try rotating the objects so that they look as though they were in the same position as they were before. Determine how many planes of symmetry can be identified in these objects. Sketch the objects and show the planes of symmetry.

5.12.4 Surface Models (Developments)

Place the cutting plane on a surface of the object (Figure 5.99A). The face on the cutting plane would be the same as the object's face. If you put a cutting plane on every surface of the object (Figure 5.99B), the collection of cutting planes would form a wrap, or *skin,* around the object. Visualizing this skin is another way to visualize the solid object. The skin is flexible and conforms to the exact shape of the faces of the object. It wraps around curved surfaces and creases wherever there is an edge. To determine what the primitive would look like, "remove" the skin by cutting it at the edges, not on any of the faces, and then flatten the skin out (Figure 5.100).

The flattened skin, called the **development,** clearly shows all of the object's faces, in their true size and shape. It also provides information concerning how those faces are connected. In some cases, the edges are still connected in the development. In other cases, they are cut in order to

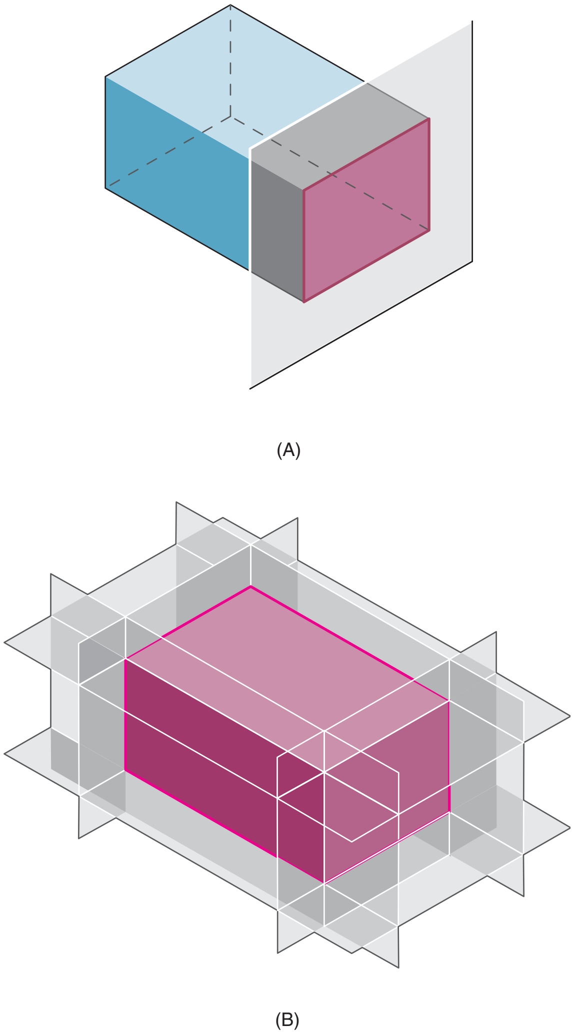


Figure 5.99

Surface cutting planes

Cutting planes can be used to cover the surface of the brick.

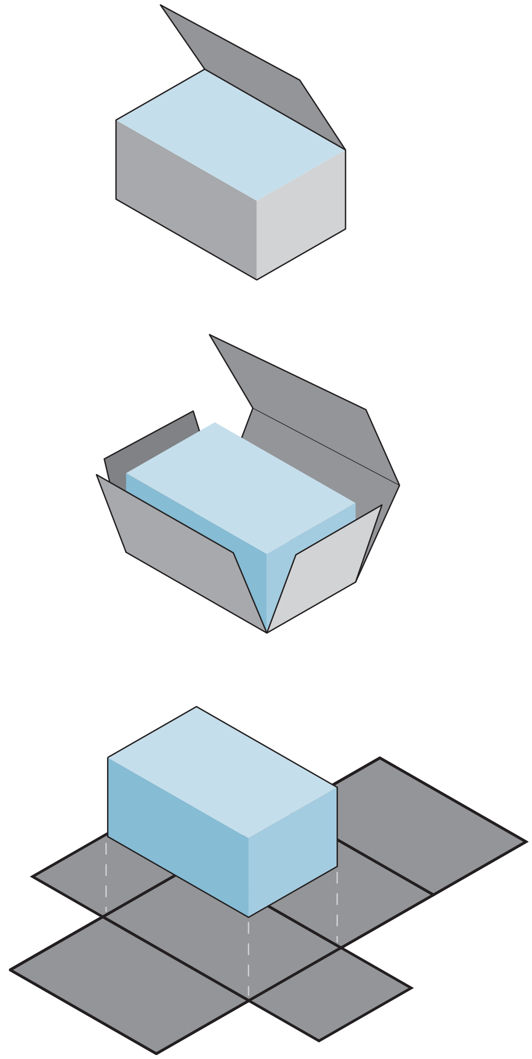


Figure 5.100

Development

Development of the brick is accomplished by cutting the skin of the brick along some of the edges, then unfolding the skin and flattening it.

allow the skin to unfold and lay flat. Those edges that would be reattached if the development were again wrapped around the solid are indicated by dashed lines (Figure 5.101). It is important to note that the edges cut to unfold the development can vary. For example, Figure 5.102 shows another possibility for developing the brick. However, do not completely cut a face free from the rest of the development.

Developments can also be made for objects that have curved surfaces, and the nature of the curved surface directly affects the ease with which the development is made. A **single-curved surface** is a surface that only curves in one dimension (such as a cylinder). A development for this type of curved face can be made without many cuts (Figure 5.103A). A sphere, on the other hand, is a **double-curved surface,** that is, one which curves in two dimensions (Figure 5.103B). This surface can only be approximated in a development and only after the face is cut in a number of places.

Visualization techniques are specific to certain types of objects and manufacturing processes. For example, the visualization with solids technique would be helpful to a

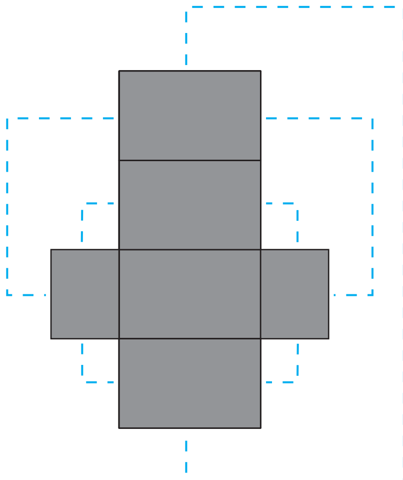


Figure 5.101

Brick edges that are attached to form the brick skin are indicated by dashed lines.

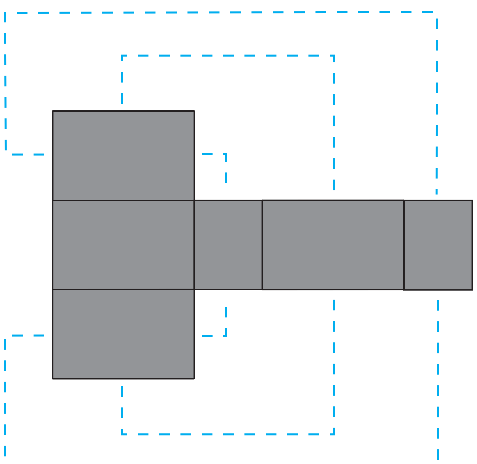


Figure 5.102

There are many alternative methods of creating the development for the brick, such as the one shown here.

machining operation that removes material from an object. In contrast, the development technique would be indispensable in sheet metal and package design work. For technical drawings, cutting planes are useful in creating sectional views of complicated parts or structures such as buildings.

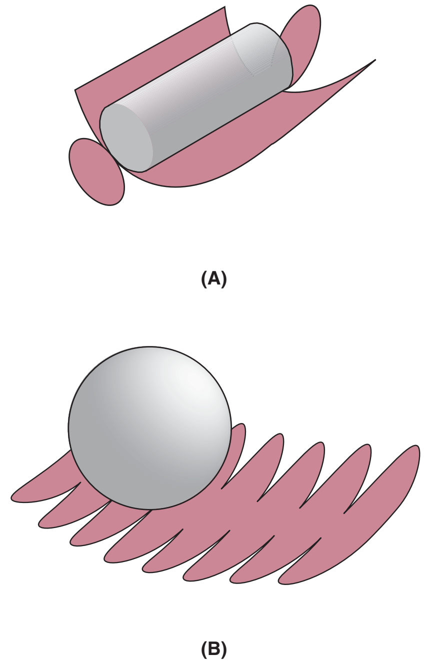


Figure 5.103

Single- and double-curved surface development
The difference between developing a single-curved surface (a cylinder) and a double-curved surface (a sphere).

Practice Exercise 5.18

Using some of the primitive objects you have made, create developments by wrapping the objects in paper. Start by placing the paper on the object. Fold the paper around a few of the edges, creasing the paper lightly as you go. As you proceed, trim the paper and cut the edges at the creases. For the rectilinear forms, such as the cube or the brick, make more than one development and cut different edges. Make developments of cylinders, cones, and other objects with single-curved surfaces. Try making a development of a sphere. Can you wrap the paper around it without wrinkling the paper? With a sphere, how many separate surfaces are you actually developing?

5.13 Multiview Drawings Visualization

With sufficient practice, it is possible to learn to read 2-D engineering drawings, such as the multiview drawings in Figure 5.104, and to develop mental 3-D images of the objects. Reading a drawing means being able to look at a

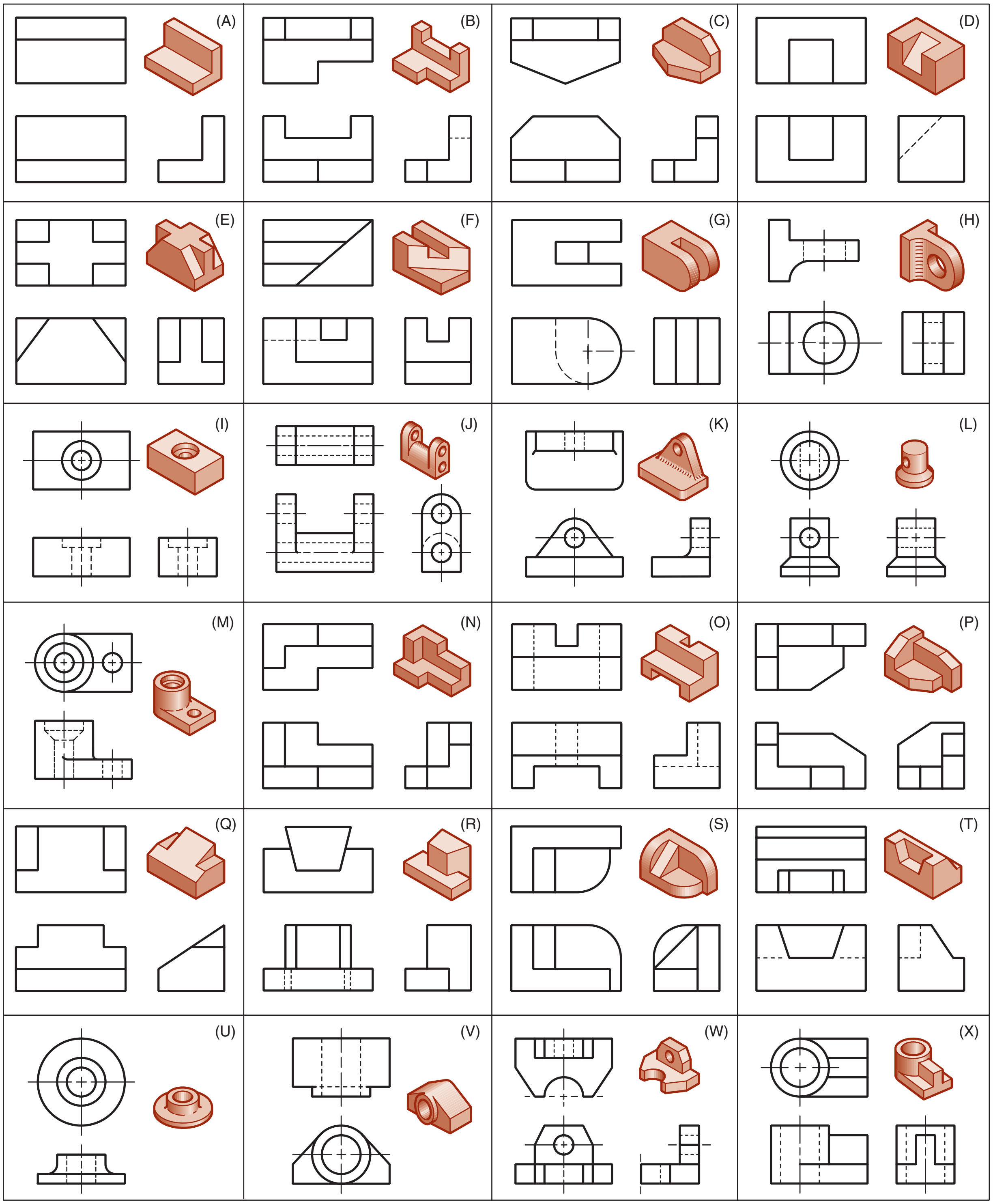


Figure 5.104

Examples of the standard representations of various geometric forms

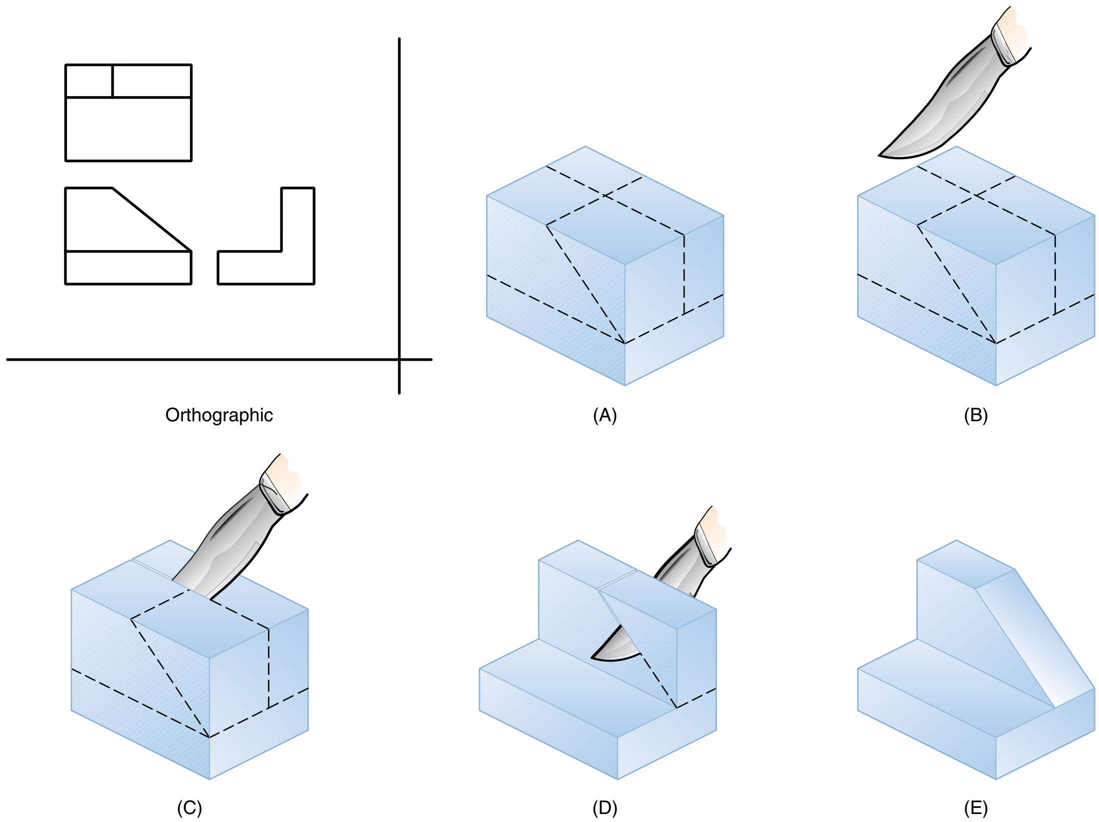


Figure 5.105

Creating a real model

Using Styrofoam or modeling clay and a knife, model simple 3-D objects to aid the visualization process.

two- or three-view multiview drawing and form a clear mental image of the three-dimensional object. A corollary skill is the ability to create a multiview drawing from a pictorial view of an object. Going from pictorial to multiview and multiview to pictorial is an important process performed every day by technologists. The following sections describe various techniques for improving your ability to visualize multiview drawings. Additional information on visualizing 3-D objects is found in Sections 5.10 through 5.12.

5.13.1 Projection Studies

One technique that will improve multiview drawing visualization skills is the study of completed multiviews of various objects, such as those in Figure 5.104. Study each object for orientation, view selection, projection of visible and hidden features, tangent features, holes and rounded surfaces, inclined and oblique surfaces, and dashed line usage.

5.13.2 Physical Model Construction

The creation of physical models can be useful in learning to visualize objects in multiview drawings. Typically, these models are created from modeling clay, wax, or Styrofoam. The two basic techniques for creating these models are cutting the 3-D form out of a rectangular shape (Figure 5.105) and using analysis of solids (Figure 5.106) to divide the object into its basic geometric primitives and then combining these shapes. (See Section 5.9.8 for more information on analysis of solids.)

Practice Exercise 5.19

Figure 5.105 shows the steps for creating a physical model from a rectangular block of modeling clay, based on a multiview drawing.

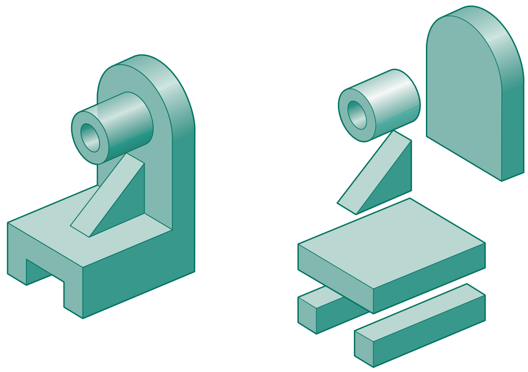


Figure 5.106

Analysis of solids

A complex object can be visualized by decomposing it into simpler geometric forms.

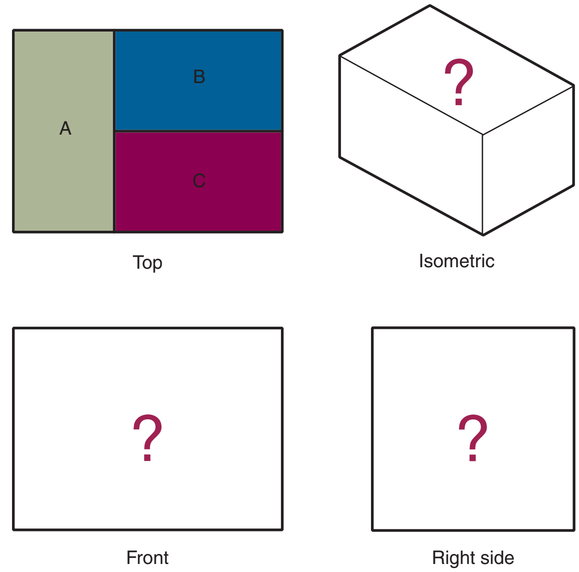


Figure 5.107

Adjacent areas

Given the top view, make isometric sketches of possible 3-D objects.

Step 1. Create a rectangular piece of clay that is proportional to the width, height, and depth dimensions shown on the multiview drawing.

Step 2. Score the surface of the clay with the point of the knife to indicate the positions of the features.

Step 3. Remove the amount of clay necessary to leave the required L-shape shown in the side view.

Step 4. Cut along the angled line to remove the last piece of clay.

Step 5. Sketch a multiview drawing of the piece of clay. Repeat these steps to create other 3-D geometric forms.

5.13.3 Adjacent Areas

Given the top view of an object, as shown in Figure 5.107, sketch isometric views of several possible 3-D forms. Figure 5.108 shows just four of the solutions possible, and demonstrates the importance of understanding adjacent areas when reading multiview drawings. **Adjacent areas** are surfaces which reside next to each other. The boundary between the surfaces is represented as a line indicating a *change in planes*. No two adjacent areas can lie in the same plane. Adjacent areas represent either:

1. Surfaces at different levels.
2. Inclined or oblique surfaces.
3. Cylindrical surfaces.
4. A combination of the above.

Going back to Figure 5.107, the lines separating surfaces A, B, and C represent three different surfaces at different heights. Surface A may be higher or lower than surfaces B and C; surface A may also be inclined or cylindrical. This ambiguity emphasizes the importance of using more than one orthographic view to represent an object clearly.

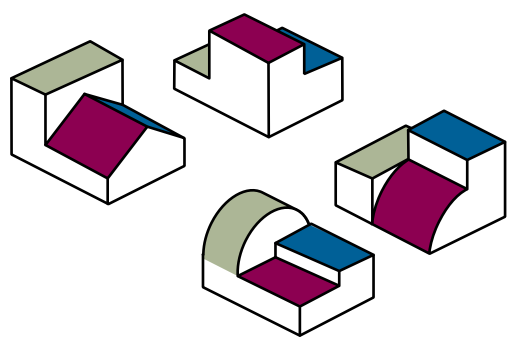


Figure 5.108

Possible solutions to Figure 5.107

5.13.4 Similar Shapes

One visualization technique involves identifying those views in which a surface has a similar configuration and number of sides. (See Section 5.8.2, Rule 5, “Configura-

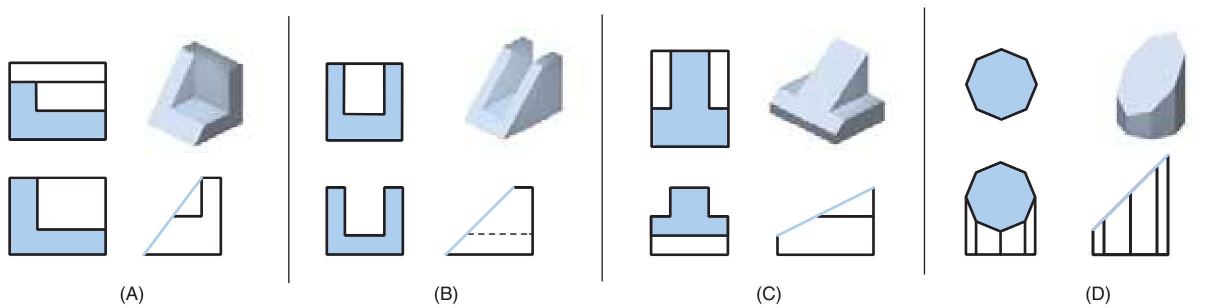


Figure 5.109

Similar-shaped surfaces

Similar-shaped surfaces will retain their basic configuration in all views, unless viewed on edge. Notice that the number of edges of a face remains constant in all the views and that edges parallel in one view will remain parallel in other views.

tion of Planes," and Rule 6, "Parallel Features.") Similar shape or configuration is useful in visualizing or creating multiview drawings of objects with inclined or oblique surfaces. For example, if an inclined surface has four edges with opposite edges parallel, then that surface will appear with four sides with opposite edges parallel in any orthographic view, unless you are viewing the surface on edge. By remembering this rule you can visually check the accuracy of an orthographic drawing by comparing the configuration and number of sides of surfaces from view to view. Figure 5.109 shows objects with shaded surfaces that can be described by their shapes. In Figure 5.109A, the shaded surface is L-shaped and appears similar in the top and front views, but it is an edge in the right side view. In Figure 5.109B, the shaded surface is U-shaped and is configured similarly in the front and top views. In Figure 5.109C, the shaded surface is T-shaped in the top and front views. In Figure 5.109D, the shaded surface has eight sides in both the front and top views.

5.13.5 Surface Labeling

When multiview drawings are created from a given pictorial view, surfaces are labeled to check the accuracy of the solution. The surfaces are labeled in the pictorial view and then in each multiview, using the pictorial view as a guide. Figure 5.110 is the pictorial view of an object with each of the visible surfaces labeled with a number; for example, the inclined surface is number 5, the oblique surface is number 8, and the hole is number 4. The multiview drawing is then created, the visible surfaces in each view are labeled, and the results are checked against the pictorial.

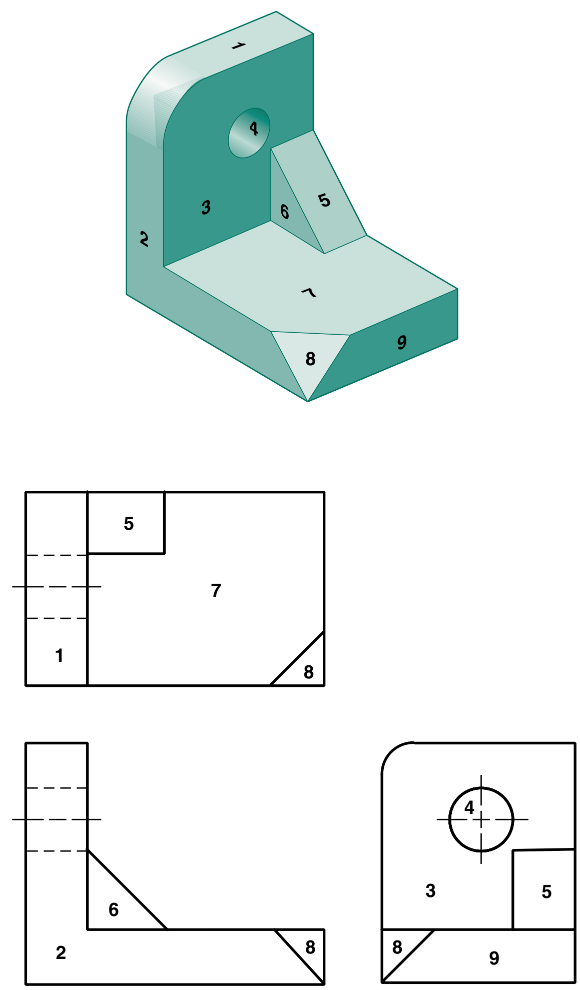


Figure 5.110

Surface labeling

To check the accuracy of multiview drawings, surfaces can be labeled and compared to those in the pictorial view.

Design in Industry

Using Parametrics with an Agile Manufacturing Strategy

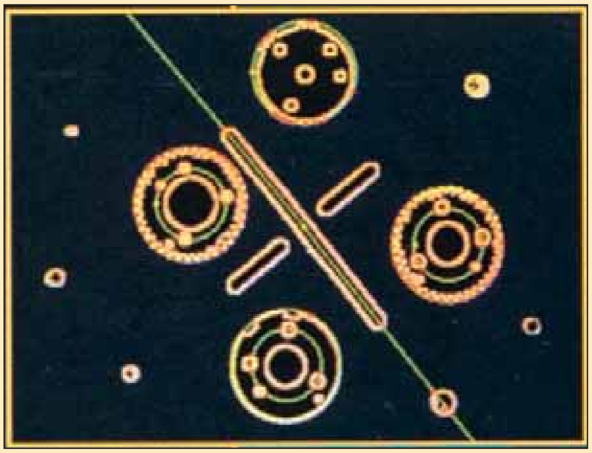
At Sandia National Laboratories, a series of test cases is being carried out to explore the concepts of agile design and manufacturing. The test cases, carried out under the umbrella of the A-Primed Project, are looking at how state-of-the-art communications, computer, and manufacturing technology can be used in the design and manufacture of precision electromechanical parts.

Agile design and manufacturing is a strategy for fast-tracking the design and implementation of manufactured components. The A-Primed Project is looking for ways to help companies gain a global market advantage using these techniques.

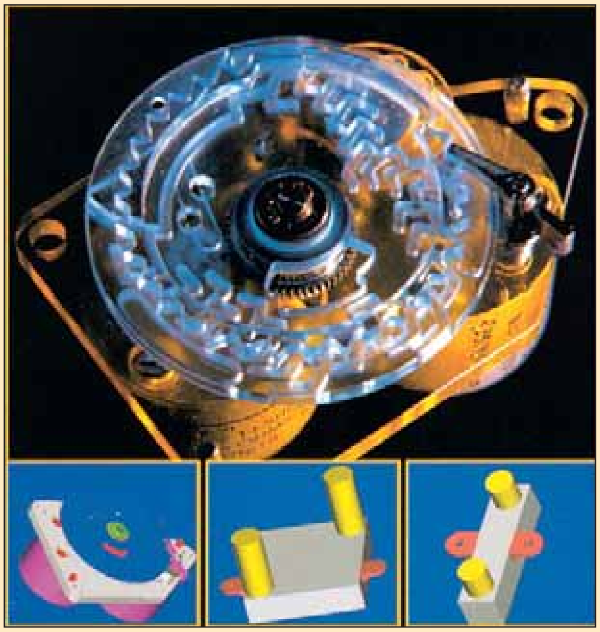
For agile design, the design engineer must implement a process that is fast, flexible, and customer driven. The A-Primed design team employed a process based around parametrics. A customer and the designer, starting with an existing design, define the requirements for the new part. The existing, or parent, design becomes the starting point for spawning a series of child designs. Because the parent design has established the fundamental standards of manufacturability, assembly, and quality, child designs can easily be compared with these design requirements.

Using Pro/ENGINEER to generate the parametric-driven CAD model, virtual prototypes were evaluated with finite element analysis and thermal analysis software tools to make sure the part met design specifications. Once the design was finalized, Pro/MANUFACTURE was used to generate the CNC programs to guide the machine tool paths, saving considerable time in producing the initial parts. The A-Primed assembly team developed highly flexible assembly processes that could be rapidly adapted to new design variations. New assembly procedures could be tested first using computer-generated 3-D visualizations of the assembly process rather than tying up the actual robots on the assembly line.

Given that design and manufacturing groups are often geographically dispersed, the A-Primed Project developed teleconferencing techniques that allowed team members to share CAD files and hold interactive conferences on a variety of computer platforms at locations across the country. These networked, interactive tools allowed design information to be exchanged in real time over long distances while minimizing misunderstandings and maximizing information flow. The end result of the project has been the development and manufacture of precision electromechanical parts for the defense industry in less time and at a lower cost than when using traditional methods.



(Courtesy of Sandia National Laboratories.)



(Courtesy of Sandia National Laboratories.)

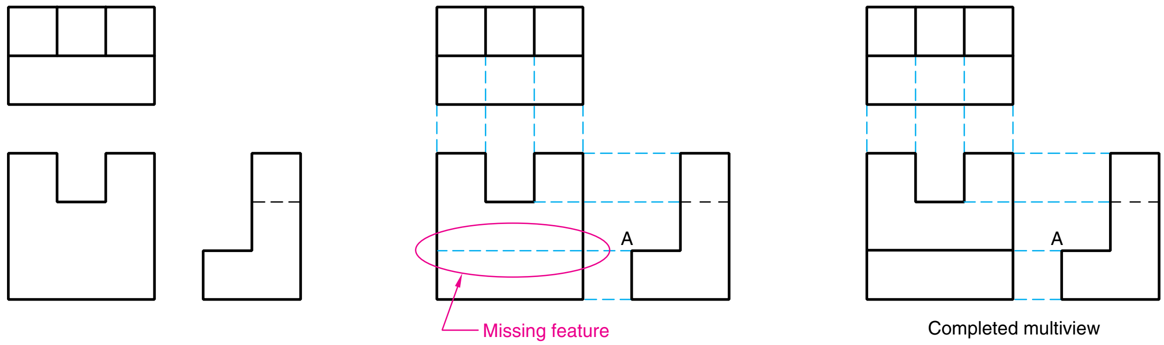


Figure 5.111

Missing-line problems

One way to improve your proficiency is to solve missing-line problems. A combination of holistic visualization skills and systematic analysis is used to identify missing features.

5.13.6 Missing Lines

Another way of becoming more proficient at reading and drawing multiviews is by solving missing-line problems. Figure 5.111 is a multiview drawing with at least one line missing. Study each view, then add any missing lines to the incomplete views. Lines may be missing in more than one of the views. It may be helpful to create a rough isometric sketch of the object when trying to determine the location of missing lines.

> **Step by Step: Locating Missing Lines in an Incomplete Multiview Drawing**
>
> ***Step 1.*** Study the three given views in Figure 5.111.
>
> ***Step 2.*** Use analysis by solids or analysis by surfaces, as described earlier in this text, to create a mental image of the 3-D form.
>
> ***Step 3.*** If necessary, create a rough isometric sketch of the object to determine the missing lines.
>
> ***Step 4.*** From every corner of the object, sketch construction lines between the views. Because each projected corner should align with a feature in the adjacent view, this technique may reveal missing details. For the figure, corner A in the right side view does not align with any feature in the front view, thus revealing the location of the missing line.

5.13.7 Vertex Labeling

It is often helpful to label the vertices of the isometric view as a check for the multiview drawing. In the isometric view in Figure 5.112, the vertices, including hidden

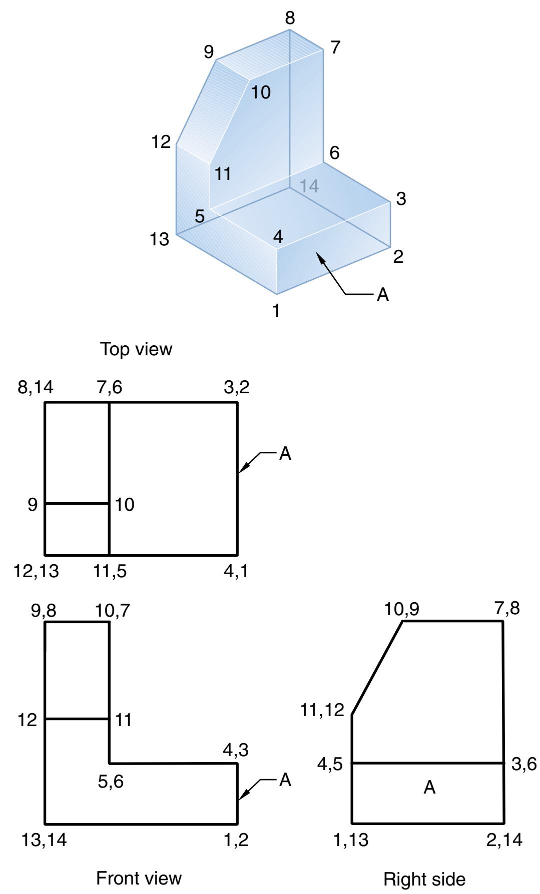


Figure 5.112

Numbering the isometric pictorial and the multiviews to help visualize an object

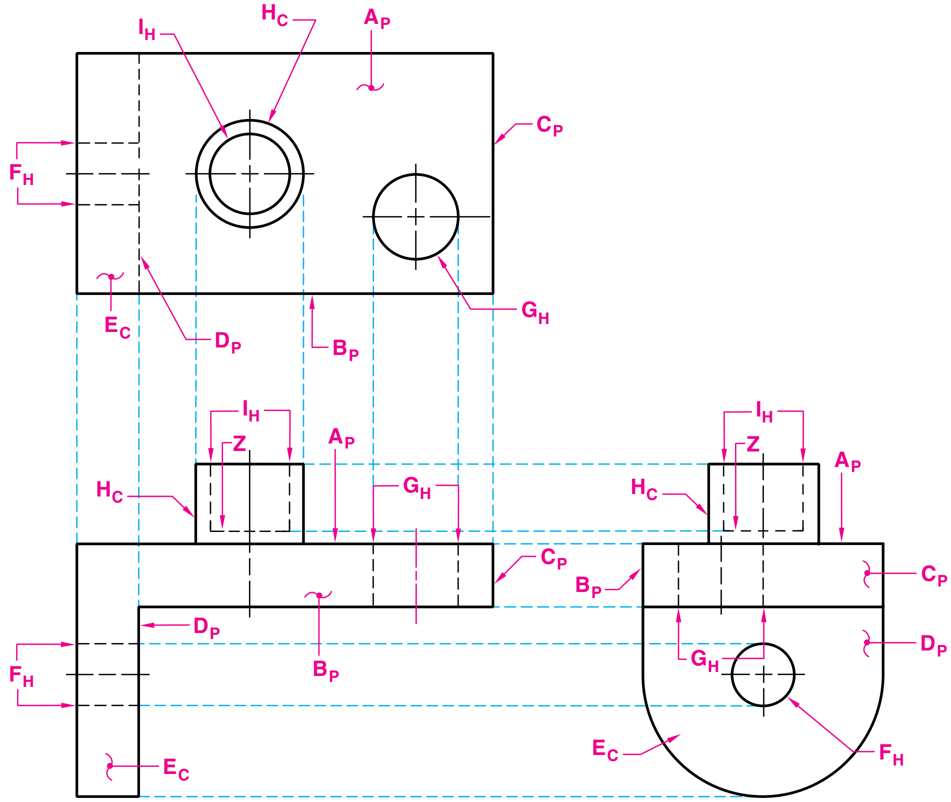


Figure 5.113

Visualizing a multiview drawing using analysis by solids

ones, are labeled with numbers, then the corresponding vertices in the multiviews are numbered. In the multiviews, hidden vertices are lettered to the right of the numbered visible vertices. For example, the vertices of surface A are numbered 1, 2, 3, and 4. In the front view, surface A appears on edge, and vertices 1 and 4 are in front of vertices 3 and 2. Therefore, in the front view, the vertices of surface A are labeled 4, 3 and 1, 2.

5.13.8 Analysis by Solids

A common technique for analyzing multiview drawings is **analysis by solids,** in which objects are decomposed into solid geometric primitives, such as cylinders, negative cylinders (holes), square and rectangular prisms, cones, spheres, etc. These primitives are shown in Figure 5.53. Their importance in the understanding and visualization of multiview drawings cannot be overemphasized.

Figure 5.113 is a multiview drawing of a 3-D object. Important features are labeled in each view. Planes are labeled with a P subscript, holes (negative cylinders) with an H subscript, and cylinders (positive) with a C subscript.

Step by Step: Analysis by Solids

Step 1. Examine all three views as a whole and then each view in detail. In the top view is a rectangular shape labeled A_P and three circles labeled G_H, H_C, and I_H. On the left end of the rectangular area are dashed lines representing hidden features. These hidden features are labeled D_P, E_C, and F_H.

Step 2. In the front view is an L-shaped feature labeled B_P. At opposite ends of the L-shaped area are dashed lines representing hidden features and labeled G_H and F_H. On top of the L-shaped area is a rectangular feature with dashed lines representing more hidden features. The rectangular feature is labeled H_C and the hidden feature is labeled I_H.

Step 3. In the right side view are two rectangular areas and a U-shaped area with a circular feature. The rectangular feature adjacent to and above the U-shaped area is labeled C_P and has hidden lines labeled G_H. The rectangular feature above C_P is labeled H_C and contains dashed lines labeled I_H. The U-shaped area is labeled D_P and the arc is labeled E_C. The circular feature in the U-shaped area is labeled F_H.

This general examination of the views reveals some important information about the 3-D form of the object. Adjacent views are compared to each other and parallel projectors are drawn between adjacent views to help further analysis of the object.

Step 4. In the top view, rectangular area A_P extends the full width of the drawing, can only be aligned with area B_P in the front view, and appears as an edge in the front and right side views. Area B_P in the front view is aligned with area C_P in the right side view. B_P appears as a vertical edge in the right side view and a horizontal edge in the top view. The conclusion is that areas A_P, B_P, and C_P are top, front, and right side views, respectively, of a rectangular prism, which is the main body of the part.

Step 5. Circular area G_H in the top view is aligned with the hidden lines labeled G_H in the front view. Because these hidden lines go from top to bottom in the front view, it is concluded that the circle represents a hole. This can be verified by the dashed lines G_H in the right side view.

Step 6. In the front view, rectangular area H_C projects above the main body of the part; therefore, it should be visible in the top view. This rectangular area is in alignment with circular area H_C in the top view, and with rectangular area H_C in the right side view. The conclusion is that area H_C is a cylinder because it appears as a circle in one view and as a rectangle in the other two views.

Step 7. The circle I_H in the top view is aligned with dashed lines I_H in the front view and is inside cylinder H_C. This indicates that circle I_H in the top view is a negative cylinder (hole) centered within cylinder H_C. The dashed line labeled Z in the front and right side views shows the depth of the negative cylinder I_H.

Step 8. In the top view, the dashed lines at the left end of rectangular area A_P represent one or more feature(s) below the main body of the part. Hidden line D_P in the top view is aligned with visible line D_P in the front view, and dashed lines F_H in the top view are directly above dashed lines F_H in the front view. Area E_C in the top view is aligned with area E_C in the front view. So the features hidden in the top view must be D_P and E_C in the front view.

D_P and E_C in the front view are aligned with D_P and E_C in the right side view. The right side view appears to be the most descriptive view of these features. In this view, area E_C is a partial cylinder represented by arc E_C. The side view also reveals that dashed lines F_H in the top and front views represent the diameter of hole F_H. Therefore, area D_P and partial cylinder E_C are a U-shaped feature with a hole whose width is revealed in the front and top views.

Analysis by solids should result in a clear mental image of the 3-D form represented in a 2-D multiview drawing. Figure 5.114 is a pictorial view of the object in the multiview drawing, and it should be similar to the mental image created after following the preceding eight steps.

5.13.9 Analysis by Surfaces

Figure 6.76 lends itself to analysis by solids because there are no inclined or oblique surfaces. With inclined and oblique surfaces, such as those shown in Figure 5.115, **analysis by surfaces** may be more useful.

Step by Step: Analysis by Surfaces

Step 1. Examine all three views in Figure 5.115. There are no circular or elliptical features; therefore, all the areas must be bounded by planar surfaces. In the top view, areas A and B are separated by lines; therefore, they are not in the same plane. The same is true for areas C and D in the front view, and areas E and F in the right side view. The reason for this is that no two contiguous (adjacent) areas can lie in the same plane. If they were in the same plane, a line would not be drawn to separate them. This is an example of Rule 8.

Step 2. The lines of projection between the top and front views indicate that area B corresponds to area D. Areas B and D are also similar in shape in that they both have six sides, thus reinforcing the possibility that areas B and D are the same feature. Similarly, areas A and C are aligned and are similar in shape, so they could be the same feature. However, before accepting these two possibilities, the side view must be considered.

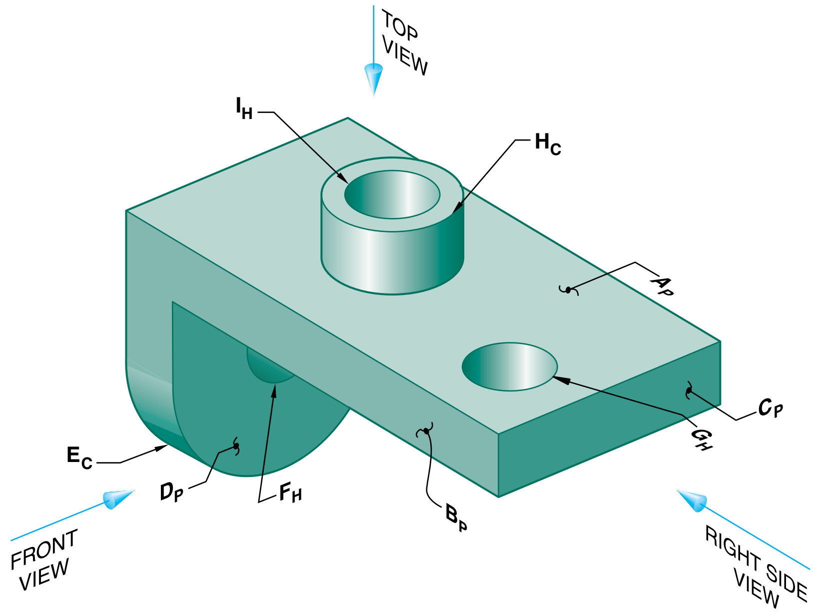


Figure 5.114

A pictorial view of the multiview drawing in Figure 5.113, revealing its three-dimensional form

Step 3. Area D aligns with area F, but they are not similar in shape; area F is three-sided and area D is six-sided. Therefore, areas D and F are not the same feature. In the right side view, area D must be represented as an edge view separating areas E and F; therefore, area D is the inclined plane in the right side view. Area C aligns with area E, but they are not similar in shape; area C is four-sided and area E is three-sided. In the right side view, area C must be represented as an edge view and is the vertical line on the left side of the view.

Step 4. Areas E and F are not represented in the top or front views; therefore, areas E and F are edge views in the front and top views (Figure 5.116). Because areas E and F are visible in the right side view, they are at the right end of the front and top views. Therefore, they must be located at the right end of the object.

Step 5. Based on alignment and similarity of shape, surfaces B and D must be the same surface.

Step 6. Area A in the top view is an edge view represented as a horizontal line in the front and side views. Area C in the front view is a horizontal edge view in the top view and a vertical edge view in the right side view. Areas A and C are therefore not the same.

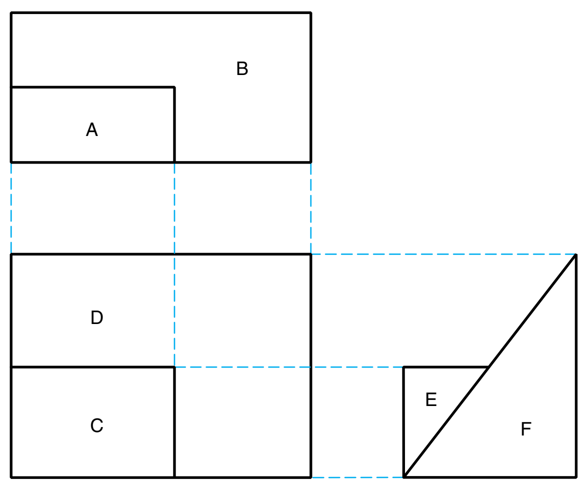


Figure 5.115

Visualizing a multiview drawing using analysis by surfaces

3-D Modeling Project

Chapter 5: Stapler Modeling Project

After you have created 3-D models of the parts, create multiviews using CAD. Depending on your CAD software, you will either be able to automatically extract the views or will have to create the views yourself. If the views are automatically created, make sure that the CAD-generated views conform to ANSI standards.

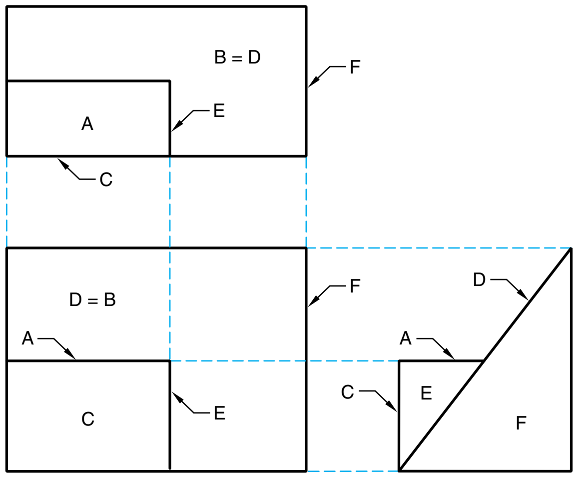


Figure 5.116

Conclusions drawn about Figure 5.115

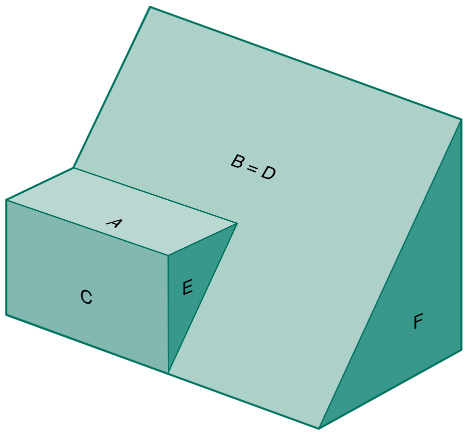


Figure 5.117

A pictorial view of Figure 5.115, revealing its three-dimensional form

Figure 5.117 is a pictorial view of the object. Areas B and D are the same inclined plane, area A is a horizontal plane, and areas C, E, and F are vertical planes.

> Principles of Orthographic Projection Rule 8:
> ***Contiguous Areas***
> No two contiguous areas can lie in the same plane.

5.14 Summary

Multiview drawings are an important part of technical graphics. Creating multiview drawings takes a high degree of visualization skill and considerable practice. Multiview drawings are created by closely following orthographic projection techniques and ANSI standards. The rules of orthographic projection are listed here for your reference.

Rule 1: Every point or feature in one view must be aligned on a parallel projector in any adjacent view.

Rule 2: Distances between any two points of a feature in related views must be equal.

Rule 3: Features are true length or true size when the lines of sight are perpendicular to the feature.

Rule 4: Features are foreshortened when the lines of sight are not perpendicular to the feature.

Rule 5: Areas that are the same feature will always be similar in configuration from one view to the next, unless viewed as an edge.

Rule 6: Parallel features will always appear parallel in all views.

Rule 7: Surfaces that are parallel to the lines of sight will appear on edge and be represented as a line.

Rule 8: No two contiguous areas can lie in the same plane.

Auxiliary views are a type of orthographic projection used to determine the true size and shape of inclined and oblique surfaces of objects. Normally, auxiliary views are projected from existing principal views. Successive auxiliary views can be created by projecting from an existing auxiliary view.

Goals Review

1. Explain orthographic and multiview projection. Sections 5.1, 5.2
2. Identify frontal, horizontal, and profile planes. Sections 5.2.1, 5.2.2, 5.2.3
3. Identify the six principal views and the three space dimensions. Section 5.4
4. Apply standard line practices to multiview drawings and sketches. Section 5.4.6
5. Create a multiview drawing by sketching or CAD. Section 5.5
6. Identify normal, inclined, and oblique planes in multiview drawings. Sections 5.7.2, 5.7.3, 5.7.4
7. Represent lines, curves, surfaces, holes, fillets, rounds, chamfers, runouts, and ellipses in multiview sketches. Section 5.8
8. Identify how ANSI standard drawing representation sometimes diverges from true projection. Section 5.9
9. Apply different visualization techniques used to the representation of 3-D objects. Sections 5.10, 5.11, 5.12
10. Apply visualization by solids and surfaces to multiviews. Sections 5.13.8, 5.13.9
11. Explain the importance of multiviews. Section 5.3
12. Identify limiting elements, hidden features, and intersections of two planes in multiviews. Section 5.8

Questions for Review

1. Define orthographic projection.
2. How is orthographic projection different from perspective projection? Use a sketch to highlight the differences.
3. Define multiview drawings. Make a simple multiview sketch of an object.
4. Define frontal, horizontal, and profile planes.
5. List the six principal views.
6. Define fold lines.
7. List the space dimensions found on a front view, top view, and profile view.
8. Define a normal plane.
9. Define an inclined plane.
10. Define an oblique plane.
11. List the eight rules of orthographic projection.
12. Why is visualization important in engineering and technical graphics? Is it useful in any other fields? Are you born with the ability to visualize, or is it learned?
13. What is the relationship between faces and edges in the visualization of an object?
14. Do planar and curved surfaces reveal themselves differently on an object?
15. Explain the different visual results of additive and subtractive combinations of two solids. Are there ways of arranging additive or subtractive combinations such that the resulting object doesn't look any different?
16. What are the differences in the way normal, inclined, and oblique faces are visualized? How are cutting planes used to generate these faces?
17. Define a development. How is it used in visualization?

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Workbook Problems

Workbook Problems are additional exercises to help you learn the material presented in this chapter. The problems are located at the back of the textbook and can be removed from the book along the perforated edge.

5.1 Surface Identification. In the table, match the given surface letter from the pictorial drawing with the corresponding surface number from the multiview drawing for each view.

5.2 Object Feature Identification. Identify the feature on the object as either an edge (E), face (F), vertex (V), or limiting element (L) in the space provided.

5.3 Surface Labeling. Draw or sketch the front, top, and right side views of the object shown. Number each visible surface of the multiviews to correspond to the numbers shown in the given view.

5.4 Object Rotation. Target shapes P and Q are to be matched with the correct rotated three-dimensional representations of the letters P and Q. Write the letter P or Q in the square below the rotated letter.

5.5 Multiview Sketching 1. Sketch the front, top, and right side views using the gridded space.

5.6 Multiview Sketching 3. Sketch the front, top, and right side views using the gridded space.

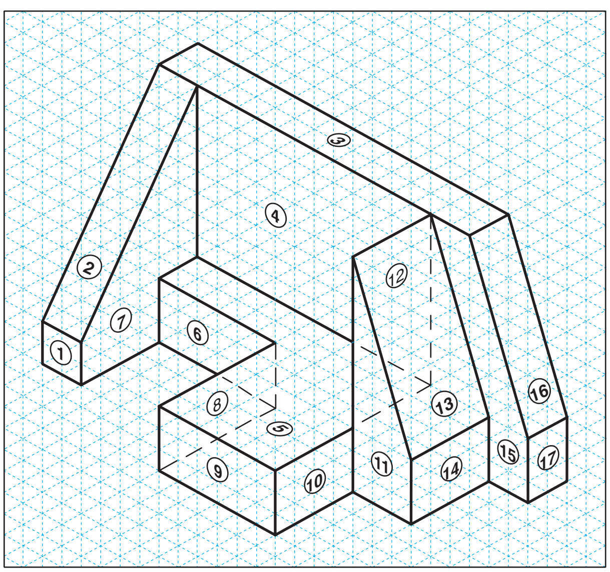


Figure 5.118

Solid object for Problem 5.1

Problems

The website contains starter files for most of the drawing problems in either your native CAD file format or as a DXF file which can be imported into most CAD software programs. If you are sketching the problems, use either paper recommended by your instructor or the workbook that accompanies this text.

Hints for Multiview Sketching

- Identify the major features and overall dimensions of the object.
- Use clean, crisp strokes.
- Do not use straightedges or scales when sketching.
- Start by drawing bounding boxes and a miter line, using construction lines.
- Align the views.
- Use light construction lines to locate vertices and edges.
- Only measure dimensions along the primary axes.
- Map inclined and oblique faces between all three views.
- Follow the precedence of lines.
- Double-check to make sure there are no missing hidden or center lines.
- Darken all visible, hidden, and center lines.

5.1 (Figure 5.118) Draw or sketch the front, top, and right side views of the object shown in the pictorial. Number each visible surface in each of the multiviews to correspond to the numbers given in the pictorial view.

5.2 (Figure 5.119) Given the front view shown in the figure, design at least six different solutions. Sketch your solutions in pictorial and in front and side views.

5.3 (Figure 5.120) Given the two views of a multiview drawing of an object, sketch or draw the given views or use CAD, and then add the missing view. As an additional exercise, create a pictorial sketch of the object.

5.4 (Figure 5.121) Given three incomplete views of a multiview drawing of an object, sketch or draw the given views or use CAD, and then add the missing line or lines. As an additional exercise, create a pictorial sketch of the object.

5.5 (Figure 5.122) Sketch, or draw with CAD multiviews of the objects shown in the pictorials.

5.6 (Figure 5.123) Sketch or use CAD to draw the given views and an auxiliary view of the inclined surfaces.

5.7 (Figures 5.124 through 5.161) Sketch or draw with CAD multiviews of the objects, or create 3-D CAD models for the parts shown.

5.8 On square grid paper, sketch a series of multiviews of a cube, at least eight squares on a side. Visualize the following modifications to the cube and draw the resulting multiviews:

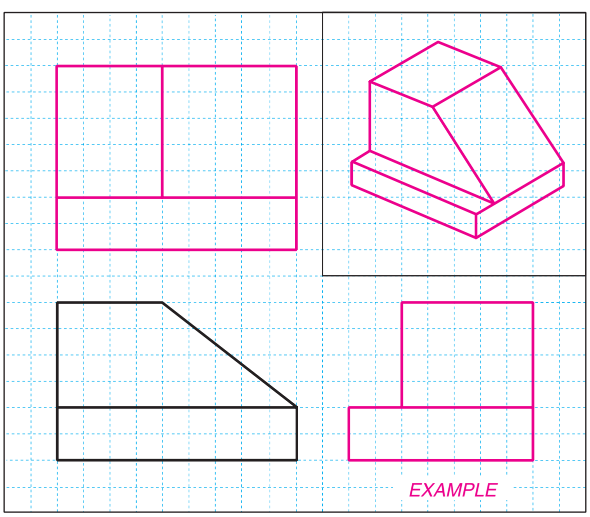


Figure 5.119

Front view for Problem 5.2

a. Looking at the front view, drill a hole 3 squares in diameter and parallel to the line of sight.

b. Take the result of (a) and drill another hole 2 squares in diameter to the right of the first hole.

c. Take the result of (a) and drill another hole 3 squares in diameter above the first hole.

d. Take the result of (a) and drill a hole 5 squares in diameter in the same location as the first hole, but only halfway through the cube.

e. Instead of drilling a 3-square-diameter hole through the object, create a cylinder projecting 2 squares out of the cube and parallel to the line of sight of the front view. Compare this to the views in (a).

f. Same as (e), except raise the cylinder along the line of sight of the top view.

g. Same as (a), except remove a square feature, rather than a round hole. Compare this to the views in (a).

h. Same as (a), except place the center 2 squares to the right. Enlarge the drill to a diameter of 5 squares; 7 squares; 9 squares.

i. Find the midpoints of the top and right side edges of the front view. Draw a line connecting these points and project it along the line of sight for the front view to create a cutting plane. Remove this corner of the cube.

j. Same as (i), except rotate the cutting plane to be 15°, 30°, 60°, and 75° to the horizontal. Compare the dimensions of the inclined surface projections at each of these angles (including the original 45° angle).

k. Same as (i), except move the cutting plane toward the lower left corner of the front view, in 2-square increments. When is the inclined surface the largest?

l. Same as (i), except the cutting plane is defined by the midpoints of the top and right side edges of the front view and the midpoint of the top edge of the right side view.

m. Same as (l), except move the cutting plane in 2-square increments toward the opposite corner of the cube.

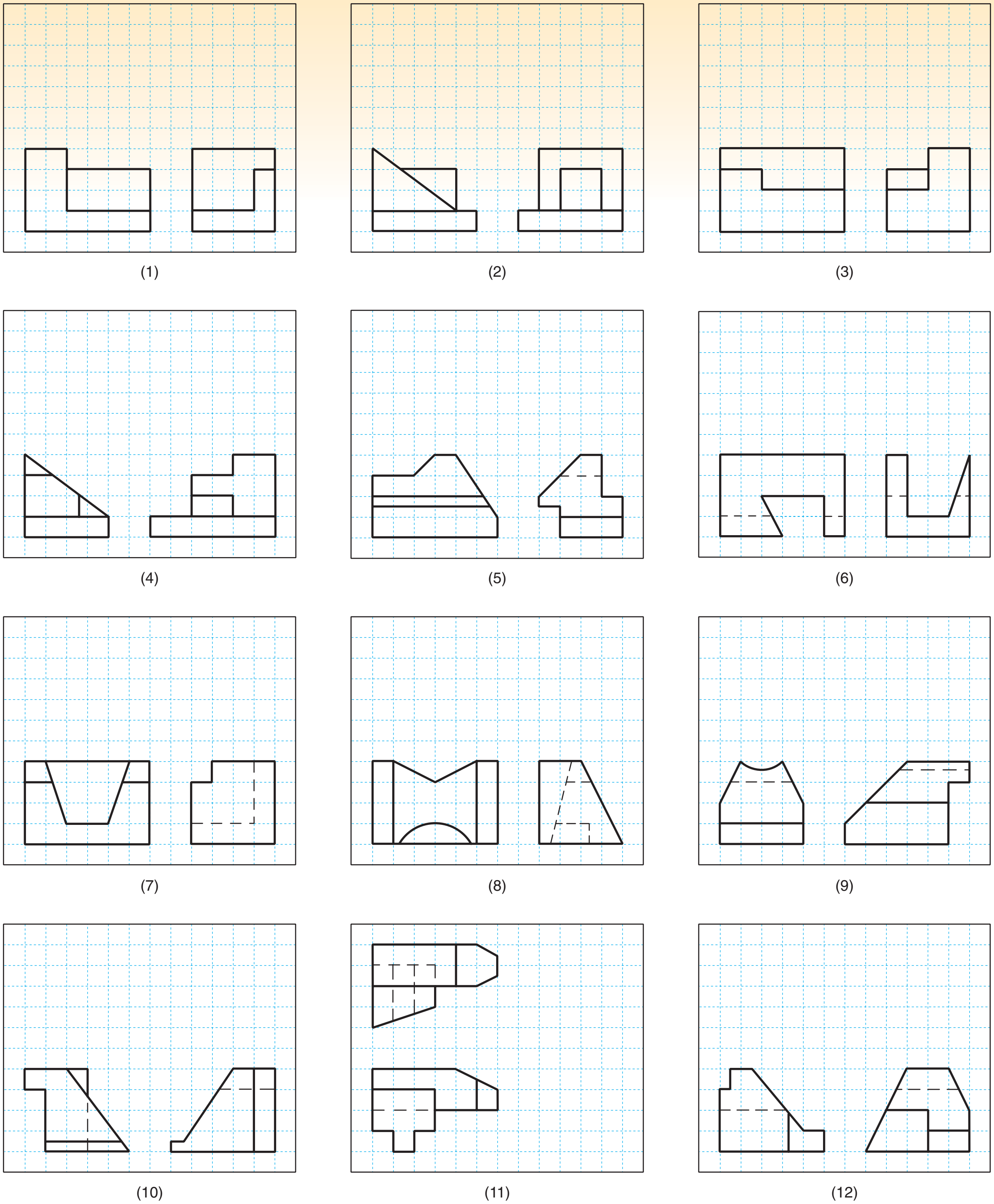
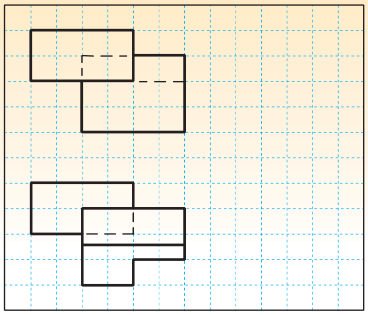


Figure 5.120

Two-view drawings of several objects for Problem 5.3



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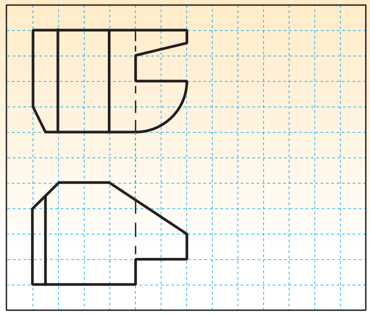

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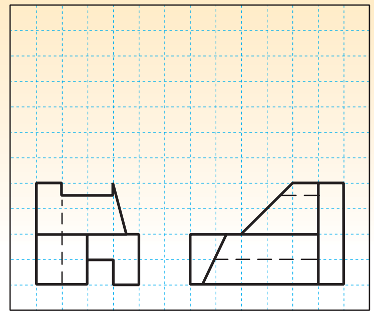

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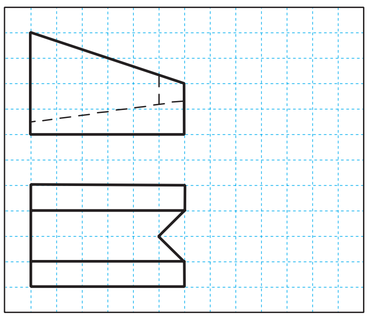

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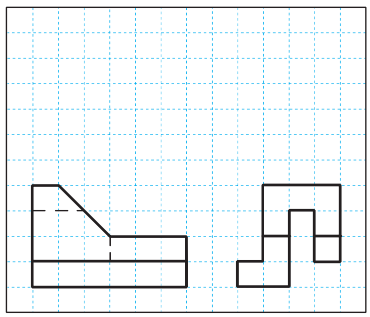

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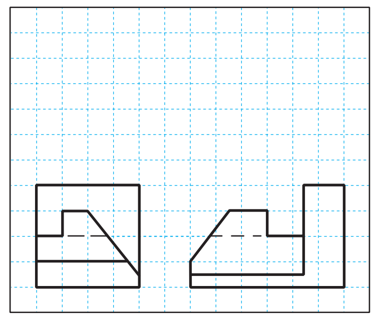

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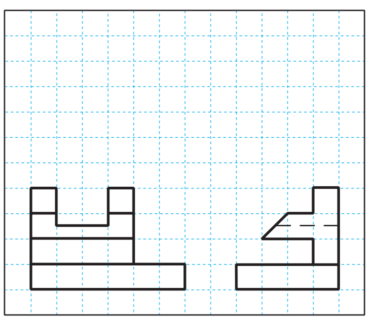

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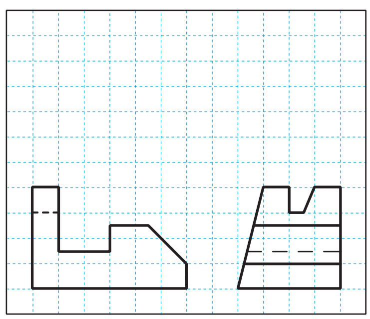

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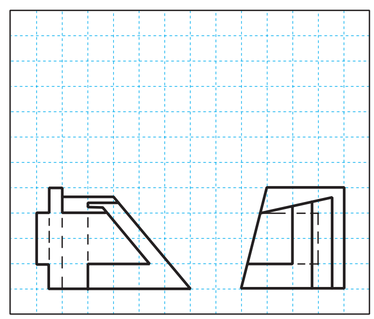

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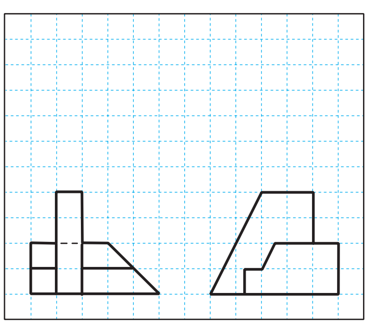

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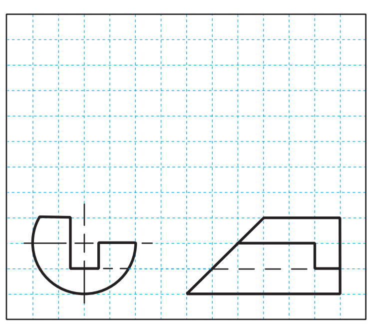

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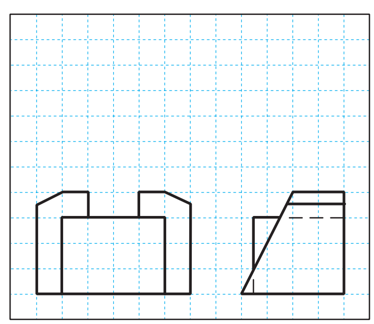

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Figure 5.120

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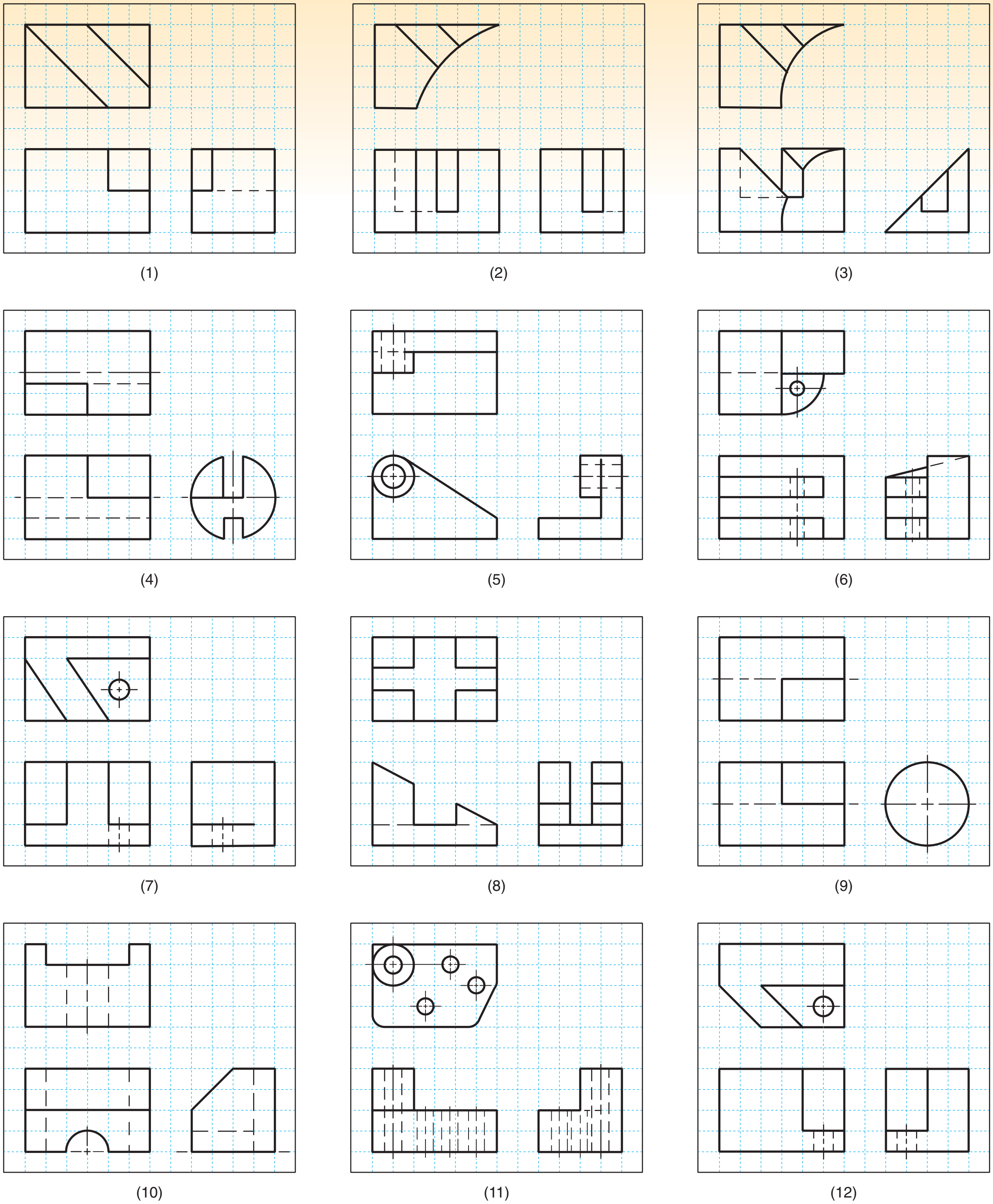
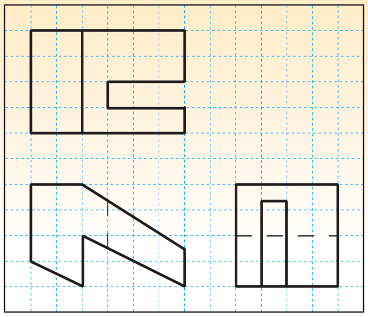


Figure 5.121

Three incomplete views of a multiview drawing of an object for Problem 5.4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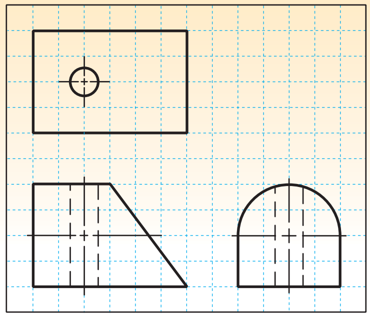
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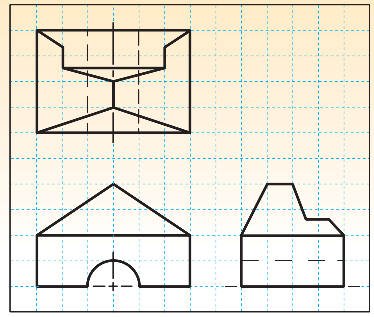
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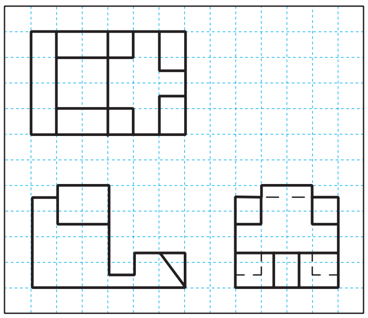
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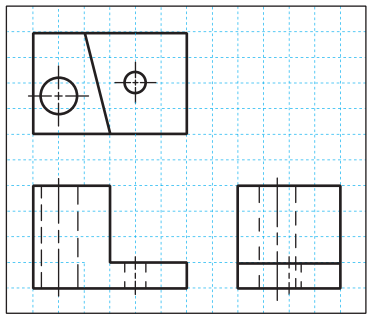
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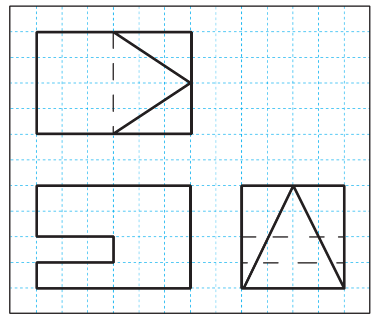
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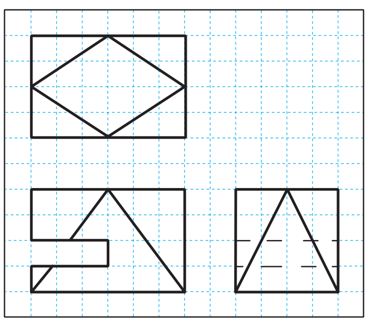
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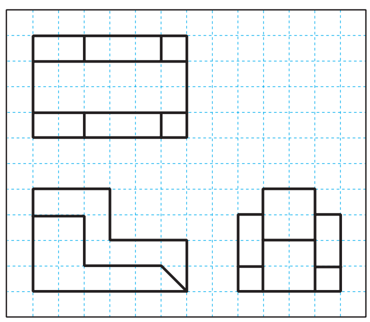
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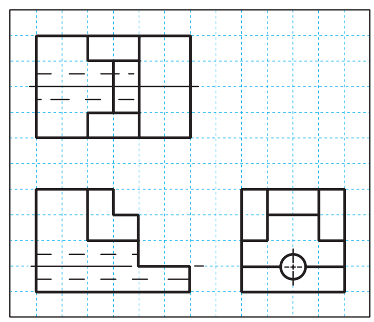
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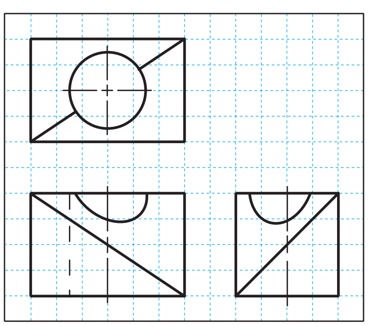
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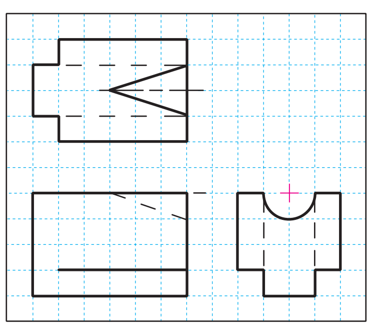
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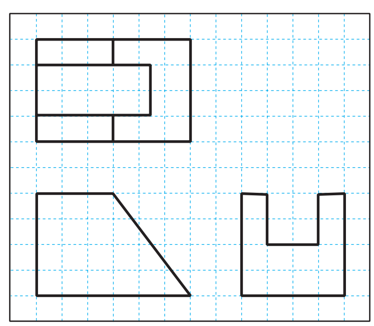
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Figure 5.121

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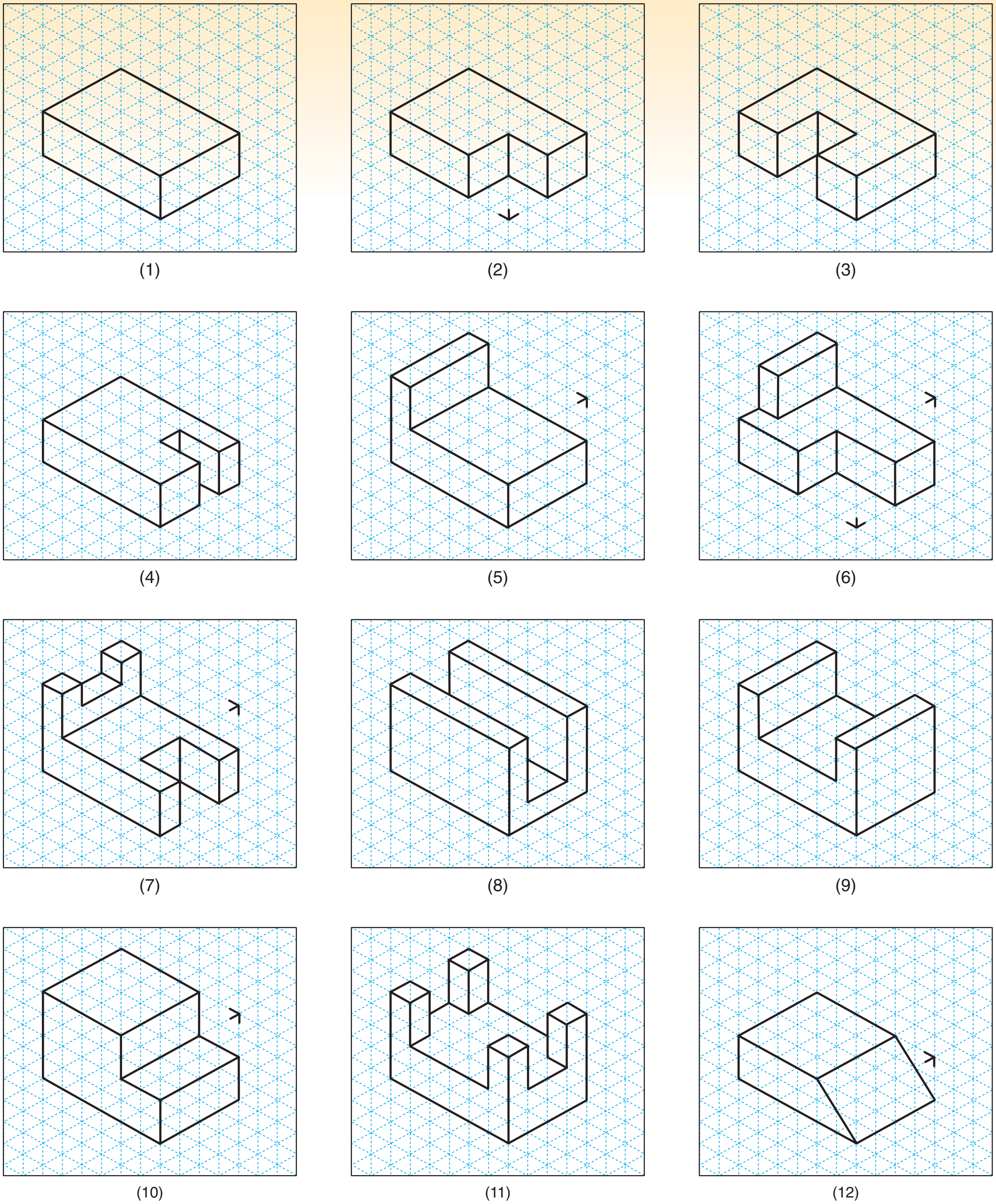
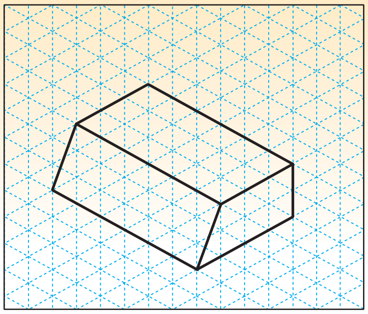


Figure 5.122

Problem 5.5 multiview sketching problems
Assume all holes to be through.



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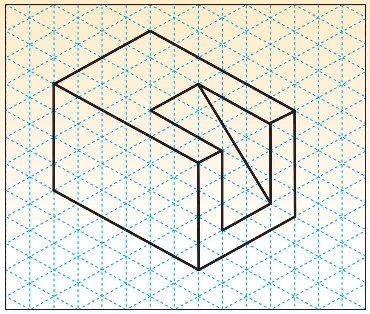

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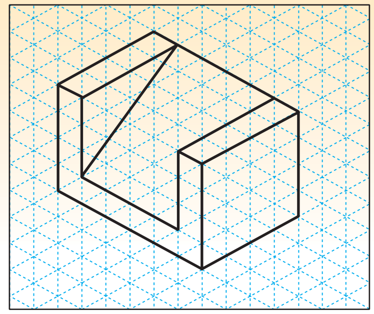

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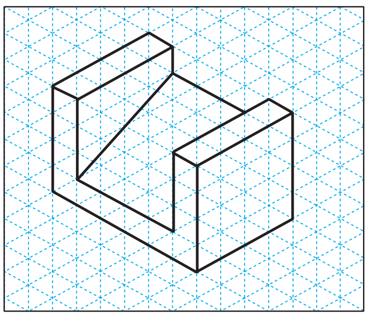

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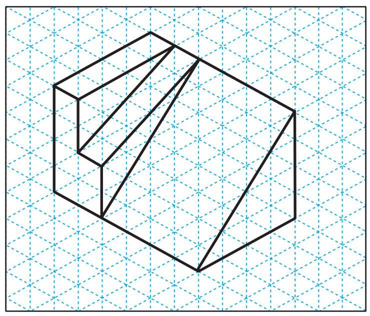

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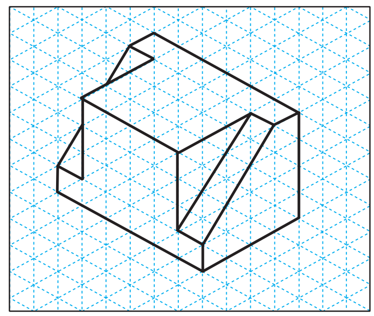

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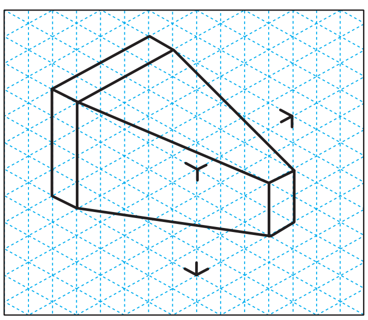

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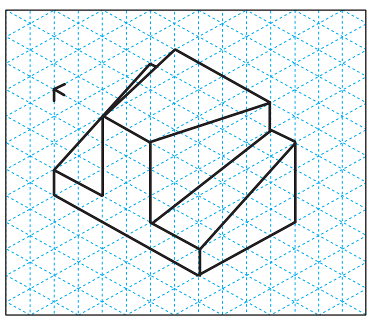

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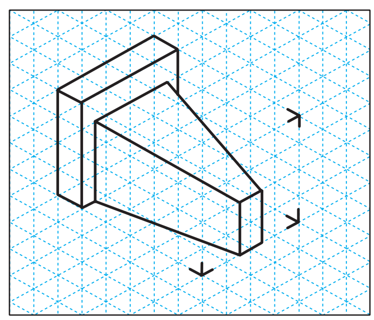

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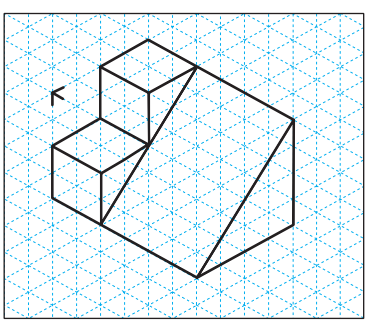

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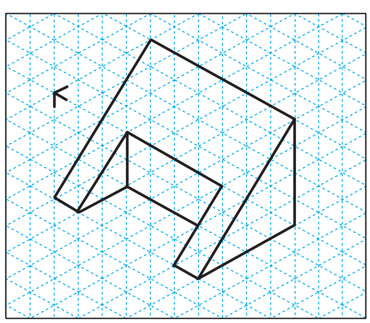

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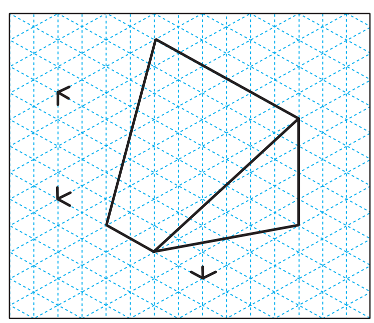

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Figure 5.122

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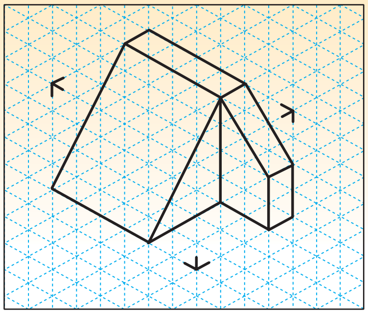
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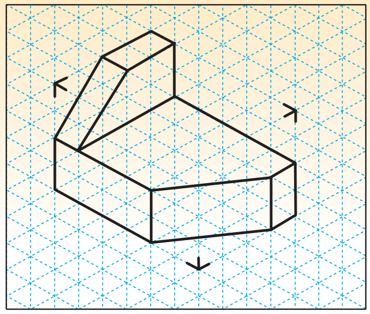
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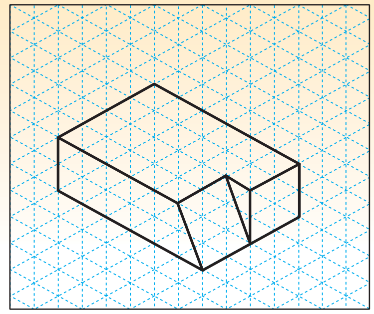
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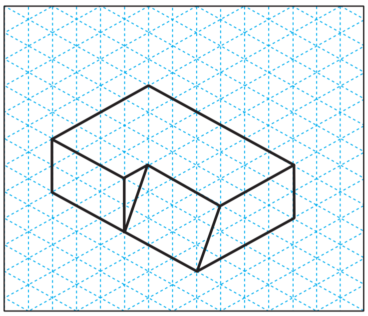
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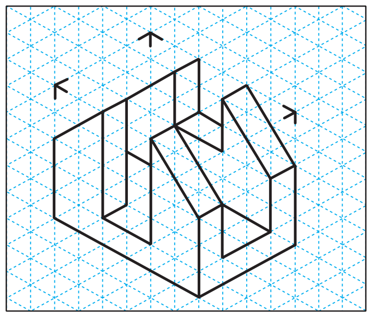
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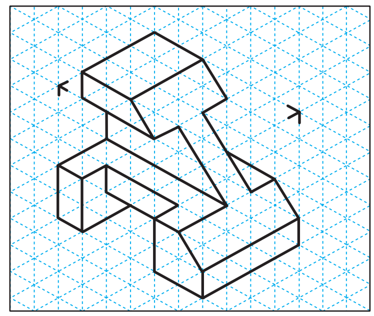
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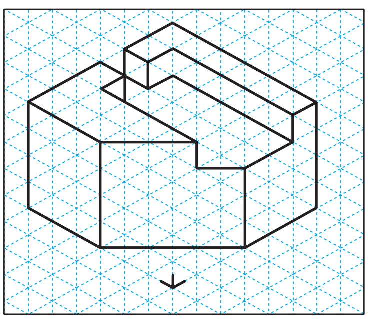
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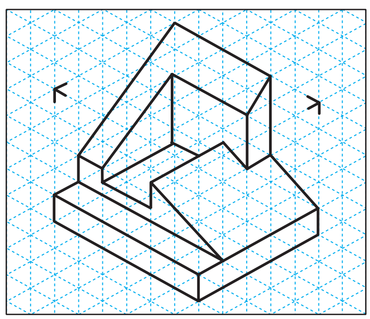
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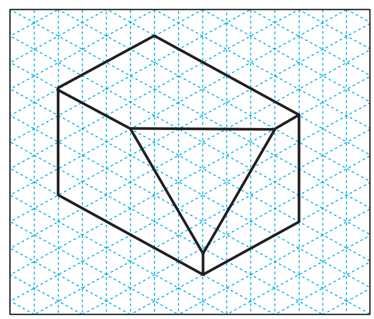
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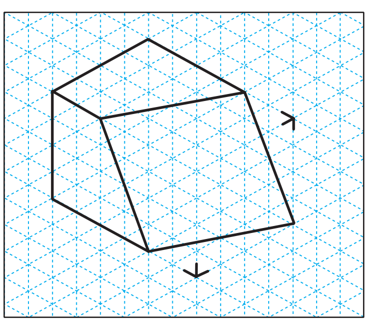
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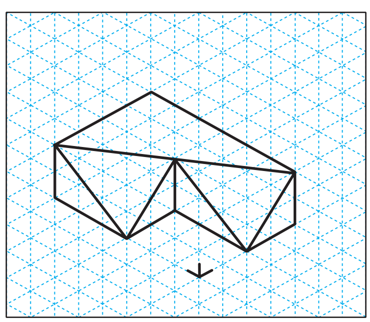
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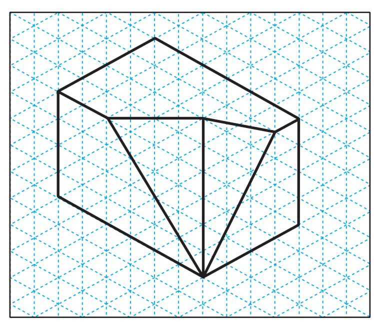
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Figure 5.122

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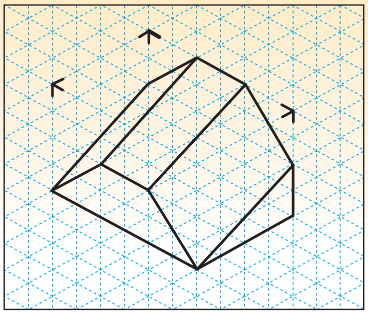

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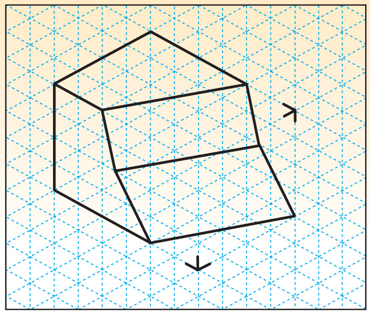

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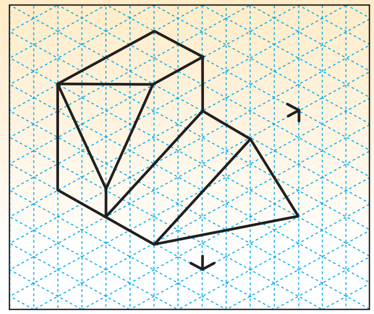

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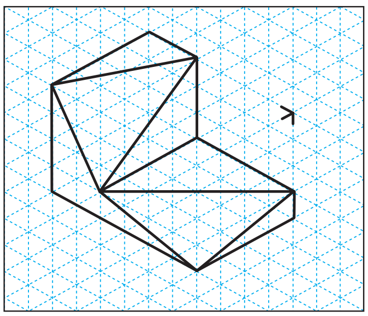

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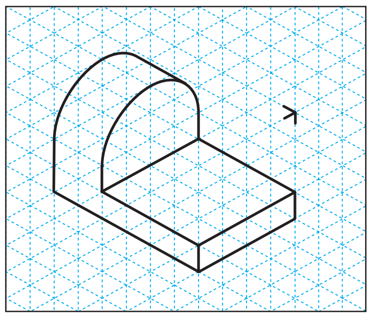

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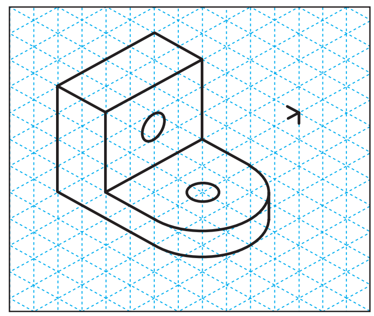

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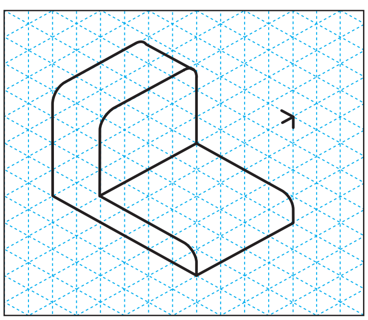

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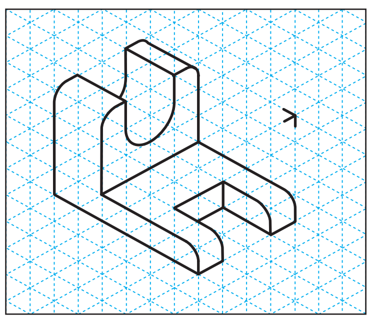

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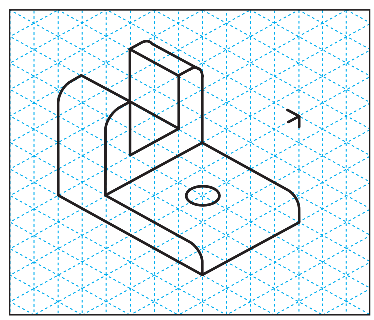

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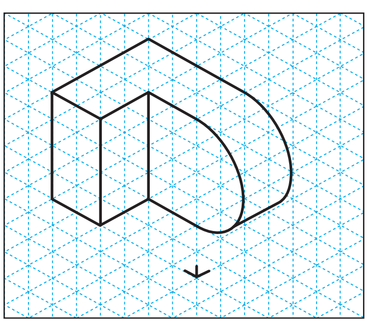

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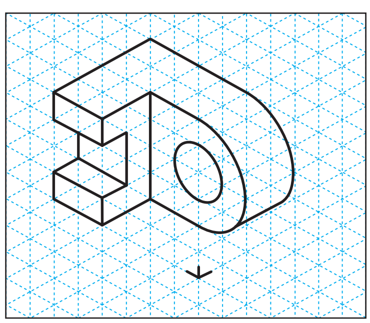

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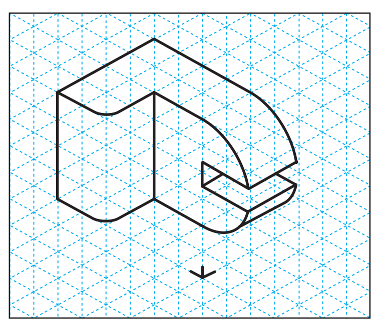

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Figure 5.122

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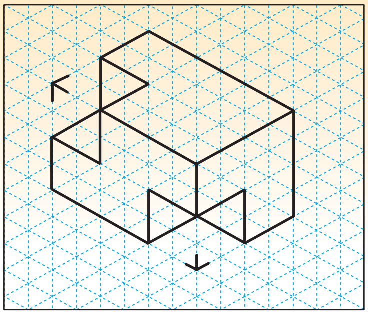
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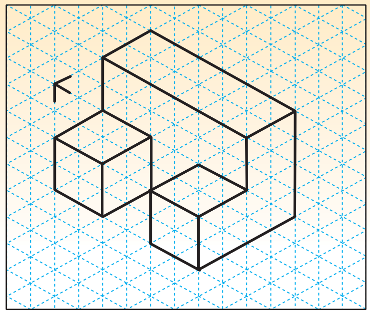
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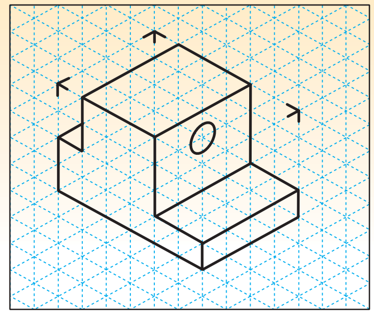
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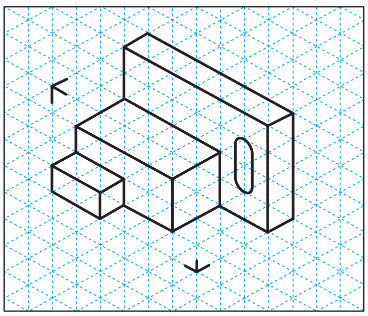
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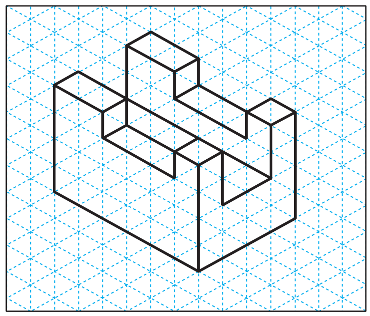
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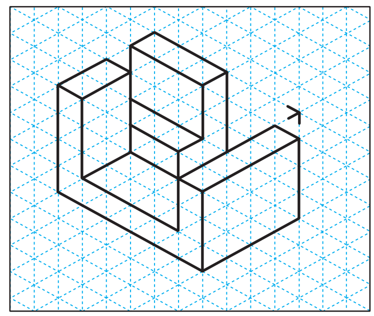
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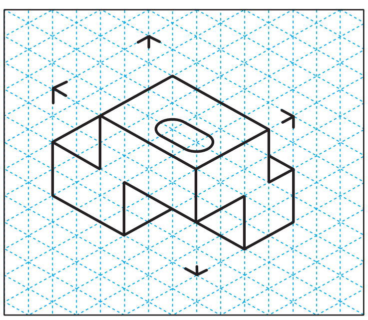
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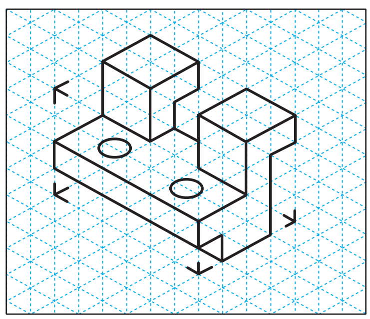
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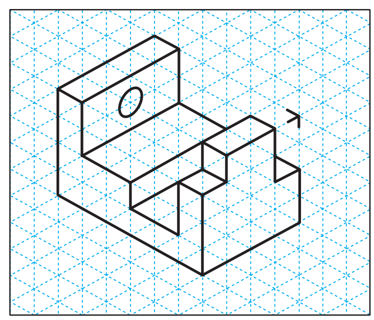
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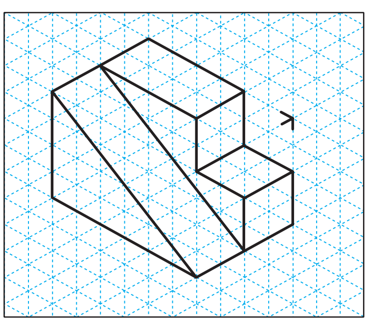
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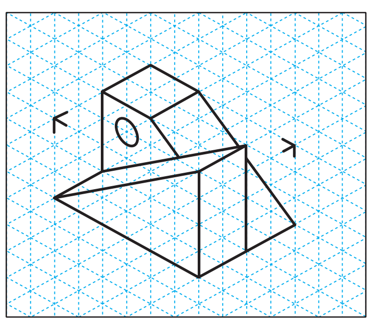
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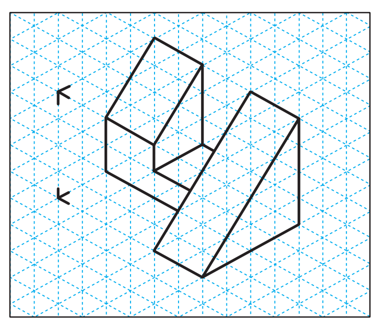
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Figure 5.122

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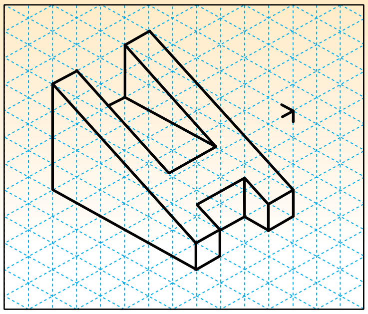
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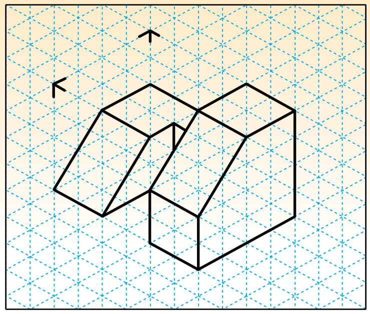
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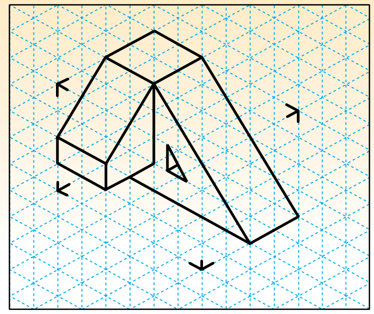
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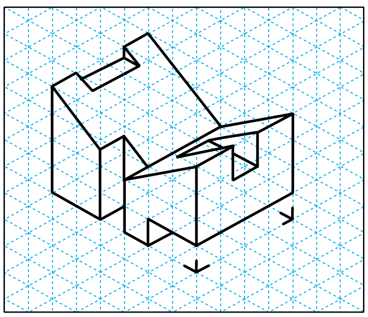
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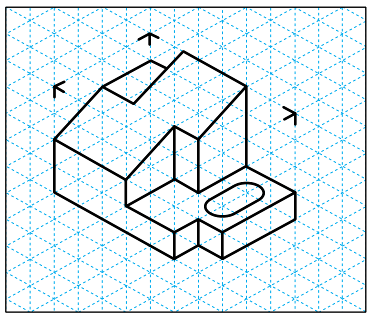
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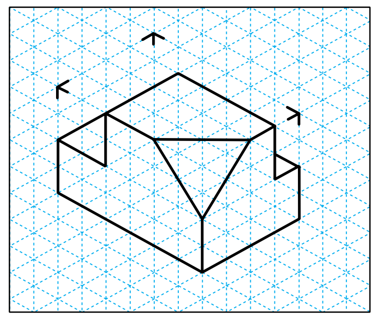
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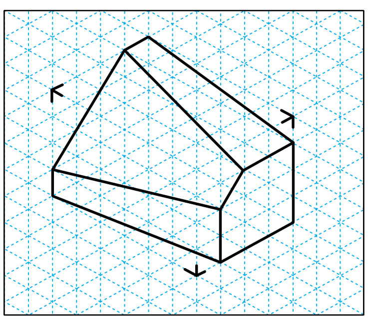
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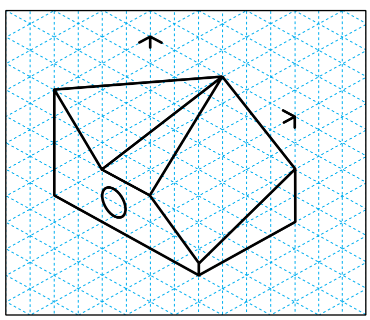
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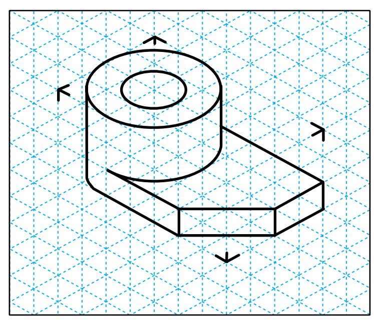
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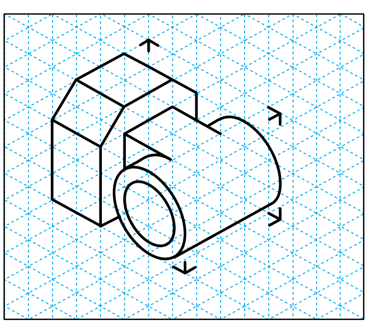
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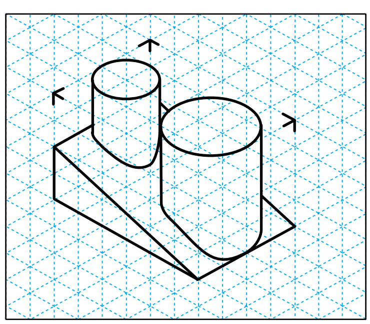
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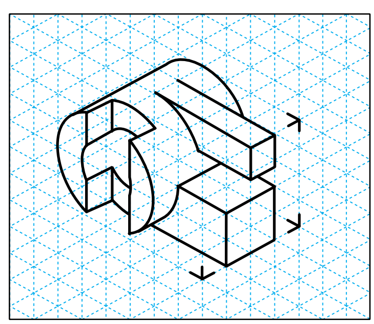
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Figure 5.122

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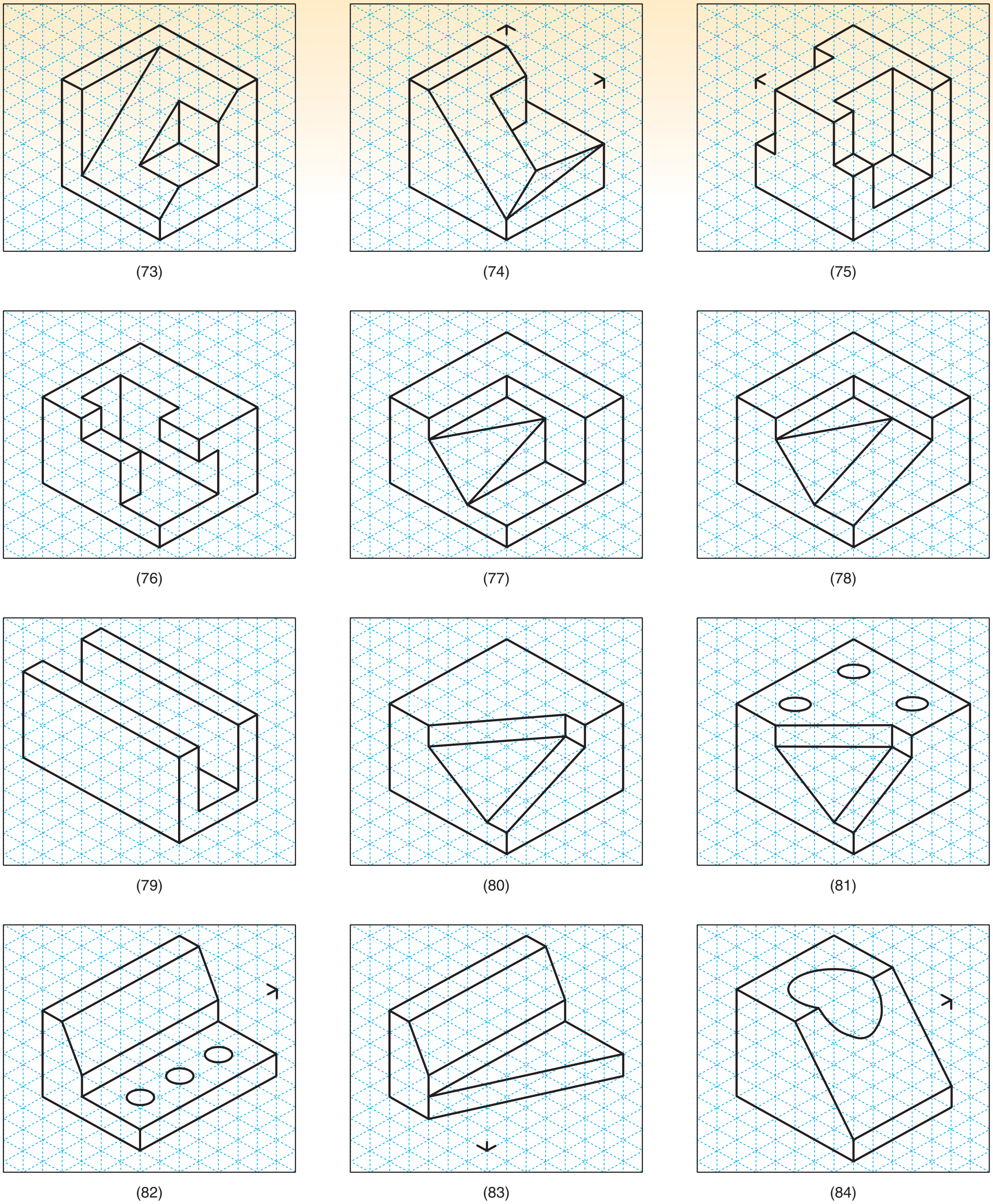

Figure 5.122

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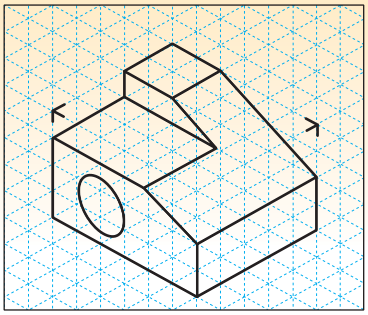
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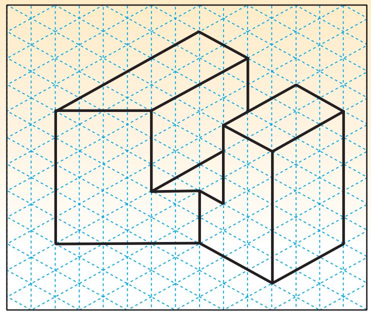
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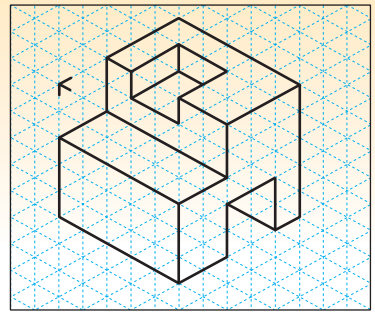
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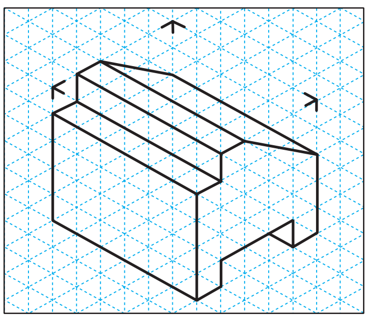
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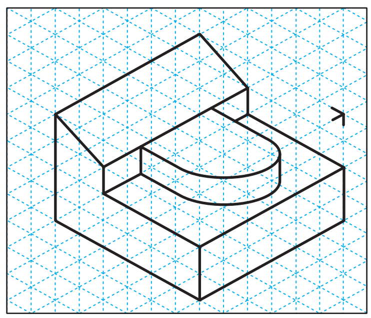
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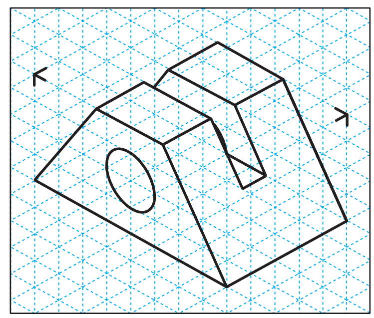
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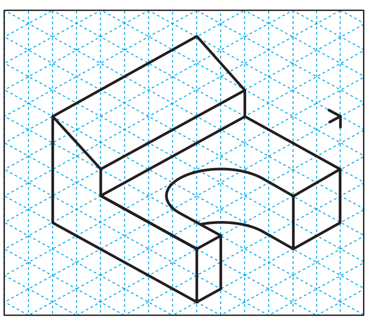
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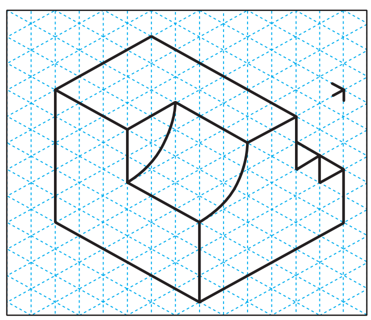
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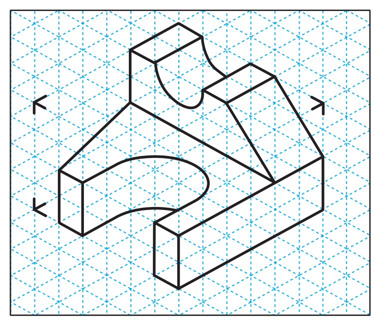
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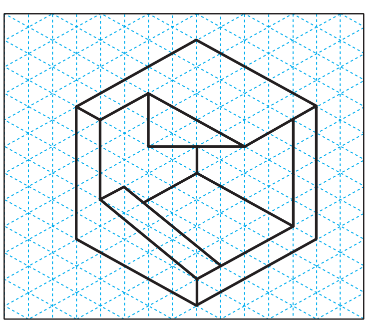
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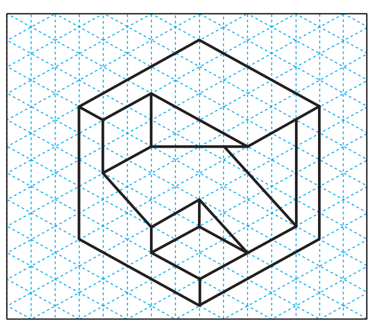
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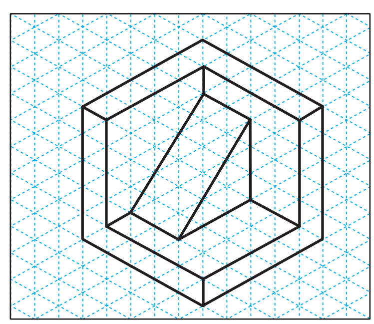
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Figure 5.122

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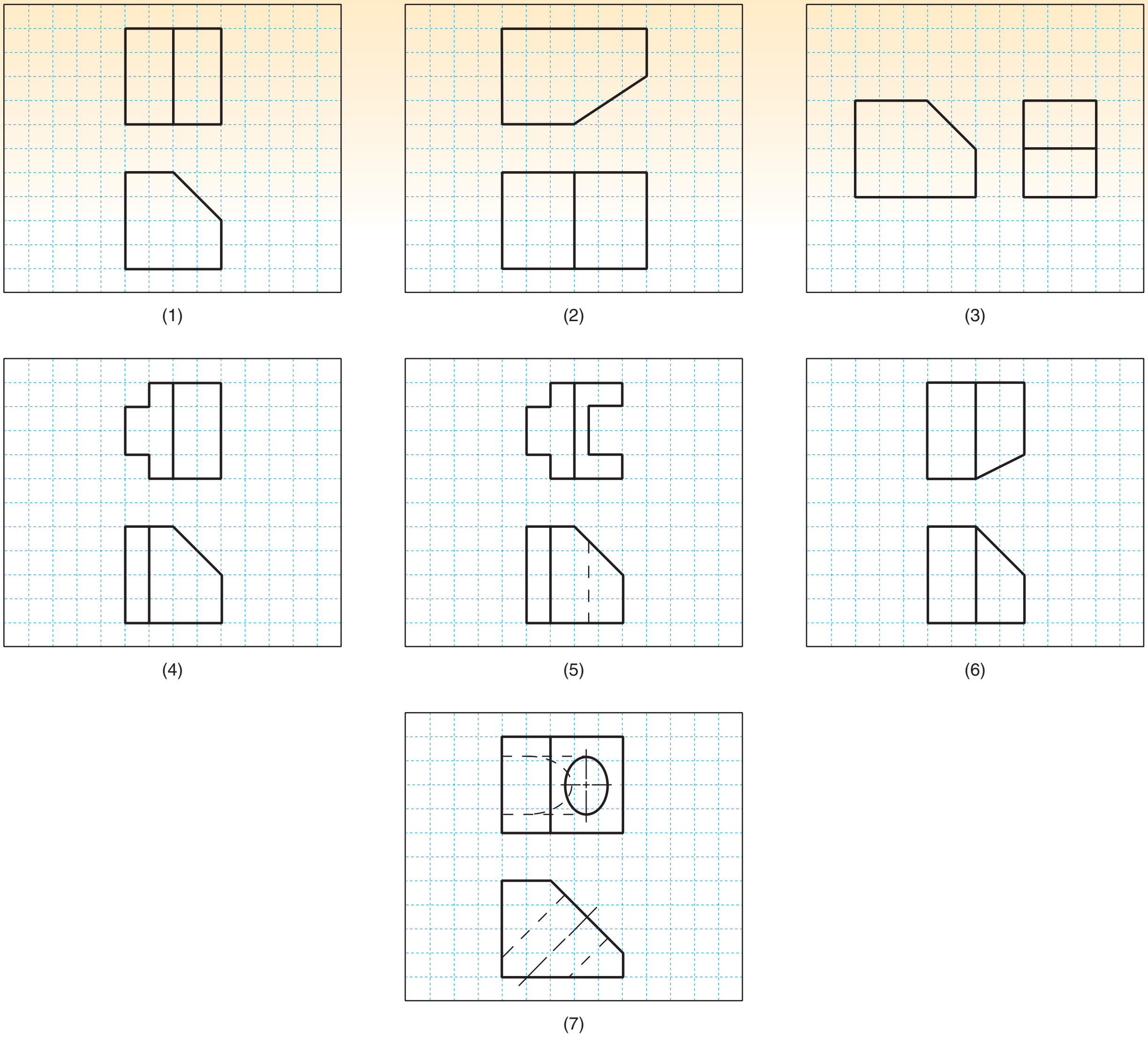

Figure 5.123

Objects with inclined surfaces and multiviews for Problem 5.6

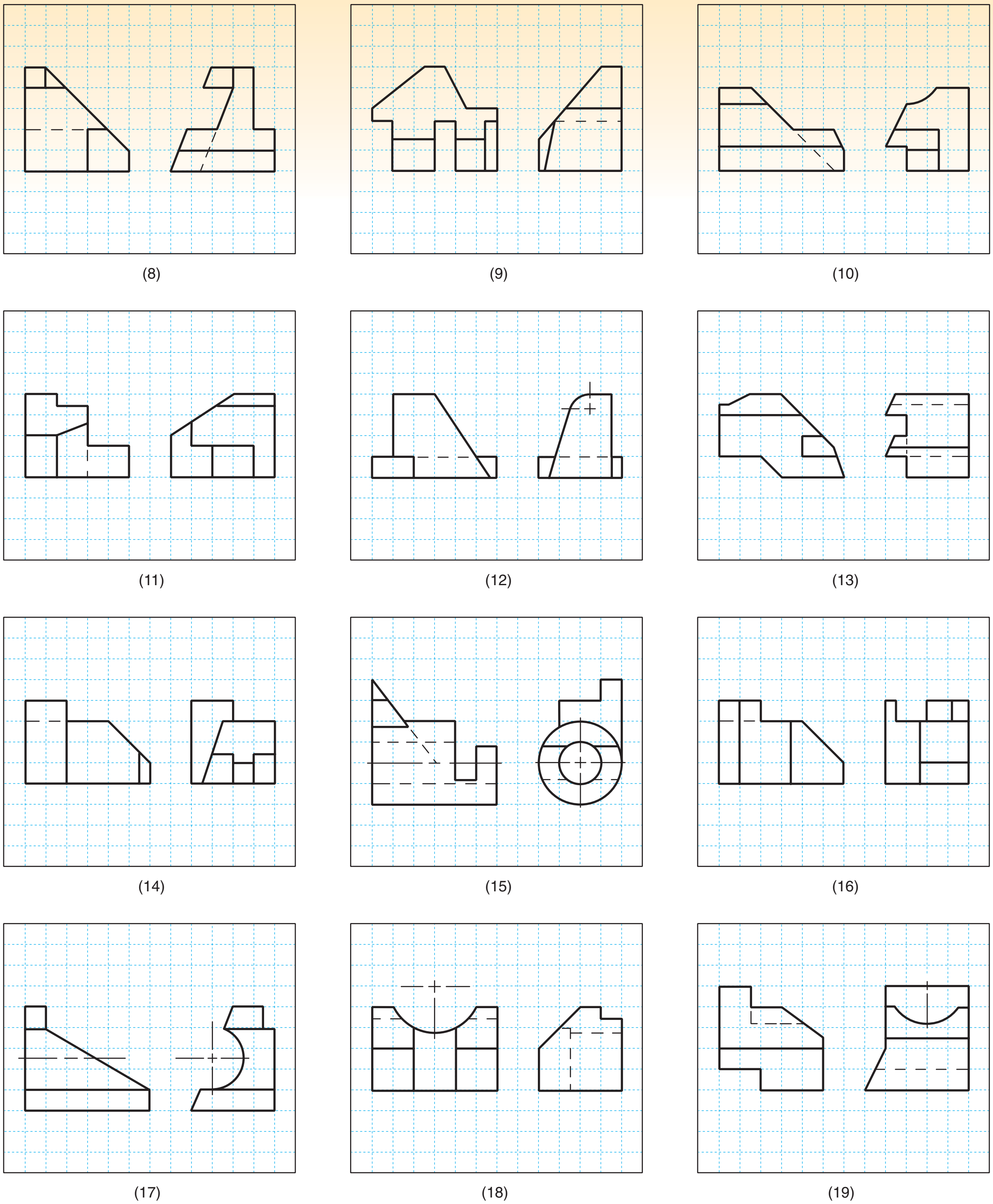

Figure 5.123

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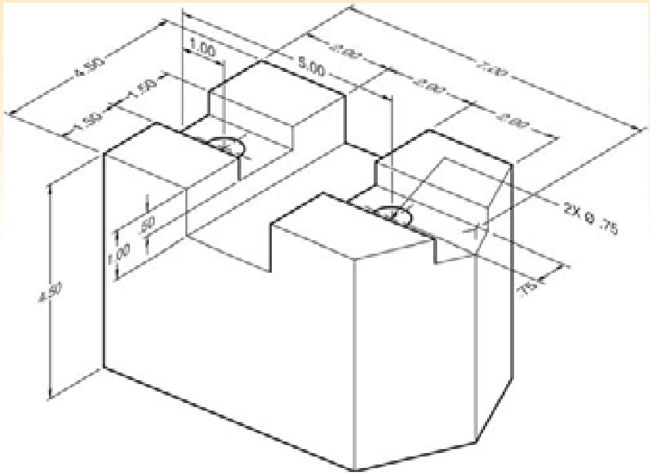


Figure 5.124

Tool block

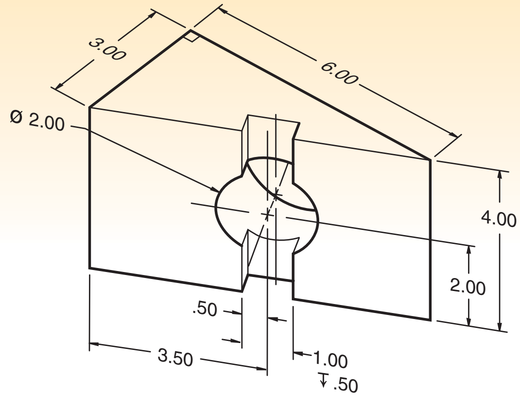


Figure 5.125

Wedge support

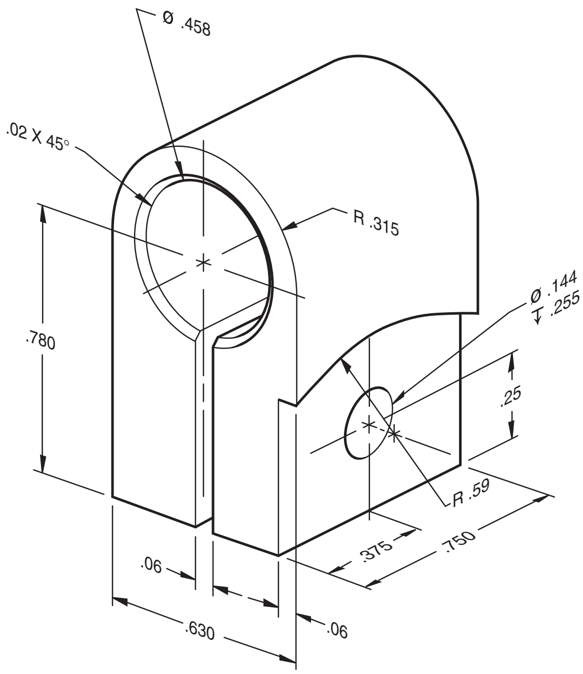


Figure 5.126

Coupling

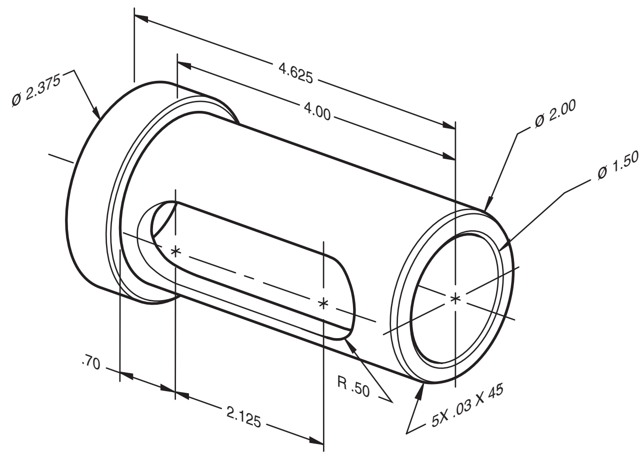


Figure 5.127

Retainer

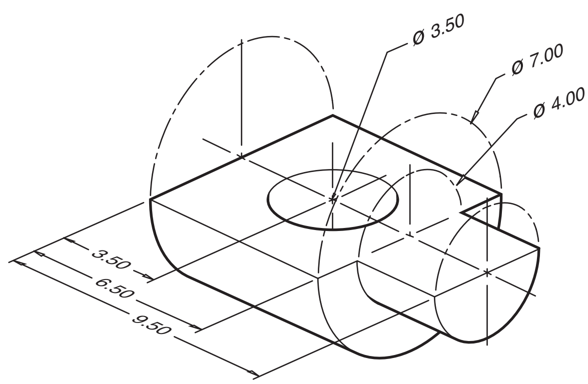


Figure 5.128

Half pin

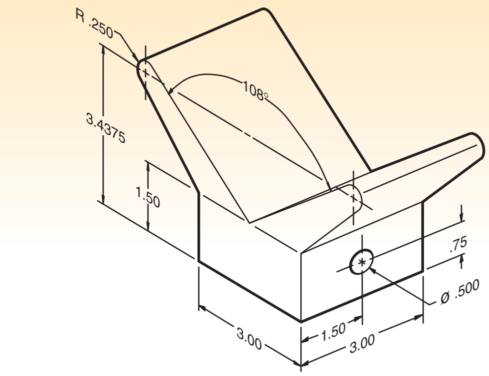


Figure 5.129

Snubber

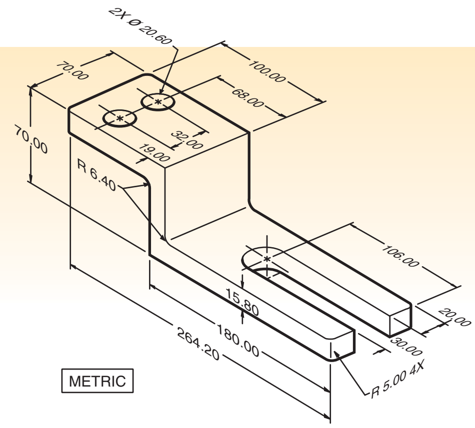


Figure 5.130

Motor plate

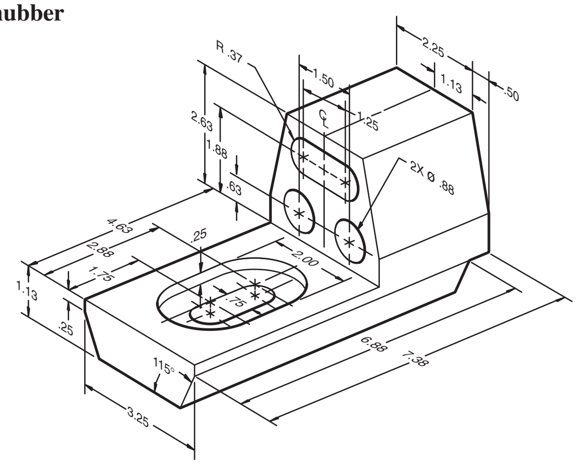


Figure 5.131

Seat

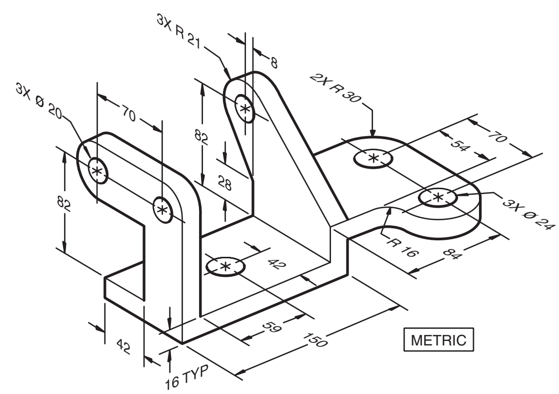


Figure 5.132

Cutoff

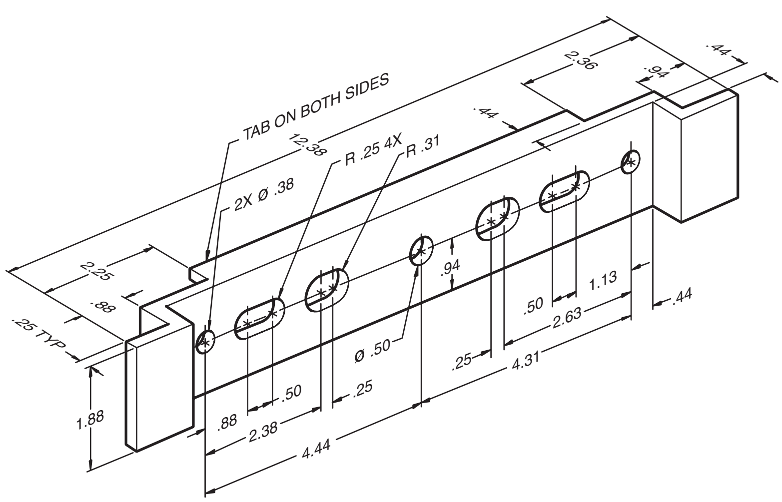


Figure 5.133

Control back

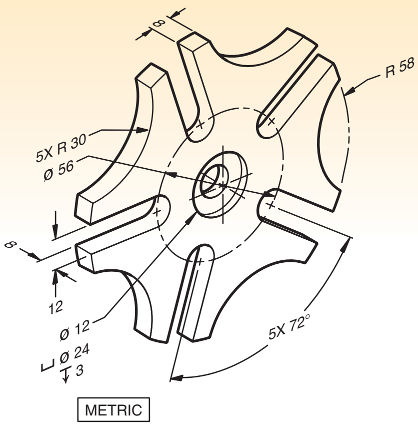


Figure 5.134

Gear index

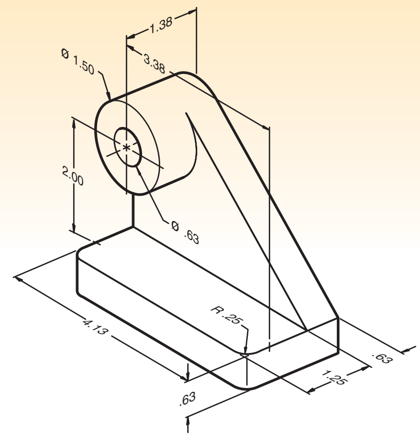


Figure 5.135

Shaft support

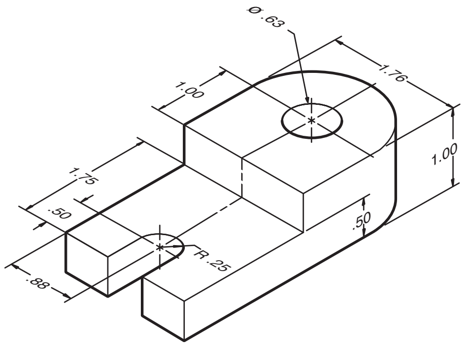


Figure 5.136

Stop base

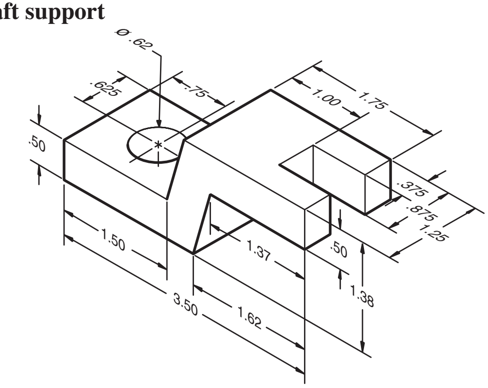


Figure 5.137

Tool holder

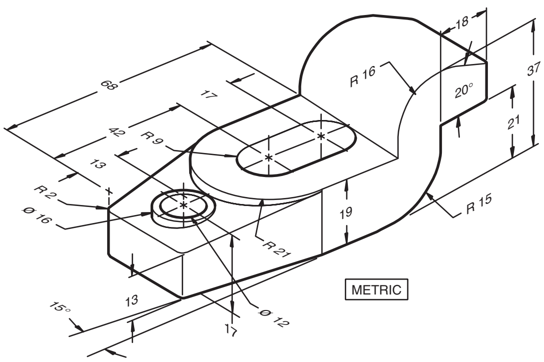


Figure 5.138

CNC clamp

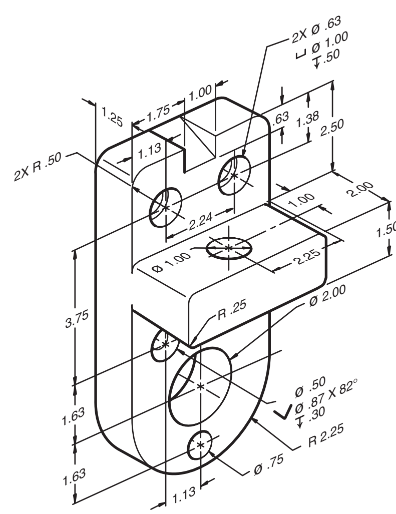


Figure 5.139

Pen block

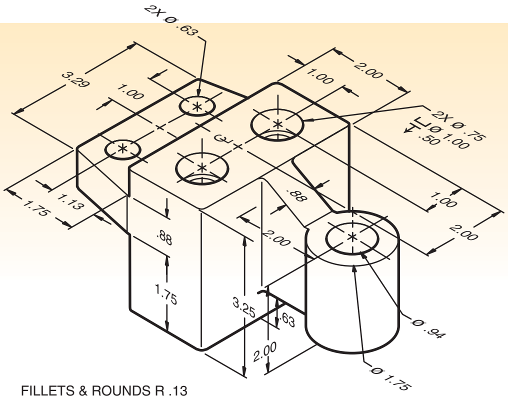


Figure 5.140

Cover guide

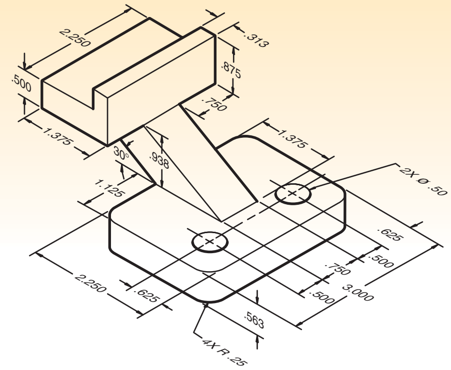


Figure 5.141

Dial bracket

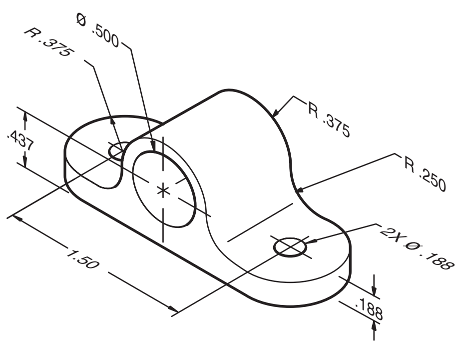


Figure 5.142

Bearing block

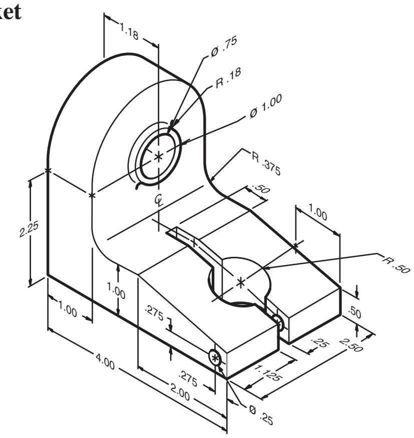


Figure 5.143

Adjustable guide

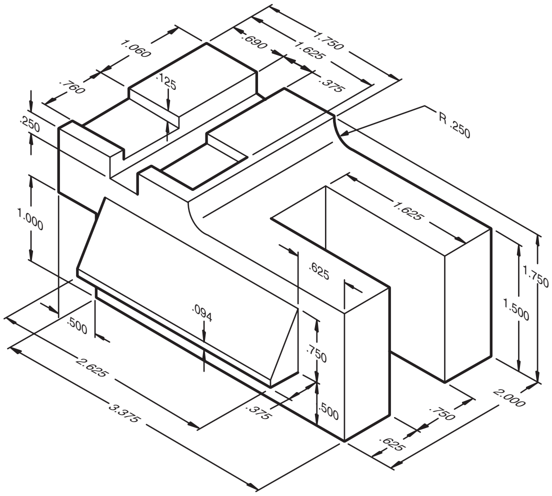


Figure 5.144

Pump base

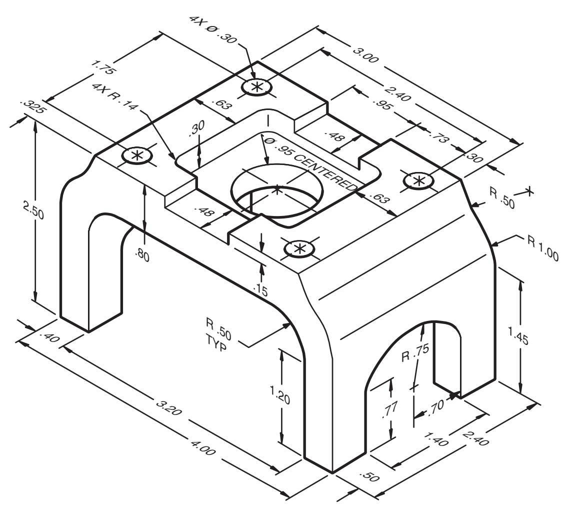


Figure 5.145

Dryer clip

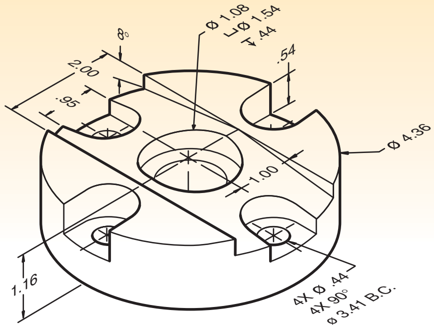


Figure 5.146

Retaining cap

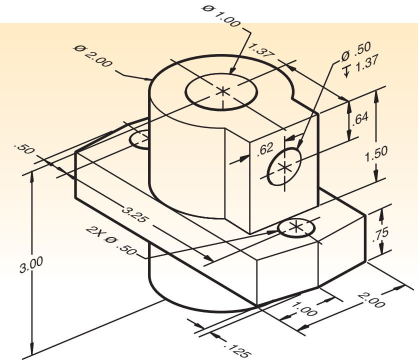


Figure 5.147

Pen block

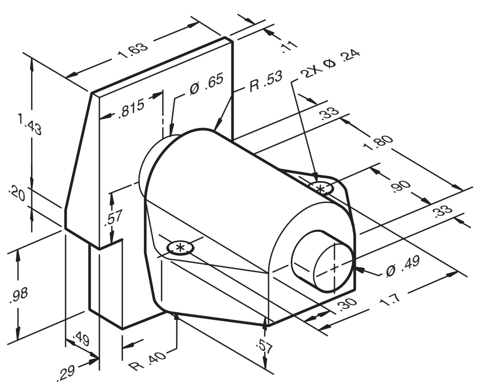


Figure 5.148

Tool pad

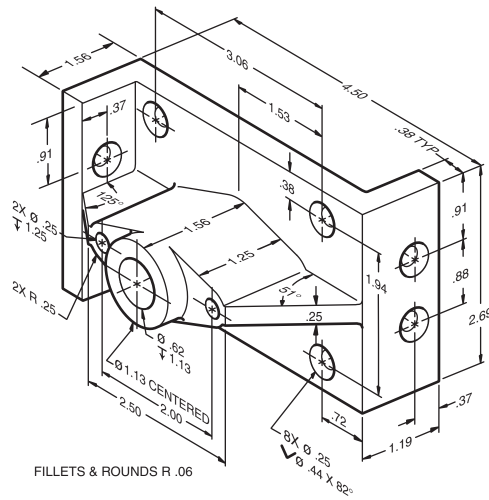


Figure 5.149

Locating base

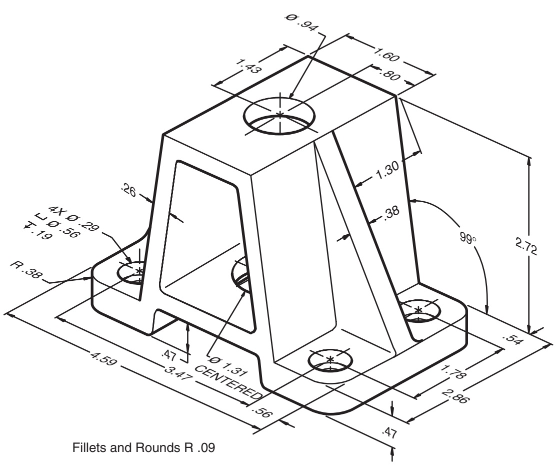


Figure 5.150

Anchor base

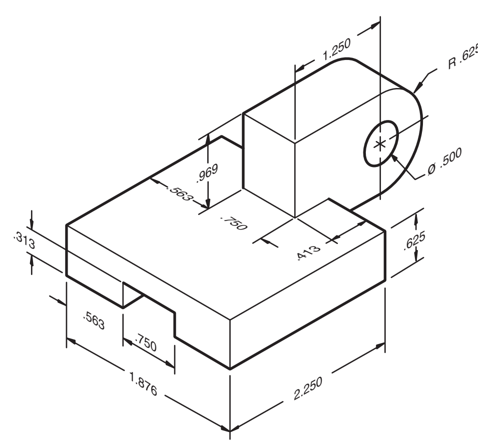


Figure 5.151

Slide base

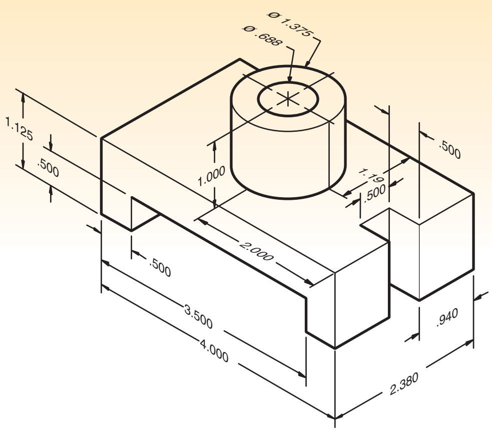


Figure 5.152

Retainer clip

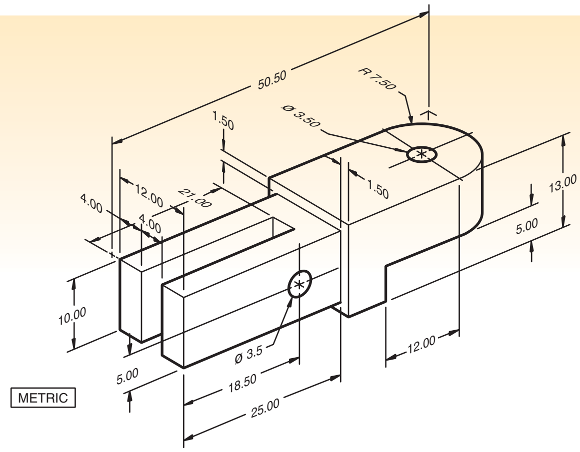


Figure 5.153

Strike arm

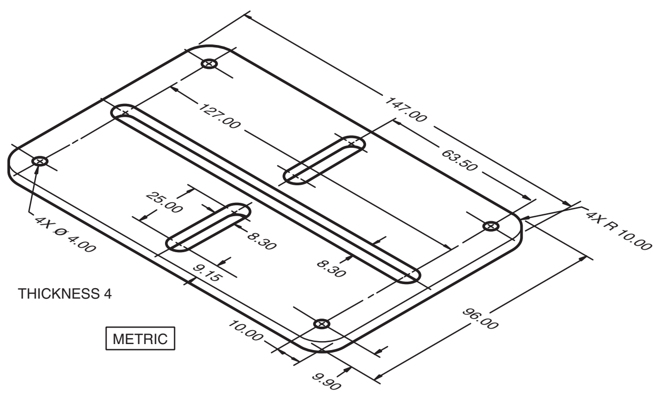


Figure 5.154

Offset plate

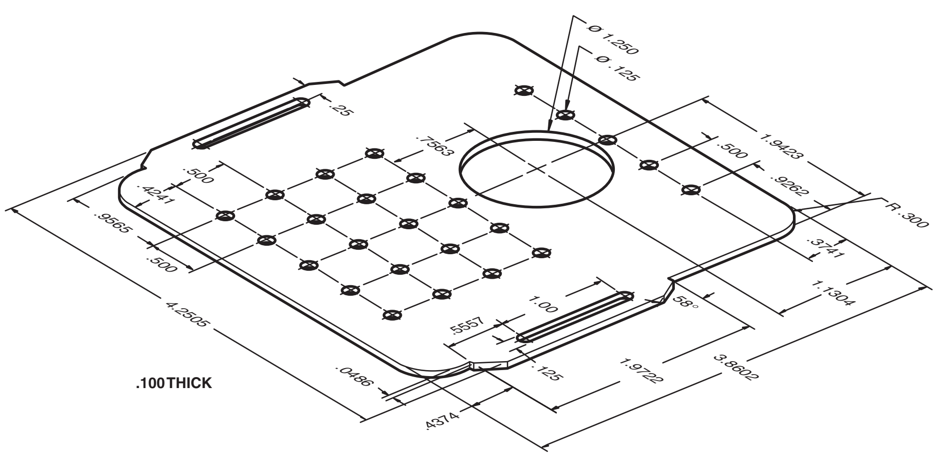


Figure 5.155

Manifold plate

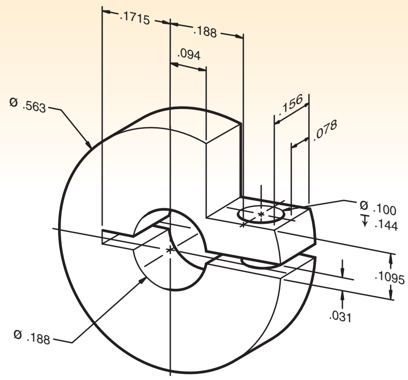


Figure 5.156

Protector

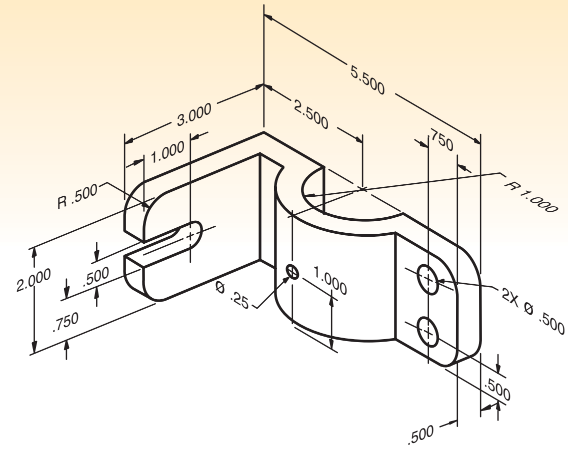


Figure 5.157

Bearing plate

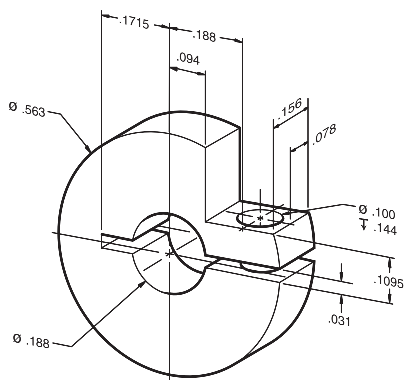


Figure 5.158

Drive collar

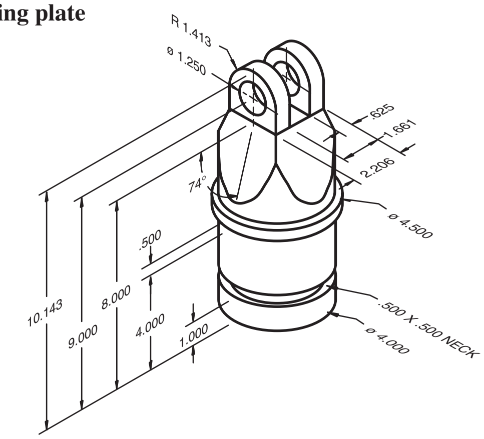


Figure 5.159

Elevator guide

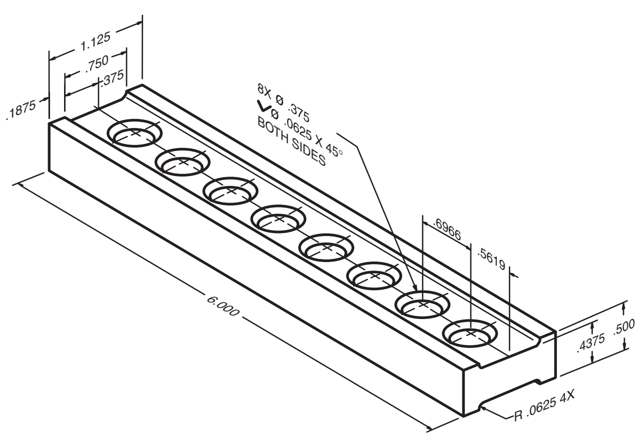


Figure 5.160

Burner cap

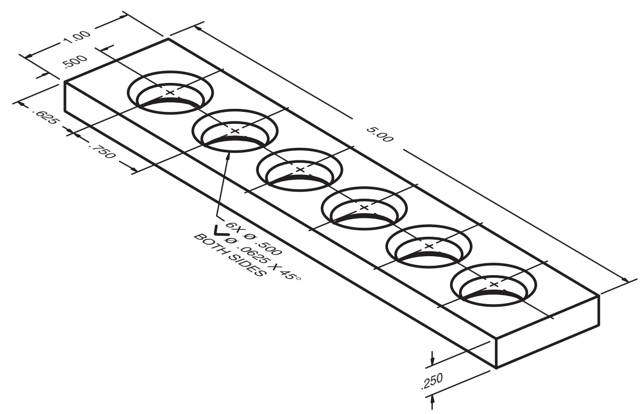


Figure 5.161

Grate

5.9 Same as 5.8 (a–k), except use a cylinder 8 squares in diameter, 8 squares deep, and seen in its circular form in the front view.

5.10 Using any of the objects shown in the exercises in the back of this chapter, decompose the objects into primitive geometric shapes. Color code these shapes to show whether they represent positive material added to the object or negative material removed from it. This can be done by:

- Drawing isometric pictorial sketches of the objects.
- Overdrawing on top of photocopies of the drawings.
- Tracing over the drawings.

5.11 Gather real examples and/or magazine photographs of both single and multiple objects. The objects should vary in complexity of form. Some should have only simple planar features, while others should have curved, sculpted surfaces. Larger objects or scenes around school or home can simply be identified. These objects, photographs, and scenes will be used in the rest of the problems in this chapter. Some ideas are as follows:

Motor vehicles.

Farm equipment.

Household appliances.

Aircraft and nautical vessels.

Computer equipment.

Audiovisual equipment.

Furniture.

Lighting fixtures.

Sports and exercise equipment.

Hand tools.

Stationary and handheld power tools.

5.12 Using a photograph of a single, complex object, create a tracing, showing a single contour line around the object. Then create another tracing and add two more contours outlining what you consider to be the two most important features on the object. Repeat the process until you have five or six sketches, each time adding two or more contours to the sketch. At what point can you identify the object in the sketch without looking at the photograph?

5.13 Using real scenes and photographs showing multiple items, or using objects created from the patterns on the end pages at the back of the book, create sketches using contour lines to identify the boundaries between the elements. First, use photographs, and then real-world scenes or objects. Trace the contour lines, and then create more sketches of the same scenes, objects, or photographs, drawing contour lines that divide the scenes into different groupings.

5.14 Make two photocopies of each sketch created in Problem 5.13 and shade in:

- The positive space (the objects in the scene).
- The negative space (the background).

5.15 Repeat Problem 5.13 and Problem 5.14, using CAD or other computer graphics software to draw the contours and fill in the negative and positive spaces.

5.16 Choose a photograph of a complex scene showing familiar objects and/or people and sketch it without tracing. Now, sketch the same scene with the photograph upside down. Do not try to identify the objects in the photograph. Concentrate on the individual contours and their relationships to each other.

5.17 Choose either four objects representing basic geometric forms (e.g., a book, a rolling pin, a pencil, etc.), or primitive objects made from the patterns on the end pages at the back of the book. The lighter their color, the better. Place the objects in a strong light coming from behind you, over your shoulder (or equivalent).

a. Sketch the contours of the object.

b. Shade the surfaces of the object to show the darkness as it appears.

c. Move to a new location and sketch them again.

d. Move the light source to a new position.

e. Repeat (c) and (d), but this time imagine the movement in your mind rather than actually moving the object. Create the sketches from what you imagine they would look like.

5.18 Using the objects and setup from Problem 5.17, create the following series of contour and shaded sketches:

a. Systematically move the object in 90-degree increments about all three axes.

b. Systematically move the object in 5-degree increments through 90 degrees.

c. Repeat (a) and (b) with a different object, but do the rotations in your mind.

d. Make photocopies of the 5-degree increment sketches. Pick one face of the object and shade it in all of the sketches. How does it change shape?

5.19 Repeat Problem 5.18a through 5.18c, with two or three objects in the scene. Rotate the objects around a common imaginary axis. Try setting them on a lazy susan. Make photocopies of the 5-degree increments and darken in the contours that divide one object from another. Do their locations on the background stay the same in the different sketches?

5.20 Figures 5.162 through 5.164. Match objects with target shapes.

5.21 Figures 5.165 through 5.167. In the table, match the given surface letter from the pictorial drawing with the corresponding surface number from the multiview drawing for each view.

5.22 Figure 5.168A–E. In this exercise, a development (unfolded) is to be matched to one of five three-dimensional objects. The development shows the inside surfaces of a three-dimensional object with the shaded portion being the bottom surface.

5.23 Figure 5.169A–E. In this exercise, the figure that appears first is rotated into a new position. The figure that follows is rotated exactly the same way as the first figure. Indicate which of the numbered figures shows the second figure rotated like the first one is.

5.24 Figure 5.170A–E. In this exercise, the dot represents your position in relation to the object in a glass box. Match the correct view of the object to one of the alternative views.

5.25 Object Feature Identification. Identify the feature on the object as either an edge (E), face (F), vertex (V), or limiting element (L) in the space provided (Figure 5.171).

5.26 Sketch a reflection of the object on isometric grid paper as if plane M were a mirror (Figures 5.172 to 5.177).

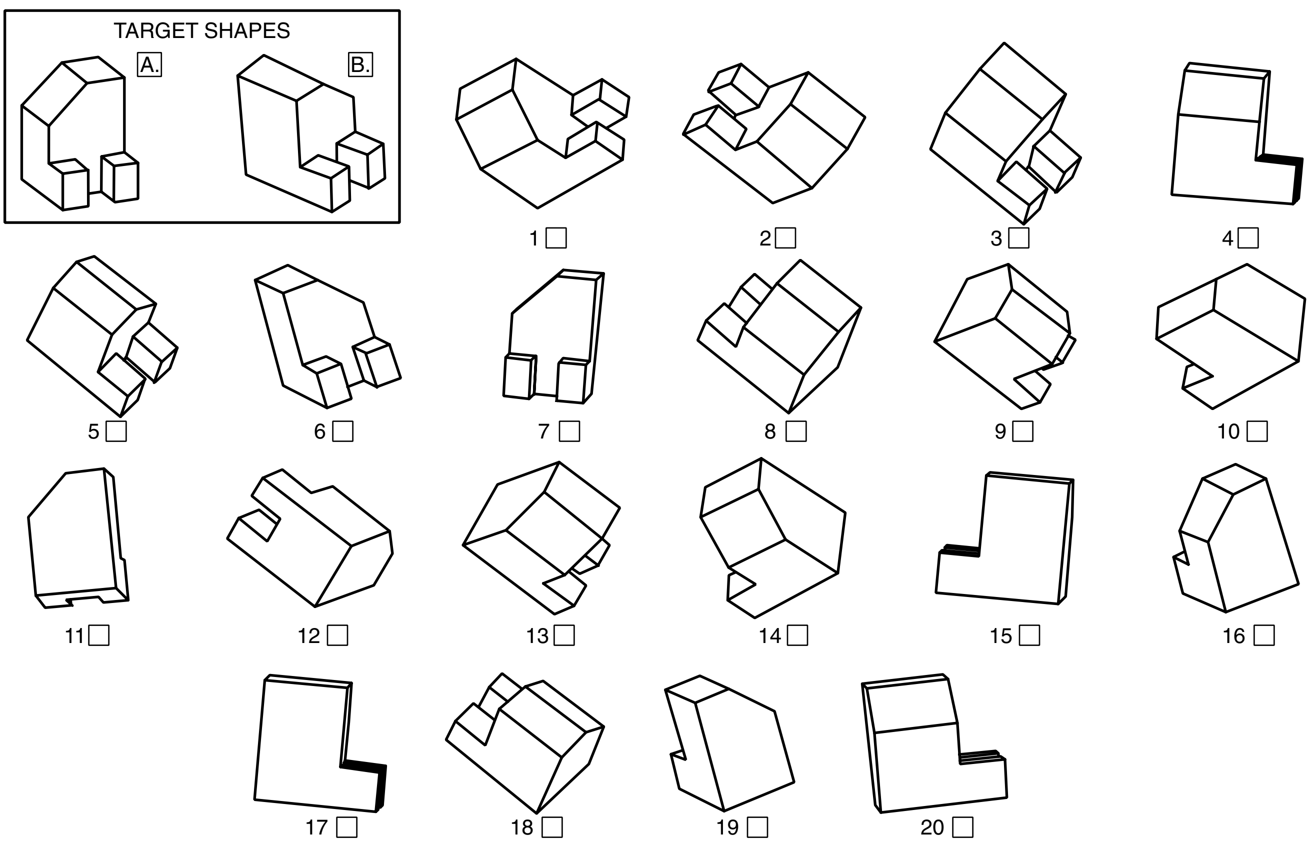


Figure 5.162

Match objects with target shapes.

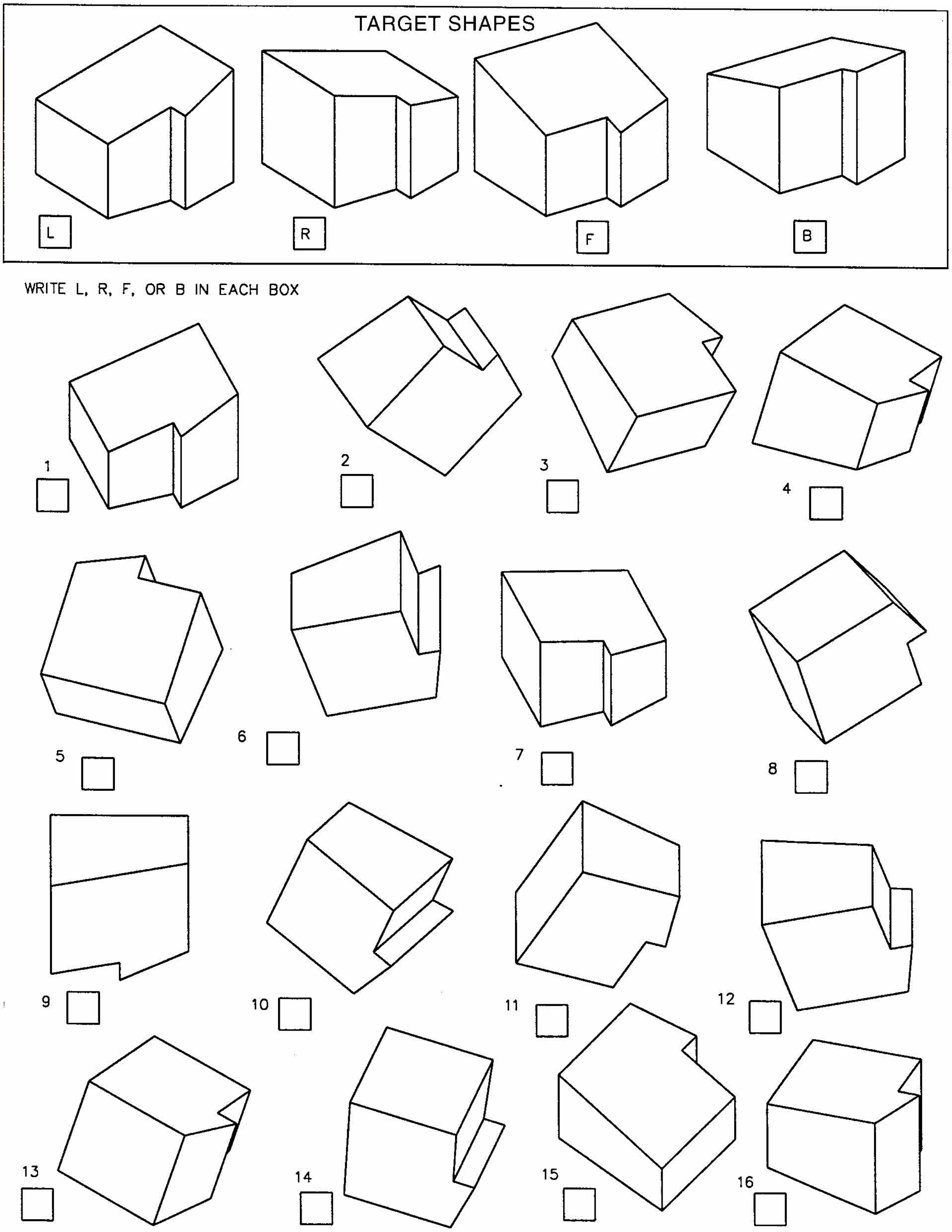


Figure 5.163

Match objects with target shapes.

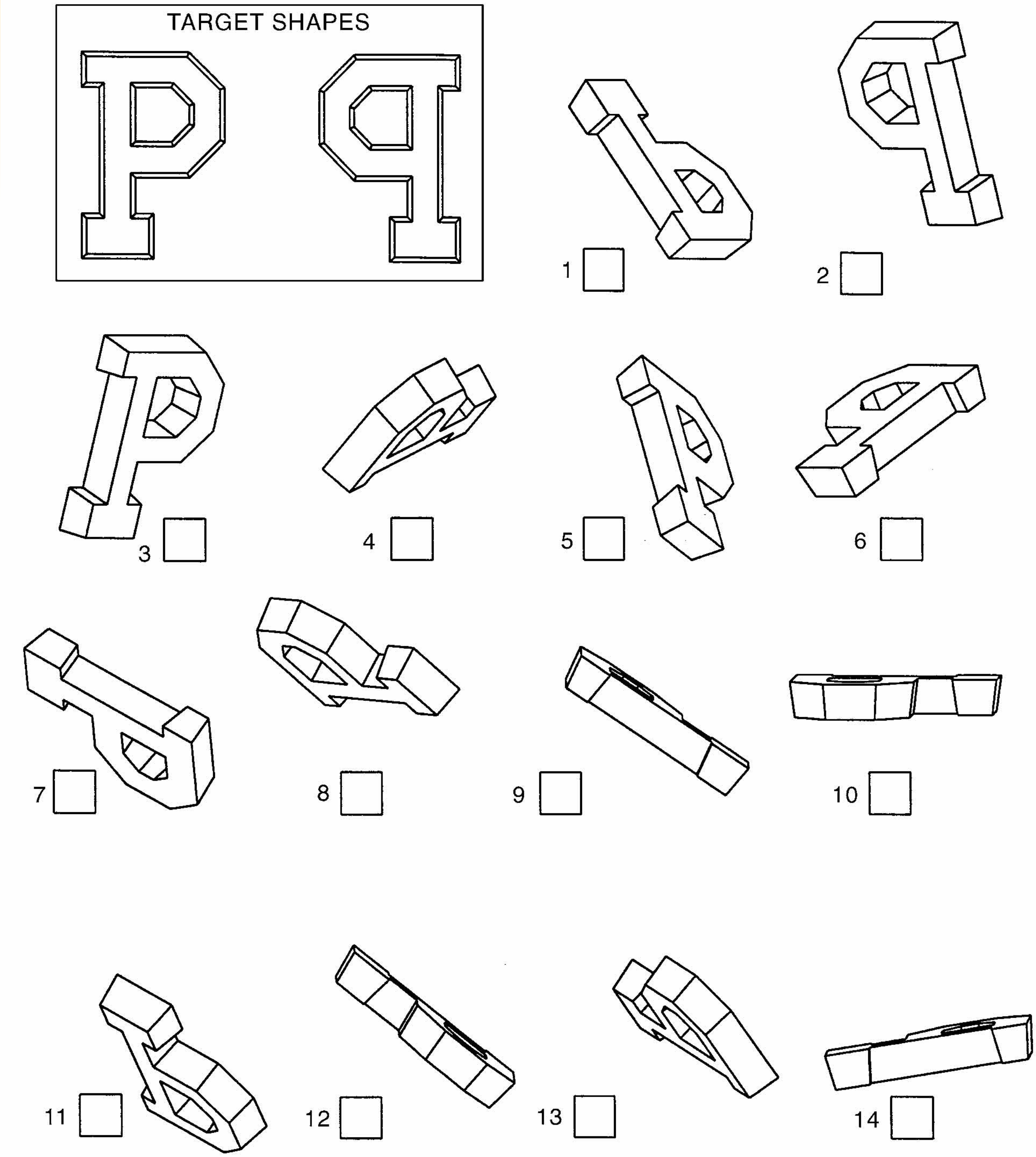
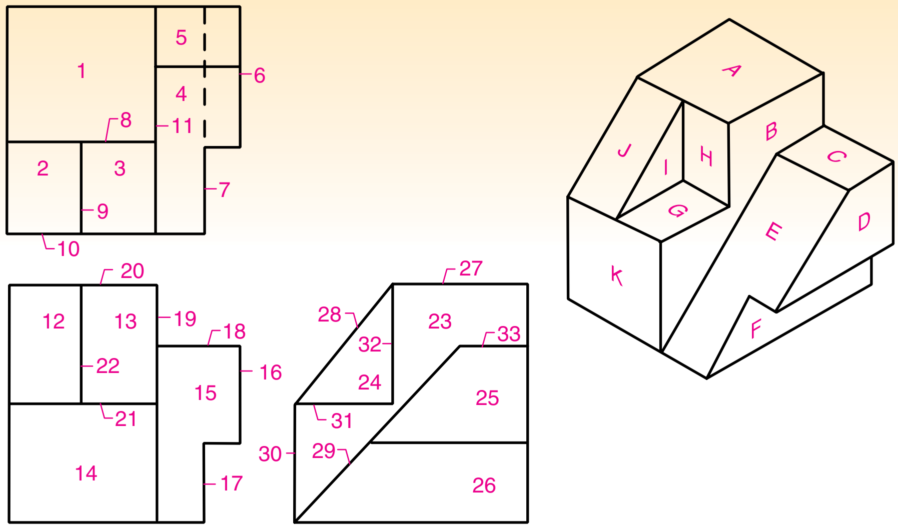


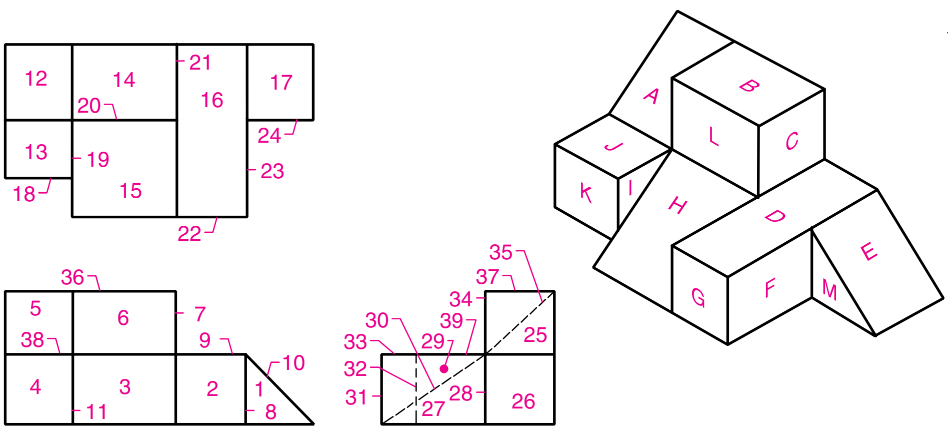
Figure 5.164

Write the letter "p" or "q" in the square near the rotated letter.



Surface	Top	Front	Side
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			

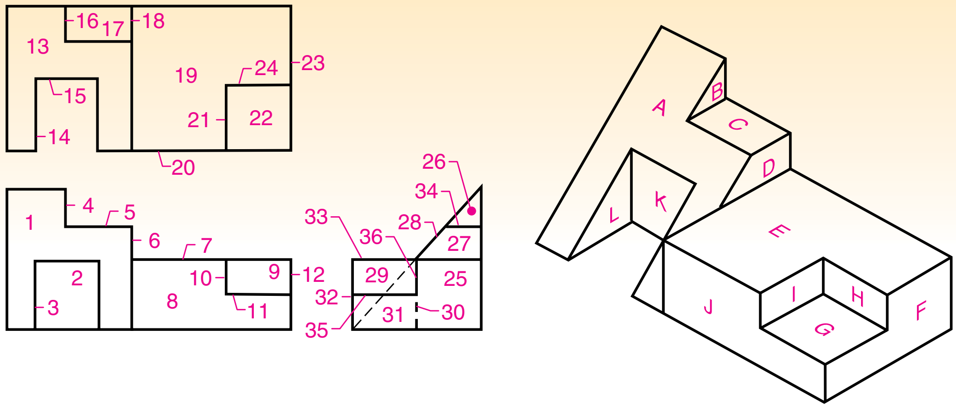
(A)



Surface	Top	Front	Side
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			
L			
M			

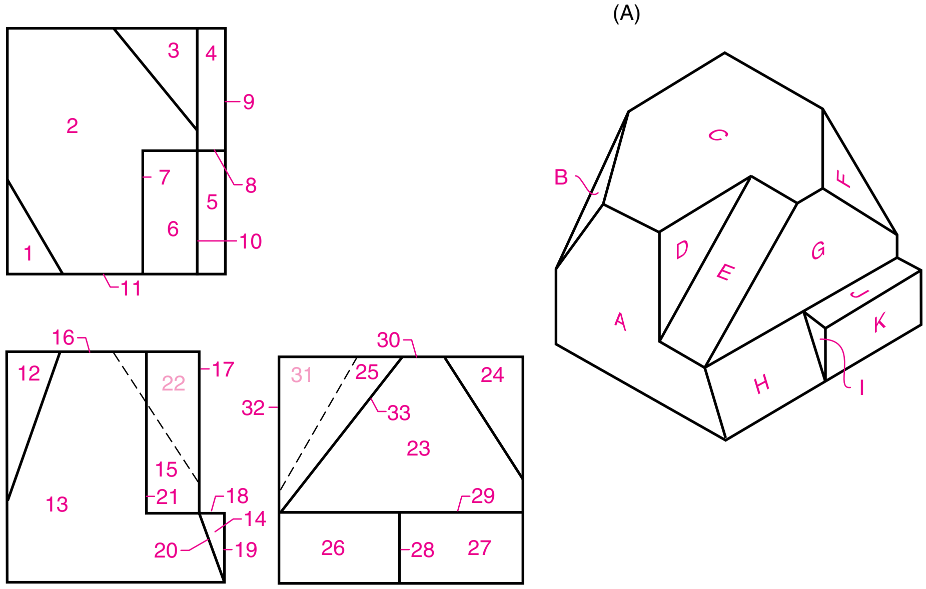
(B)

Figure 5.165



Surface	Top	Front	Side
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			
L			

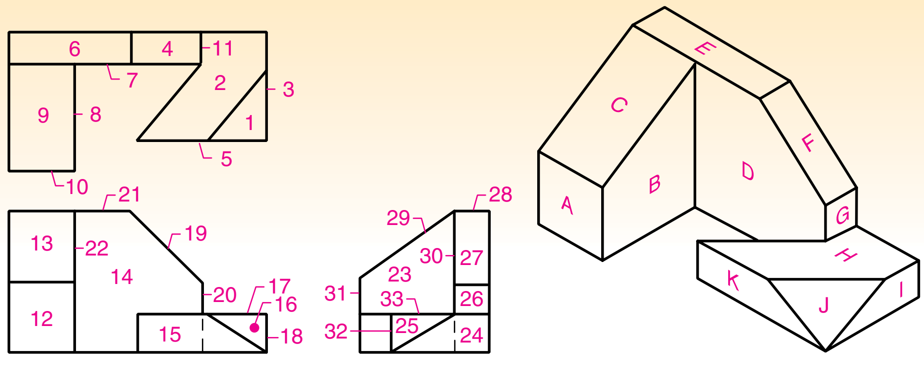
(A)



Surface	Top	Front	Side
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			

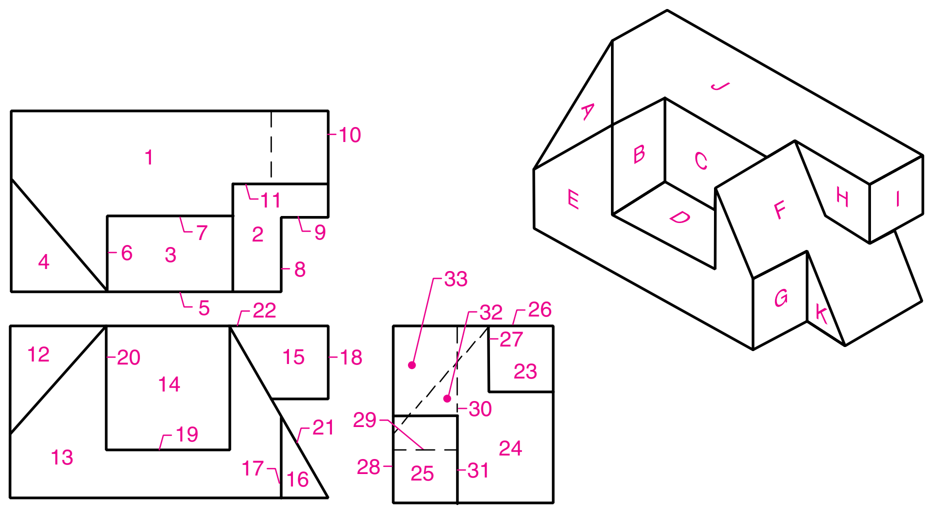
(B)

Figure 5.166



Surface	Top	Front	Side
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			

(A)



Surface	Top	Front	Side
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			

(B)

Figure 5.167

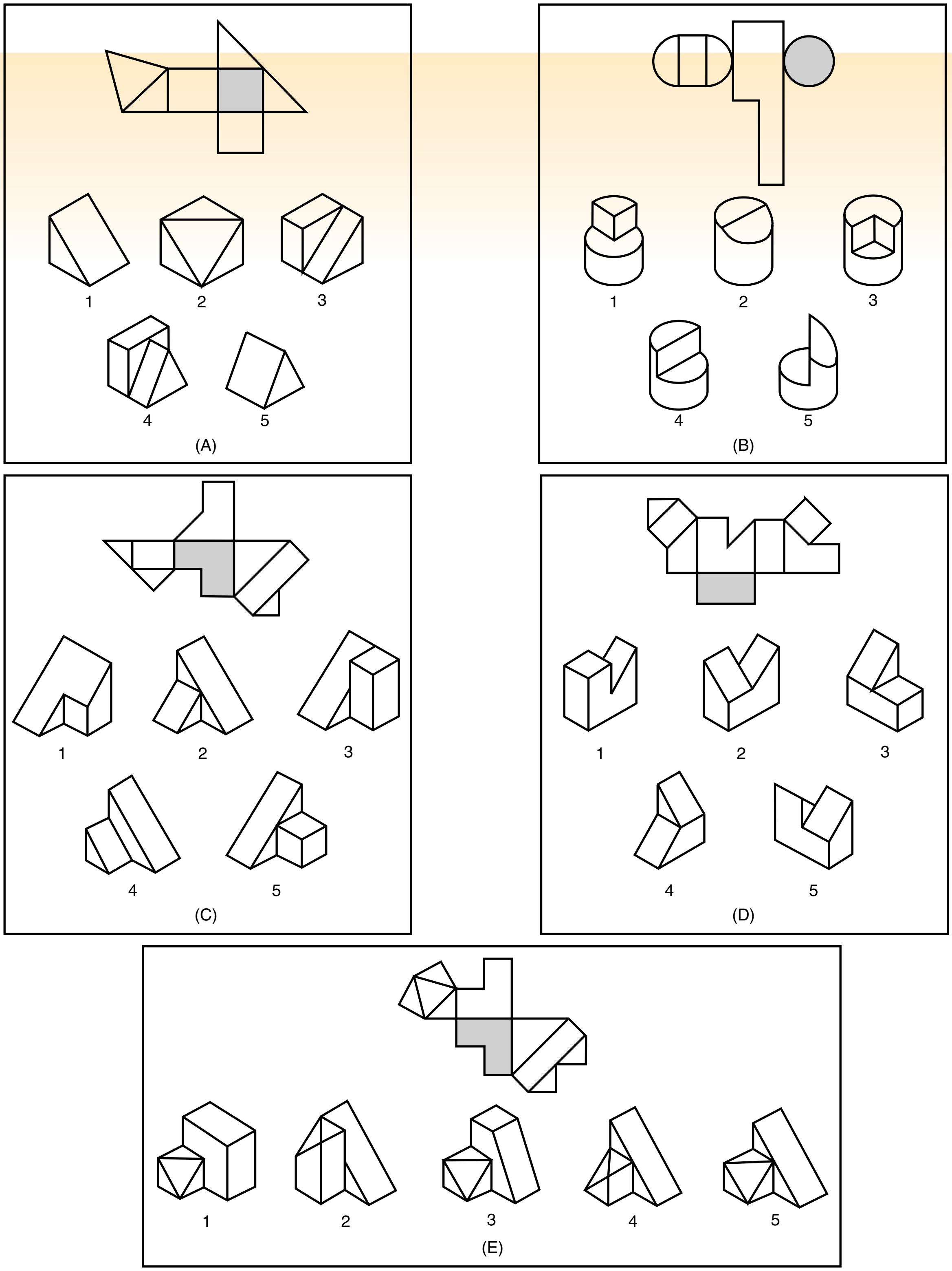


Figure 5.168

(Reproduced with permission from the Purdue Spatial Visualization Test by Roland Guay, Ph.D. Copyright 1976, Purdue Research Foundation.)

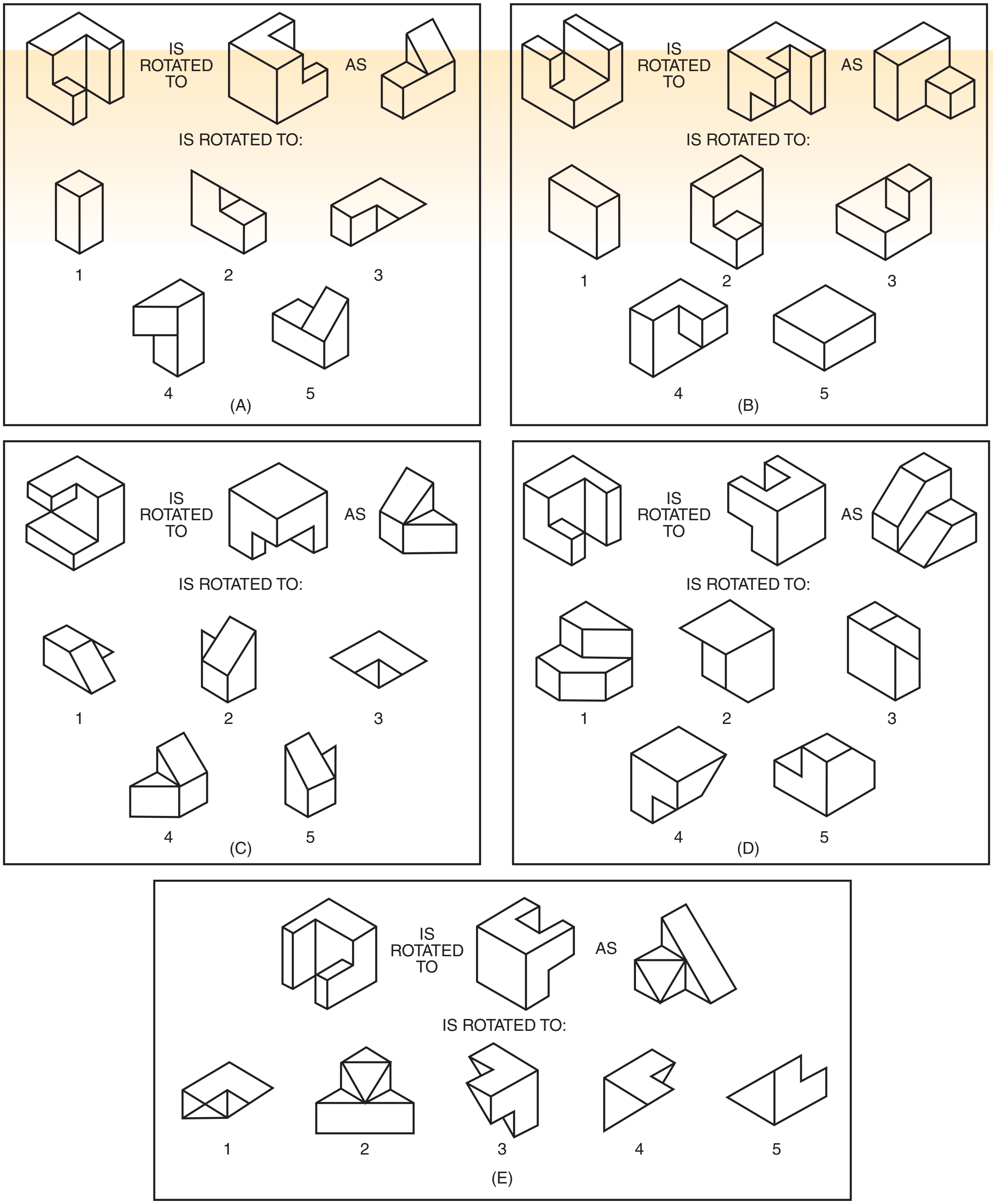

IS ROTATED TO
AS
IS ROTATED TO:
1
2
3
4
5
(A)
IS ROTATED TO
AS
IS ROTATED TO:
1
2
3
4
5
(B)
IS ROTATED TO
AS
IS ROTATED TO:
1
2
3
4
5
(C)
IS ROTATED TO
AS
IS ROTATED TO:
1
2
3
4
5
(D)
IS ROTATED TO
AS
IS ROTATED TO:
1
2
3
4
5
(E)

Figure 5.169

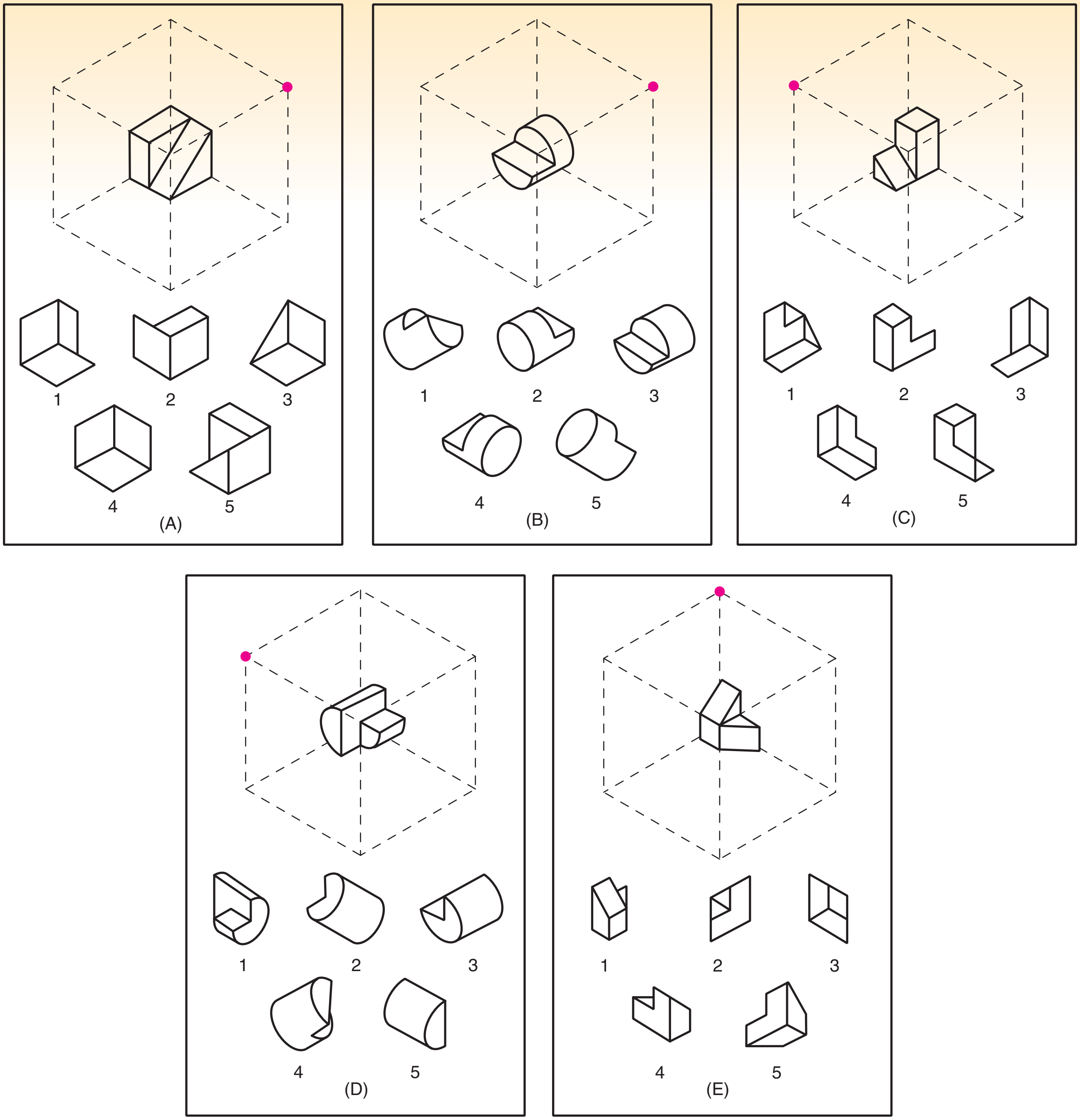


Figure 5.170

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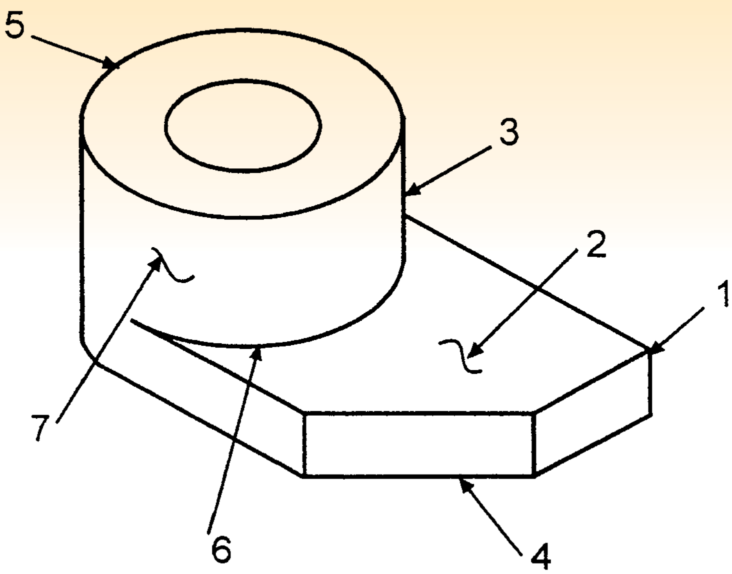
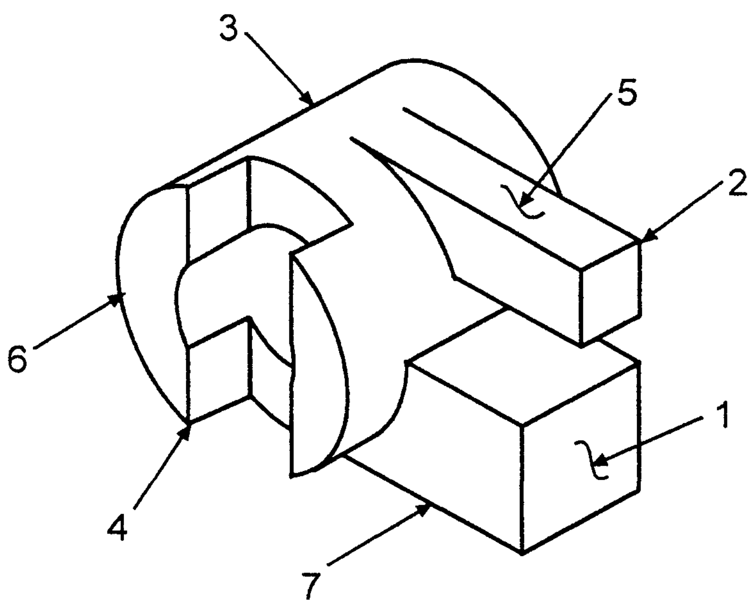


A
1. ______
2. ______
3. ______
4. ______
5. ______
6. ______
7. ______

A



B
1. ______
2. ______
3. ______
4. ______
5. ______
6. ______
7. ______

B

Figure 5.171

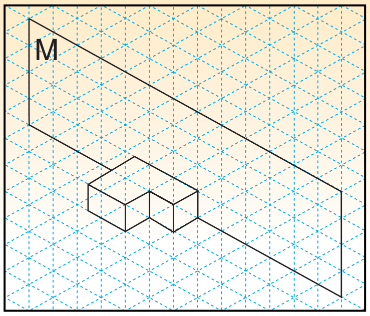


Figure 5.172

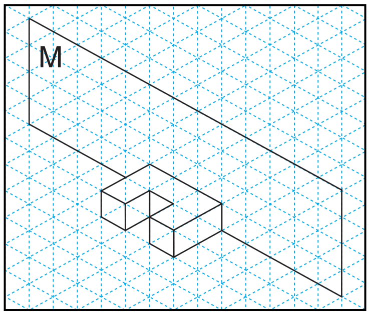


Figure 5.173

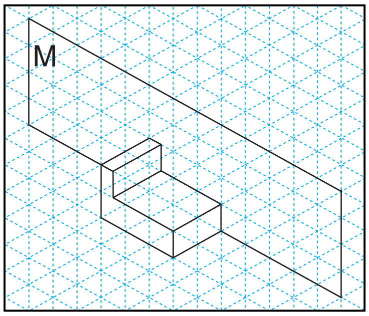


Figure 5.174

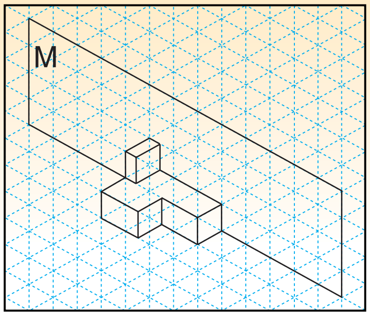


Figure 5.175

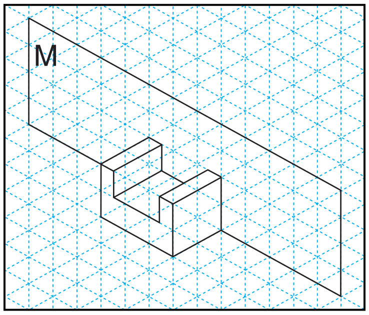


Figure 5.176

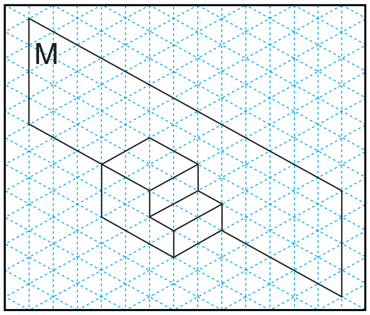
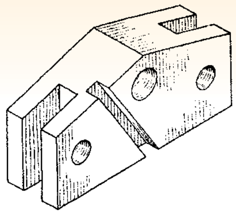


Figure 5.177

Classic Problems

The following classic problems were taken from *Engineering Drawing & Graphic Technology,* 14th Edition, by Thomas E. French, Charles J. Vierck, and Robert Foster. All fillets and rounds .125″ or 2 mm unless otherwise indicated.

1. Pieces to be drawn freehand in orthographic projection.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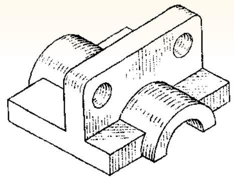
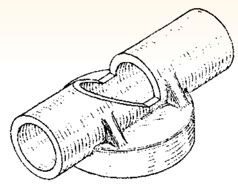
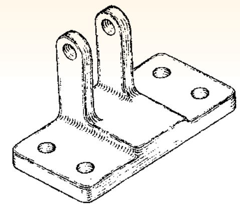
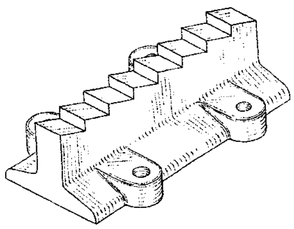
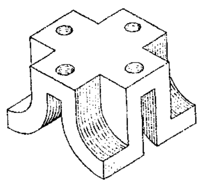

(B)


(C)


(D)


(E)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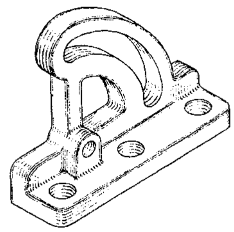
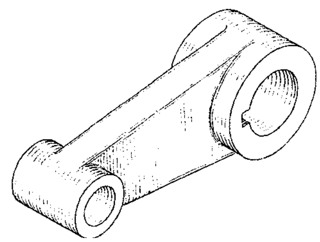
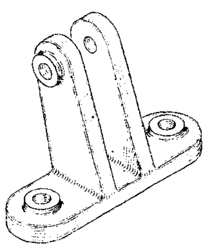
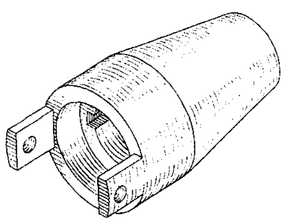
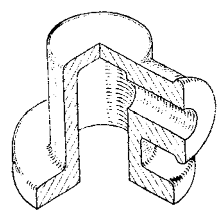
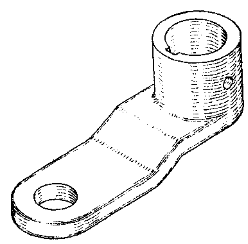

(G)

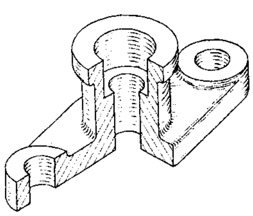

(H)


(I)


(J)


(K)


(L)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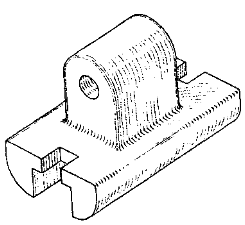
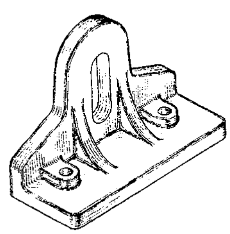
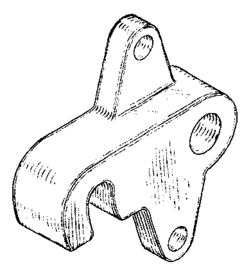
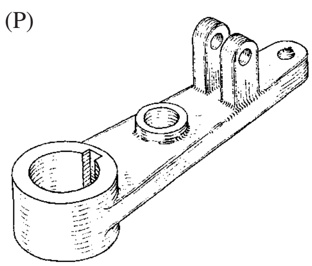

(N)


(O)

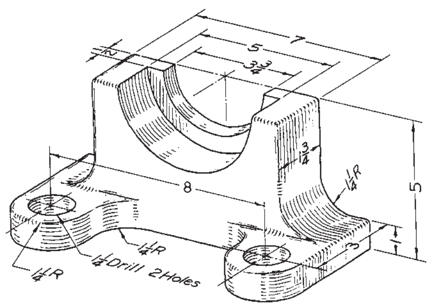

(P)


(Q)

Problem 1

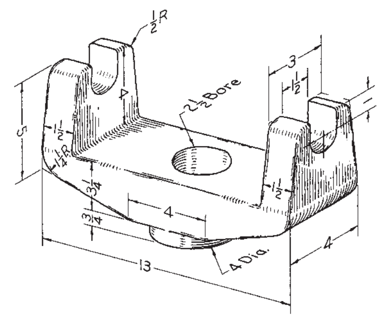
Draw freehand orthographic projections

2. Draw three views of the bearing rest.
3. Draw three views of the swivel yoke.
4. Draw three views of the truss bearing.
5. Draw three views of the wire thimble.
6. Draw three views of the hanger jaw.
7. Draw two views of the shifter fork.
8. Draw three views of the bedplate stop.
9. Draw three views of the tube hanger.
10. Draw three views of the end plate.
11. Draw three views of the angle connector.
12. Make working drawing of shifter fork. Cast steel.
13. Make working drawing of rubber support anchor.
14. Make working drawing of relief-valve body. Cast brass.
15. Make working drawing of bearing block, cast iron.
16. Make a unit-assembly working drawing of the wing-nose rib.



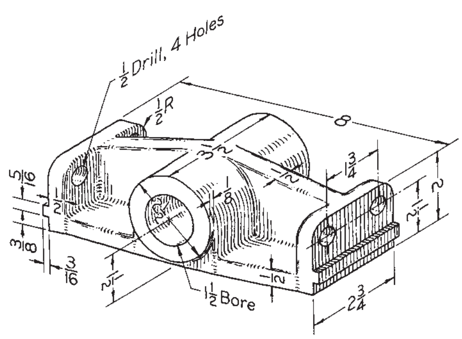
Problem 2

Bearing rest



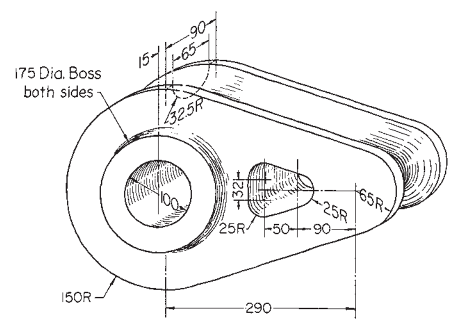
Problem 3

Swivel yoke



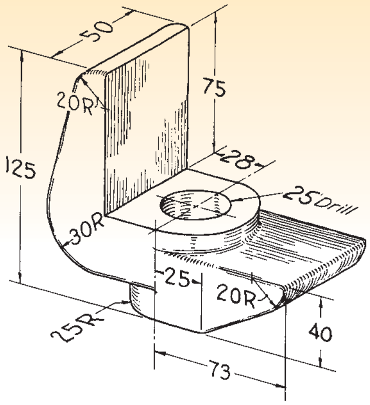
Problem 4

Truss bearing



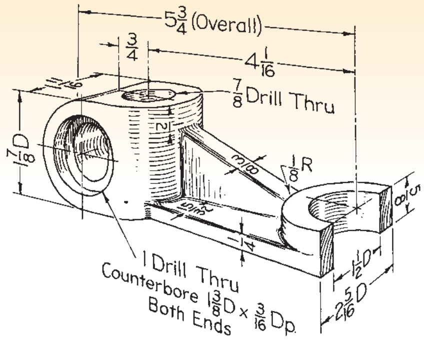
Problem 5 Metric

Wire thimble



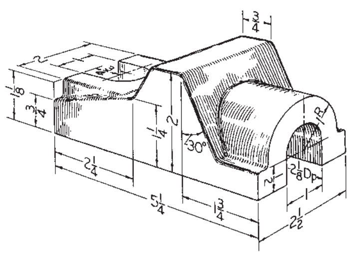
Problem 6 Metric

Hanger jaw



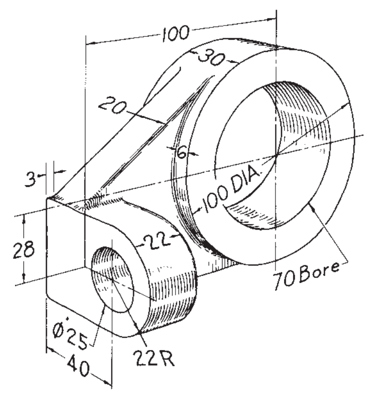
Problem 7

Shifter fork



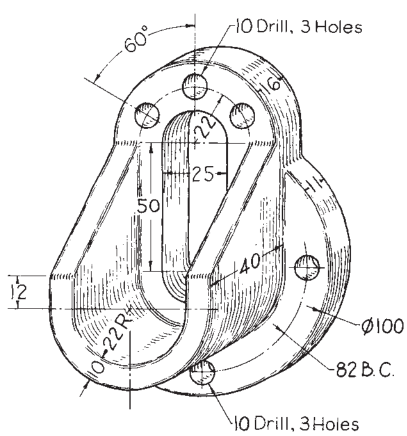
Problem 8

Bedplate stop



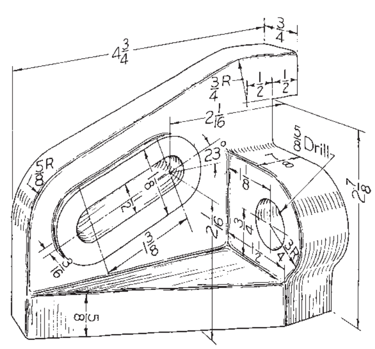
Problem 9 Metric

Tube hanger



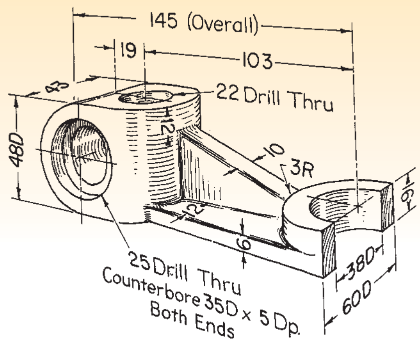
Problem 10 Metric

End plate



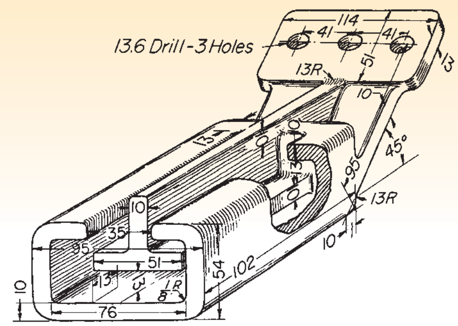
Problem 11

Angle connector



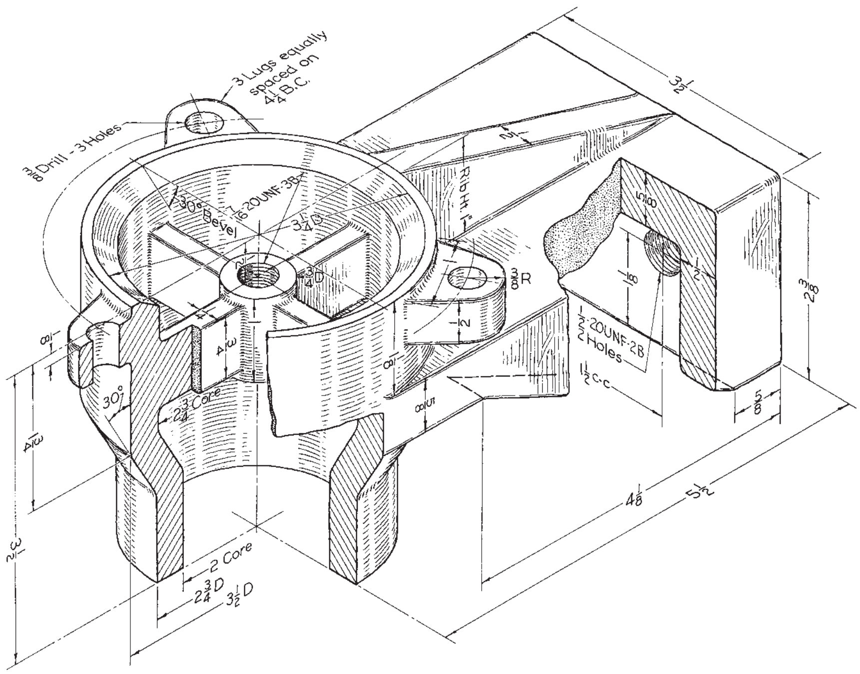
Problem 12 Metric

Shifter fork



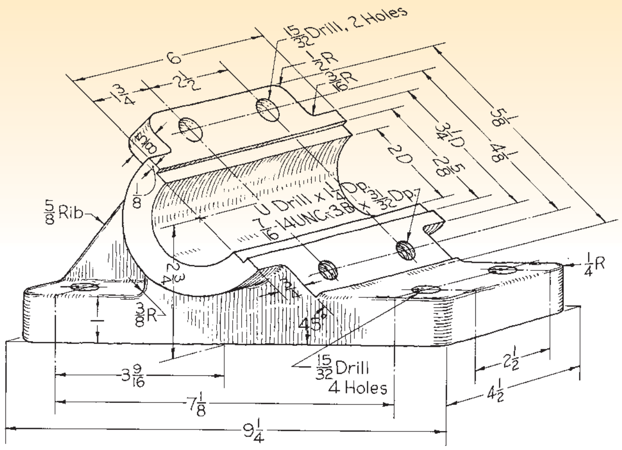
Problem 13 Metric

Rubber support anchor



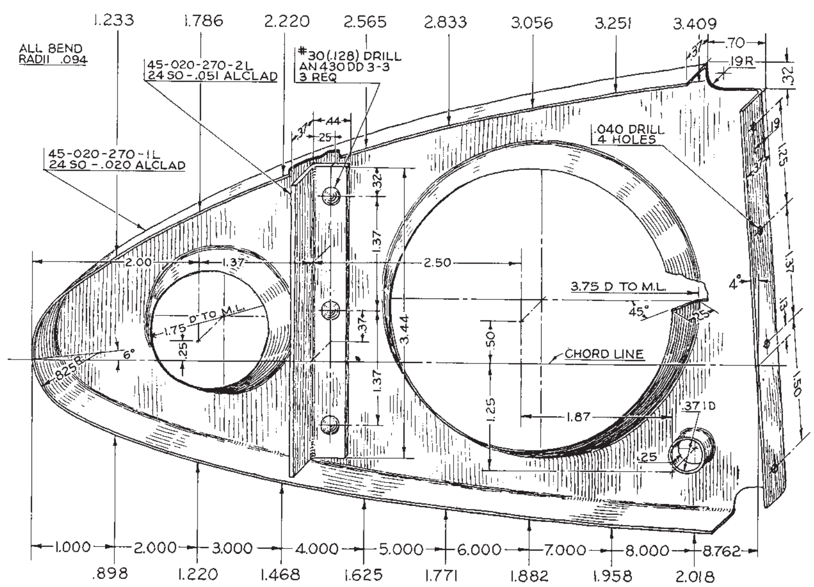
Problem 14

Relief-valve body



Problem 15

Bearing block



Problem 16

Wing-nose rib