Chapter 6
Drafting: Projections and Sketching

Topics

1.0.0 Parallel Projection
2.0.0 Perspective Projection and Perspective Drawing
3.0.0 Sketching

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Overview

This chapter deals with projection theory and methods of preparing projection drawings. You should be able to clearly represent any given object or structure on paper by applying basic geometric construction to the various projection methods. Although the methods discussed here are basic to all drawings, you can easily adapt them for construction drawings. This chapter also covers various techniques of freehand sketching. You will learn how to prepare quick sketches to convey or develop your ideas.

Every object or structure you draw has length, width, and depth, regardless of its size. Your goal, however, is to draw the object or structure on paper, which is a flat two-dimensional plane. To show the three dimensions by lines alone, you must use either a system of related views or a single pictorial projection. You must be able to show clearly the shape of the object, give the exact size of each part, and provide necessary information for constructing the object.

In theory, projection is done by extending lines of sight (called projection lines) from the eye of the observer, through lines and points of an object being viewed, to the plane of projection.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of parallel projection.
2. Describe the different types of perspective projection and perspective drawing.
3. Describe the different techniques used in sketching.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.
Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
• Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
1.0.0 PARALLEL PROJECTION

To satisfy requirements for preparing single or multi-view drawings, there are two main types of projection: parallel and perspective (Figure 6-1). Parallel projection (Figure 6-2) is further classified into subtypes according to the direction of its projection lines relative to the plane of projection. If the projection lines are not only parallel to each other but are also perpendicular (normal) to the plane of projection, the result is an orthographic projection. If they are parallel to each other but oblique to the plane of projection, the result is an oblique projection.

![Diagram of projections]

Figure 6-1 – Classification of major projections.

To better understand the theory of projection, you must become familiar with certain elements common to each type of projection. Some of these elements are defined below.

The point of sight (or station point) is the position of the observer in relation to the object and the plane of projection (Figure 6-2). It is from this observation point that the view of the object is taken. Since changing the point of view gives different views of the same object, there must be a different point of sight for each view. Imagine yourself looking first at the front of an object, then down at the top, and then at the right or left side, as the case may be. Each additional view requires a new point of sight.
Figure 6-2 – Types of projections.

The observer views the features of the object through an imaginary *plane of projection* (or *image plane*). In parallel projection, you place this theoretical transparent plane between the point of sight and the object, as shown in Figure 6-2. For perspective pictorials, you normally place the image plane between the point of sight and the object. For the purpose of studying any type of projection, assume the planes of projection are in fixed positions. Once you place the object in a definite imagined position, never change it. If you want a different view of the object, change the location of the point of sight.

The projection lines (or lines of sight) are the imaginary lines from the eye of the viewer (point of sight) to points on the object (Figure 6-2). By the use of projection lines, points on the object are projected on the image plane. These points are the points at which the projection lines appear to pierce the image plane. By the projection of the prominent points, lines, and surfaces of an object, a complete view of that object can be projected on the plane of projection.

The following sections will discuss the relationship between the point of sight (station point), the plane of projection (image plane), the projection lines (lines of sight), and the manner in which to use them for each individual type of projection.

1.1.0 Orthographic Projection

When called upon to draw a three-dimensional object or figure, you are expected to represent the parts and forms on the flat plane of the drafting paper so that all features are shown in their true dimensions and in their true relationship with other features on that part of the object. To do this, you must draw a number of views of the object from different angles. Orthographic projection consists of projecting these essential views into a single plane. The term orthographic is derived from the word orthos meaning perpendicular or right-angular.
1.1.1 Multi-View Projection

When you view an object through a plane of projection from a point at infinity, you obtain an accurate outline of the visible face of the object (Figure 6-3). However, the projection of one face usually will not provide an overall description of the object; you must use other planes of projection. Establishing an object’s true height, width, and depth requires front, top, and side views, which are called the principal planes of projection. Figure 6-4 shows the three principal (or primary) planes of projection, known as the vertical, horizontal, and profile planes. The angles formed between the horizontal and the vertical planes are called the first, second, third, and fourth angles, as indicated in the figure. Currently, however, for technical reasons, only the use of first- and third-angle projection is practical.

Figure 6-3 – Basic orthographic projection.
1.1.1.1 First-Angle Projection

*Figure 6-5* is a fine example of first-angle projection using a cube. The front of the cube is facing toward the vertical plane of projection. As you can see, you get a front view on the vertical plane, a left side view on the profile plane, and a top view on the horizontal plane.

Now, to put these views on a sheet of drafting paper, put them all into the same plane. Presume that the vertical plane of projection is already in the plane of the paper. To get the other two views into the same plane, rotate the profile plane counterclockwise and the horizontal plane clockwise. The projection now appears as shown in *Figure 6-6.*
In common European drafting practice, this first-angle projection arrangement of views is considered satisfactory. In the United States, it is considered illogical because the top view is below the front view; because the right side of the object, as shown in the front view, is toward the left side view of the object; and because the bottom of the object, as shown in the front view, is toward the top view of the object. For these and other reasons, first-angle projection is not commonly used in the United States.

### 1.1.1.2 Third-Angle Projection

*Figure 6-7* shows a third-angle projection of a cube. As you can see, you get a front view on the vertical plane, a top view on the horizontal plane, and a right side view on the profile plane.

![Figure 6-7 – Example of a third-angle projection.](image)

Assume that the vertical plane is already in the plane of your drawing paper. To get the other two views onto the same plane, rotate them both clockwise. *Figure 6-8* shows a third-angle projection of an object brought into a single plane. The top view is above the front view; the right side of the object, as shown in the front view, is toward the right side view; and the top, as shown in the front view, is toward the top view.

*Figure 6-9* shows the basic principles of the method used to make the projection shown in *Figure 6-8*. Draw a horizontal line AB and a vertical line CD, intersecting at O. AB represents the joint between the horizontal and the vertical plane; CD represents the joint between these two and the profile plane. You could draw any of the three views first and the other two projected from it. Assume that the front view is drawn first on the basis of given dimensions of the front face. Draw the front view, and project it upward with vertical projection lines to draw the top view. Project the top view to CD with horizontal projection lines. With O as a center, use a compass to extend these projection lines to AB. Draw the right side view by extending the projection lines from AB vertically downward and by projecting the right side of the front view horizontally to the right.
Figure 6-8 – A third-angle projection brought into a single plane.

Figure 6-9 – Method of making a third-angle projection.
1.1.1.3 Use of a Miter Line

Using a miter line (Figure 6-10), you can lay out a third view while you are in the process of drawing two other views. Place the miter line (Figure 6-10, View B) to the right of the top view at a convenient distance, keeping the appearance of a balanced drawing. Draw light projection lines from the top view to the miter line (Figure 6-10, View C), then vertically downward (Figure 6-10, View D). Using the front view, draw horizontal projection lines (Figure 6-10, View E) to the right, intersecting the vertical projection lines. This process results in the outline and placement of the right side view (Figure 6-10, View F).

Some EAs prefer to extend the top view projection lines to the right side view.

![Diagram of views](image)

**Figure 6-10 – A third-angle projection brought into a single plane.**

1.1.1.4 Arrangement of Views

You should arrange the six principal views of an object drawn in a third-angle projection in accordance with the American standard arrangement of views. This arrangement (practiced since the late 1800s) depicts the relative position of the six principal views and their relationship to each other on a drafting plane.

As shown in Figure 6-11, all views (except the front view) are rotated toward the observer as though they are hinged. **REMEMBER**, the front view always lies in the plane of the drafting surface and does not require any rotation. Notice that the front, right side, left side, and rear views line up in direct horizontal projection.
Use the minimum number of views necessary to show an item. The three principal views are top, front, and right-side. Project and draw the top view (also called a “plan” in architectural drawings) on an image plane above the front view of the object. The front view (elevation) should show the most characteristic shape of the object or its most natural appearance when observed in its permanent or fixed position. Place the right-side view (elevation) at a right angle to the front and top views, making all the views mutually perpendicular.

![Diagram](image)

**Figure 6-11 – A third-angle projection brought into a single plane.**
1.1.1.5 Spacing of Views

Space the views as necessary on the paper to give the appearance of a balanced drawing.

**Figure 6-12** – Proper spacing of views.

*Figure 6-12, View A* shows an easy way to locate horizontally aligned views on a standard size drawing sheet. With a compass or scale, lay off the length plus the width of the object (A + B) from one end of the horizontal margin. Divide the remaining distance, C, into three equal parts (C/3). The result will be the approximate distance from either view to the vertical margin. The two views should be equidistant from the vertical margin. Adjust the spacing between views so that the apparent area is close to the apparent area between either view and the vertical margin. Basically, the shape of the object will determine the space between views. Generally, the distance from the views to the vertical margins and the distance between views (X) will be approximately equal. To locate the views vertically on the paper, lay off the depth of the object (D) on the vertical margin. Divide the remaining distance (E) into two equal parts (E/2). This will be the approximate distance from the top or bottom of the view to the horizontal margins.

*Figure 6-12, View B* shows how the same method also applies to vertically aligned views on a standard size drawing sheet.

*Figure 6-13* shows the proper spacing of a three-view drawing. As you can see, the same principle is applied as in spacing a two-view drawing. Distances are again equal as indicated, with distance B equal to, or slightly less than, distance A, and distance D equal to, or slightly less than, distance C.

*Figure 6-13* – Proper spacing of views on a three-view projection.
While the spacing of views in Figure 6-13 is technically correct, the drawing appears unbalanced because of the large empty space in the upper right corner and the right side view crowding the title block. If the drawing will contain a sizeable bill of materials in the upper right corner, this spacing will be satisfactory. If not, it should be improved, if possible.

If the object allows an arbitrary choice in designating the surfaces as top, front, and so on, you can improve the spacing by changing the designation shown in Figure 6-13 and projecting the object as shown in Figure 6-14. The surface appearing as the top in Figure 6-13 is now called the front; it follows that the surface which appears as the front in Figure 6-13 appears as the bottom in Figure 6-14. Again the right side view appears, but it now appears in the upper, rather than the lower, right corner and vertically rather than horizontally.

Spacing views in a drawing of a circular object is like spacing letters; try to equalize the areas of the spaces around and between the views. Figure 6-15 shows properly spaced two-view drawings of a perforated disk. For the views that are horizontally in line, locate the horizontal center line midway between the horizontal margins; for the views that are vertically in line, locate it midway between the vertical margins. The other spacing is as indicated. To determine the lengths of distances A and 2/3 A, set a compass to the diameter plus the thickness of the disk, and lay off this distance on the margin. Then divide the remaining segment of the margin into three intervals, two of them being equal, and the third one being 1 1/2 times as long as each of the others.
1.1.1.6 View Analysis

In order to analyze a multi-view projection, you must be able to determine what each line in a particular view represents. Remember, in a third-angle projection, always presume the plane of projection is between the object and the observer, regardless of which view you are considering. In a third-angle projection, each view of an object’s surface is depicted as it would appear to an observer looking directly at it.

Figure 6-16 shows a six-view, multi-view, third-angle projection of the block shown in a single-view projection in the upper left corner of the figure. You should not have any trouble analyzing the front view; you know that the top is up, the bottom is down, the left side is to the left, and the right side is to the right.

In the top and bottom views, it’s easy to see that the right-hand vertical line represents the right side and the left-hand vertical line, the left side. But you might have to think a minute to realize that the upper horizontal line in the top view represents the back face of the block, while the upper horizontal line in the bottom view represents the front face of the block. Note, also, that a line appears as a visible line in the top view and as a hidden line in the bottom view.

![Figure 6-16 – Multi-view analysis of a third-angle orthographic projection.](image-url)
In the right side and left side views, you can readily see that the upper horizontal line represents the top of the block and the lower horizontal line, the bottom. But you may have to think a minute to realize that the left-hand vertical line in the right side view represents the front face of the block, while the left-hand vertical line in the left side view represents the back face. Again, there is a line that appears as a visible line in the right side view and as a hidden line in the left side view.

The back view shows the block reversed, so that the cutaway part, which appears to the right in the front view, appears to the left in the back view. Similarly, the right-hand vertical line in the front view represents the right side of the block, while the right-hand vertical line in the back view represents the left side.

Note that in the top, bottom, and side views, the line that represents the front face of the block faces toward the front view of the block. Similarly, in the back view, the line that represents the left side faces toward the left side view of the block. This applies to third-angle projection only.

A point that constitutes a corner on an object is sometimes numbered for purposes of identification in various views of the object. _Figure 6-17_ shows how a corner point number may be visible or hidden in a particular view of an object. In the upper left corner of the figure, an oblique projection of a block has a corner numbered 2. You can see that this corner is visible in top, back, and left side views, but hidden in bottom, front, and right side views.

The rule for numbering is that for a hidden corner point, place the number within the outline, and for a visible corner point, outside the outline. You can see how the rule has been followed in _Figure 6-17_.

A multi-view projection should contain only as many views as required to describe the object fully. If you refer back to _Figure 6-16_, you can see at once that the back view does not convey any information that is not available in the front view; the back view is therefore superfluous and should be omitted. The same applies to the bottom view; the top view already conveys the same information. Likewise, the left side view does not convey any information not available in the right side view.
You have the choice of omitting either the top or bottom view and either the right side or left side view. Some general rules to consider: a top view is preferable to a bottom view and a right side view, to a left side view. Also, a view with a visible line is preferable to a view with the same line shown as a hidden line. Both rules apply here to eliminate the bottom and the left side views. All you need here is a three-view projection showing the top, front, and right side views.

Sometimes you only require a two-view projection. The view at the top of Figure 6-18 shows a single-view projection of an object. A top view of this object tells you everything you need to know except the thickness; a right side view tells you everything you need to know except the length, and a front view tells you everything you need to know except the width. Select a particular view and couple it with another view that gives you the dimension missing in the first view.

The object shown in A, B, and C has three possible two-dimensional projections. In selecting one of these three, everything else being equal, the balance of the drawing would be the deciding factor. Either A or B appears better balanced than C, and between A and B, A would look better on a long oblong sheet of paper, and B, better on a shorter oblong sheet.

The object shown in Figure 6-18 has a definitely designated top and front; it follows that the right and left sides are also definitely designated. This is the case with many objects; you have no choice, for example, with regard to the top, bottom, front, and back of a house. Many objects, however, have no definite top, bottom, front, or back as many types of machine parts, for example. With an object of this kind, you can select a surface and call it the front, and select another and call it the top, according to convenience. As a general rule, you should show an object in the position it customarily occupies.

You can use one-view drawings for objects which can be completely defined with one view and dimensions or notes of features, such as thickness or length.
1.1.1.7 Normal and Non-Normal Lines

In a multi-view orthographic projection, a normal line is parallel to two of the planes of projection and perpendicular to the third. A line that is parallel to a plane of projection will appear on that plane in its true length (to the scale of the drawing). A line that is perpendicular to a plane of projection will appear on that plane as a point.

A line that is perpendicular to one plane of projection must of necessity be parallel to the other two. But a line that is parallel to one plane of projection may be oblique (neither parallel nor perpendicular) to one or both of the others. A line that is oblique to one or more of the planes of projection is called a non-normal line.

If a non-normal line is parallel to a plane of projection, it will appear on that plane in its true length. However, it will appear foreshortened in a view on a plane to which it is oblique. A non-normal line may, of course, be oblique to all three planes of projection, in which case it will appear foreshortened in all regular views of the object. A regular view is a view on one of the three regular planes of projection (horizontal, vertical, or profile). Views on planes other than the regular planes are called auxiliary views. Auxiliary views will be discussed later in this chapter.

The upper left corner of Figure 6-19A shows a single-view projection of a block. This block is placed for multi-view projection with the front parallel to the vertical plane, the bottom parallel to the horizontal plane, and the right side parallel to the profile plane. The line AB, then, is parallel to the vertical plane, but oblique to both the horizontal and the profile planes.

In the multi-view projections, you can see that it is only in the views on the vertical plane (the front and back views) that the line AB appears in its true length. In the views on the horizontal plane (top and bottom views) and in the views on the profile plane (right and left side views), the line appears foreshortened. Note, however, that you don’t need to calculate the amount of the foreshortening, since it works itself out as you project the various views.

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**Figure 6-19 – Foreshortening of a line in a multi-view projection.**
1.1.1.8 Circles in Multi-View Orthographic Projection

A circle on a surface parallel to the plane of projection will project as a circle. Figure 6-20 shows that a circle on a surface oblique to the plane of projection will project as an ellipse. The upper view in this figure is a top view of a wedge; the wedge has a hole bored through it perpendicular to the inclined face. The outline of this hole on the front face of the wedge projects as an ellipse in the front view. You get the minor axis of the ellipse by projecting downward as shown. The length of the major axis is equal to the diameter of the hole.

The front view shows another ellipse. This is the partly hidden and partly visible outline of the hole as it emerges through the back of the wedge. The back of the wedge is parallel to the front view plane of projection; therefore, this ellipse is the true outline of the hole on the back of the wedge. The outline is elliptical because the hole, though it is circular, is bored obliquely to the back face of the wedge.

To draw these ellipses, use any of the methods of drawing an accurate ellipse covered in the previous chapter or use an ellipse template.

1.1.1.9 Auxiliary Views

In theory, there are only three regular planes of projection: the vertical, the horizontal, and the profile. Actually, presume that each of these views are doubled; there is, for example, one vertical plane for a front view and another for a back view.

Assume, then, a total of six regular planes of projection. A projection on any one of the six is a regular view. A projection NOT on one of the regular six is an auxiliary view.

The basic rule of dimensioning requires that you dimension a line only in the view in which its true length is projected and that you dimension a plane with its details only in the view in which its true shape is represented. To satisfy this rule, create an imaginary plane that is parallel with the line or surface we want to project in its true shape. A plane of this kind that is not one of the regular planes is called an auxiliary plane.
Figure 6-21 – A line oblique to all planes of projection is foreshortened in all views.

In the upper left of Figure 6-21, the base of the single-view projection of a triangular block is a rectangle. Presume this block is placed for multi-view projection with the right side parallel to the profile plane. Draw the block using all six views of multi-view projection.

Carefully examine Figure 6-21; the lines AB, AE, BD and BC and the surfaces ABC, ABE, and BDE are oblique to three regular planes of projection. The lines are foreshortened and the surfaces are not shown in their true shape in any of the six normal views.
The first step in drawing any auxiliary view is to draw the object in normal multi-view projection, as shown in Figure 6-22. A minimum of two orthographic views is necessary. The space between these views is generally greater than normal. The reason for this will become apparent. Notice in the front view of Figure 6-22, that A is the end point of line AE (top view) and C is the end point of CD.

The second step is to decide which line or surface to show in an auxiliary view and which orthographic view it will be projected from. Consider the following facts when making this decision:

1. Always project front or rear auxiliary views from a side view.
2. Always project right or left auxiliary views from a front view.
3. Always project an elevation auxiliary view from the top view.

The third step is to select the auxiliary and reference planes. The auxiliary plane is simply a plane parallel to the desired line or lines representing an edge view of the desired surface.

In Figure 6-23, the goal is to depict the true length of line AB and the true shape of surface ABE. You need a left side auxiliary view. Draw the auxiliary plane parallel to line AB in the front view. Line AB actually represents an edge view of surface ABE. The reference plane (top view) represents an edge view of the orthographic view (front view) from which the auxiliary view will be projected. Therefore, when you want the front, rear, or side auxiliary views, the reference plane will always be in the top view. When you draw elevation auxiliary views, the reference plane may be in any view in which the top view is represented by a straight line. The reference plane in Figure 6-23 is the edge of the top view that represents the front view. Remember that although these planes are represented by lines, they are actually planes running perpendicular to the views.

Step four is to project and locate the points describing the desired line or surface. Draw the projection lines from the orthographic view perpendicular to the auxiliary plane. By scaling or with a compass, take the distances from the reference plane. The distances are the perpendicular distances from the reference plane to the desired point. Figure 6-23 shows the projection lines drawn from points A, B, and C in the front view, perpendicular to the auxiliary plane. The projection line from point A indicates the line on which point E will also be located. The projection line from point C designates the line of both C and D, and that from B locates B only. To transfer the appropriate distances, first look for any points lying on the reference plane. These points will also lie on the auxiliary plane where their projection lines intersect it (points A and C). To locate points B, D, and E, measure their perpendicular distances from the reference plane in the top view and transfer these distances along their respective projection lines in the
auxiliary view. The points are equidistant from both the reference and auxiliary planes. Therefore, any line parallel to the reference plane is also parallel to the auxiliary plane and equidistant from it.

The fifth step is to connect these points. When the total auxiliary view is drawn, it is sometimes hard to discern which lines should be indicated as hidden lines. A rule to remember is as follows:

Those points and lines lying furthest away from the auxiliary plane in the orthographic view being projected are always beneath any point or line that is closer. In Figure 6-23, point C (representing line CD) in the front view is further from the auxiliary plane than any line or surface it will cross in the auxiliary view. Therefore, it will appear as a hidden line.

The final step is to label and dimension the auxiliary view. The labeling must include an adequate description. The term AUXILIARY must be included along with the location of the view in relation to the normal orthographic views (LEFT SIDE AUXILIARY VIEW, REAR ELEVATION AUXILIARY VIEW, and so forth). Dimensions are given only to those lines appearing in their true length. In Figure 6-23, only lines AB, AE, and BE on the auxiliary view should be dimensioned.

Using the procedures previously described, follow the steps taken to project and draw the rear auxiliary view in Figure 6-24.

Figure 6-23 – Projection of left side auxiliary view.
Figure 6-24 – Projection of rear auxiliary view.

Sometimes you will not need the total auxiliary view. Such a view could possibly even make the drawing confusing. In this case, use a partial auxiliary view. Use only the points or lines needed to project the line or surface desired. This reduces the number of projection lines and greatly enhances the clarity of the view. If you use a partial auxiliary view, label it PARTIAL to avoid confusion. In Figure 6-23, if you desire only the true length of line AB, project and connect the points A and B. The view would be complete after being labeled and dimensioned.

In some cases the shape of an object will be such that neither the normal orthographic view nor the auxiliary views will show the true size and shape of a surface. When this occurs, a secondary auxiliary view is necessary to describe the surface. The procedures for projecting and drawing a secondary auxiliary view are the same as those for a normal (or primary) auxiliary view. The reference plane for a secondary auxiliary view is located in the orthographic view from which the primary auxiliary view is projected. Usually, the primary auxiliary plane becomes the secondary reference plane. The secondary auxiliary plane is in the primary auxiliary view, and its location is determined in the same manner as the primary auxiliary plane.
1.1.1.10 Auxiliary Section

An auxiliary view may be a sectional rather than a surface view. In the upper left part of Figure 6-25, there is a single-view projection of a block. The goal is to show the right side of the block as it would appear if the block were cut away on the plane indicated by the dotted line, the angle of observation to be perpendicular to this plane. The desired view of the right side is shown in the auxiliary section, which is projected from a front view as shown. Because the auxiliary plane of projection is parallel to the cutaway surfaces, these surfaces appear in true dimensions in the auxiliary section.

A regular multi-view of an orthographic drawing is a view projected on one of the regular planes of projection. An auxiliary view is a view projected on a plane other than one of the regular planes.

Figure 6-25 – Use of an auxiliary section.

Figure 6-26 – (A) Multi-view view of block in normal position (B) Multi-view view of block revolved 30 degrees on axis perpendicular to vertical plane.

A rectangular object is in normal position for regular multi-view orthographic projection when each of its faces is parallel to one regular plane of projection and perpendicular to the other two. This is the case with the object shown in Figure 6-26, View A.
1.1.1.11 Use of Revolutions

In a revolution, you project the object on one or more of the regular planes of projection. However, instead of placing the object in a normal position, rotate it on an axis perpendicular to one of the regular planes.

*Figure 6-26, View B,* depicts a three-view multi-view projection showing the block in *Figure 6-26, View A,* as it appears when revolved 30 degrees on an axis perpendicular to the profile plane of projection. *Figure 6-27, View A,* shows how the block looks when it is revolved 30 degrees on an axis perpendicular to the horizontal plane. *Figure 6-27, View B,* shows the block as it appears when revolved 30 degrees on an axis perpendicular to the vertical plane.

![Figure 6-27](image)

*Figure 6-27 – Use of revolution on axis perpendicular to (A) horizontal plane and (B) vertical plane.*

1.1.1.11 Revolved Sections

A common use of the revolution is the revolved section, shown in *Figure 6-28.* At the top of this figure is a single projection of a triangular block. You can show all the required information about this block in a two-view projection by including a revolved section in the front view as shown. First, assume that the block is cut by a plane perpendicular to the longitudinal axis. Then revolve the resulting section 90 degrees on axis perpendicular to the horizontal plane of projection.

![Figure 6-28](image)

*Figure 6-28 – Use of revolved section (A-A).*
1.1.1.13 Sectioning Techniques

Use a sectional view when it will better show the object’s internal structure than using hidden lines. The upper part of Figure 6-29 shows a single-view projection of a pulley. The lower part of Figure 6-29 shows the same object in a two-view multi-view projection. The hidden lines in the top view show the internal structure of the pulley.

The sectional view in Figure 6-30 shows the internal structure of the pulley more clearly. Note that the sectional view omits the hidden lines behind the plane of projection of the section. Customarily, you should omit these lines because eliminating hidden lines is the fundamental reason for making a sectional view. However, in the sectional view include any lines that would be visible behind the sectional plane of projection.

The section shown in Figure 6-30 is called a full section. Also, the object shown in Figure 6-30 is a symmetrical object, meaning, in general, that the shape of one half is identical to the shape of the other. This being the case, you could have used a half section like the one shown in Figure 6-31. This half section constitutes one half of the full section. Because the other half of the full section would be identical with the half shown, it need not be drawn.

Note that a center line, rather than a visible line, is used to indicate the division between the sectioned and the unsectioned part of the sectional view. A visible line would imply a line that is

**Figure 6-29** – Internal structure of an object shown by hidden lines.

**Figure 6-30** – Internal structure of an object more clearly shown by sectional view.
actually nonexistent on the object. Another term used in place of center line is line of symmetry.

Figure 6-31 – Use of half section.

A section consisting of less than half a section is called a partial section. (See Figure 6-32.) Note that here you use a break line to indicate the division between the sectioned and unsectioned part. For this reason, a partial section is often called a broken section.

The section lines drawn on a sectional surface always serve the basic purpose of indicating the limits of the sectional or cutaway surface. They may also indicate the type of material of which the sectioned surface consists. For example, Figure 6-33, View A, shows section lining for an object made of cast iron. View B shows two matching parts made of steel, and View C shows three adjacent parts made of brass, bronze, or copper. For other symbolic section lining symbols, refer to ANSI Standard Y14.2.

Figure 6-32 – Use of partial or broken section.
Figure 6-33 – Diagonal hatching on separate sectional surfaces shown in normal positions.

Drawings must always identify materials by lettered form, such as notes. In view of the vast number of different materials, it is desirable (and common practice), to use a general purpose symbol for section lining. The general purpose symbol is the cast iron symbol shown in Figure 6-33, View A. The use of other symbols should be limited to those situations when it is truly desirable, or conventional, to graphically differentiate between materials. For example, in an assembly drawing (a drawing showing different parts fitted together), it is often desirable to differentiate materials.

On a regular multi-view section, draw section lining (sometimes called diagonal hatching or crosshatching) at 45° to the horizontal, as shown in Figure 6-33, View A. However, if section liners drawn at 45° to the horizontal would be parallel or perpendicular (or nearly so) to a prominent visible outline, change the angle to 30°, 60°, or some other angle. If two adjacent sectioned surfaces are shown, draw the hatching in opposite directions, as shown in Figure 6-33, View B. If you include a third surface, hatch it at another suitable angle to make the surface clearly stand out separately from the other surfaces (Figure 6-33, View C). Note that the hatching lines on one surface are not permitted to meet those on an adjacent surface.

In drawing section lining, use a sharp, medium-grade pencil (H or 2H). Space the lines as uniformly as possible by eye. As a rule, space your lines as generously as possible, yet close enough to distinguish the sectioned surface clearly. For average drawings, space the lines about 3/32 in. or more.

Figure 6-34 – Diagonal hatching on an auxiliary section.
apart.

Draw diagonal hatching on an auxiliary section at 45 degrees to the horizontal with respect to the section. *Figure 6-34* shows this rule.

In a revolution or other view of an object in other than the normal position, draw the diagonal hatching on a section at 45 degrees to the horizontal or vertical axis of the object as it appears in the revolution. *Figure 6-35* shows this rule.

### 1.1.2 Axonometric Projection

Axonometric single-plane projection is another way of showing an object in all three dimensions in a single view. Theoretically, axonometric projection is orthographic projection in that only one plane is used and the projection lines are perpendicular to the plane of projections. It is the object itself, rather than the projection lines, that is inclined to the plane of projection.

#### 1.1.2.1 Isometric Projection and Isometric Drawing

*Figure 6-36* shows a cube projected by isometric projection, the most frequently used type of axonometric projection. The cube is inclined so that all of its surfaces make the same angle (35°16’) with the plane of projection. As a result of this inclination, the length of each of the edges shown in the projection is somewhat shorter than the actual length of the edge on the object itself. This reduction is called *foreshortening*. The degree of reduction amounts to the ratio of 1 to the cosine of 35°16’, or 1/0.8165. This means that if an edge on the cube is 1 in, long, the projected edge will be 0.8165 in.

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*Figure 6-34* – Diagonal hatching on revolution.

*Figure 6-35* – Isometric projection of a cube.
long. As all of the surfaces make the same angle with the plane of projection, the edges all foreshorten in the same ratio. Therefore, one scale can be used for the entire layout; hence the term *isometric*, which literally means “one-scale.”

*Figure 6-37* shows how an isometric projection would look to an observer whose line of sight was perpendicular to the plane of projection. Note that the figure has a central axis, formed by the lines OA, OB, and OC; this property is the origin of the term axonometric projection. In an isometric projection, each line in the axis forms a 120° angle with the adjacent line, as shown. A quick way to draw the axis is to draw the perpendicular OC, then use a T square and a 30°/60° triangle to draw OA and OB at 30 degrees to the horizontal. Since the projections of parallel lines are parallel, the projections of the other edges of the cube will be, respectively, parallel to these axes.

You can easily draw a rectangular object in isometric by the procedure known as box construction. The upper part of *Figure 6-38* shows a two-view normal multi-view projection of a rectangular block; the lower part shows an isometric drawing of the block. You can see how you build the figure on the isometric axis and how you lay out the dimensions of the object on the isometric drawing. Because you lay out the identical dimensions, it is an isometric drawing rather than an isometric projection.

*Figure 6-38* – Use of “box construction” in isometric drawing.
1.1.2.2 Non-Isometric Lines

Examining the isometric drawing shown in Figure 6-38, you will note that each line in the drawing is parallel to one or another of the legs of the isometric axis. You will also notice that each line is a normal line in the multi-view projection. Recall that a normal line, in a normal multi-view projection, is parallel to two of the planes of projection and perpendicular to the third. Thus, a non-isometric lines is not parallel to any one of the three legs of the isometric axis. It is not a normal line in a normal multi-view projection of the object.

The upper part of Figure 6-39 shows a two-view normal multi-view projection of a block.

Though the line AB is parallel to the horizontal plane of projection, it is oblique to both the vertical and the profile planes. It is therefore not a normal, but an oblique, line in the multi-view projection, and it will be a non-isometric line in an isometric projection or drawing of the same object.

The line AB appears in its true length in the top multi-view view because it is parallel to the plane of the view (the horizontal plane), but it will appear as a non-isometric line, and therefore not in its true length, in an isometric drawing, as shown in the bottom part of Figure 6-39. It follows that you cannot transfer AB directly from the multi-view projection to the isometric drawing. You can, however, transfer directly all the normal lines in the multi-view projection, which will be isometric lines appearing in their true lengths in the isometric drawing. When you have done this, you will have constructed the entire isometric drawing, exclusive of line AB and of its counterpart on the bottom face of the block. The end points of AB and of its counterpart will be located, however, and it will only be necessary to connect them by straight lines.

Figure 6-39 – A non-isometric line (AB) in an isometric projection.
1.1.2.3 Angles in Isometric

In a normal multi-view view of an object, an angle will appear in its true size. In an isometric projection or drawing, an angle never appears in its true size. Even an angle formed by normal lines, such as each of the 90-degree corner angles of the block shown in the bottom part of Figure 6-40, appears distorted in isometric.

The same principle used in transferring a non-isometric line is used to transfer an angle in isometric. The upper part of Figure 6-40 shows a two-view multi-view projection of a block. On the top face of the block, the line AB makes a 40-degree angle with the front edge. The line AB is an oblique (that is, not normal) line, which will appear as a non-isometric line in the isometric drawing. Locate the end points of AB on the isometric drawing by measuring distances along normal lines on the multi-view projection and laying them off along the corresponding isometric lines on the isometric drawing. The angle that measures 40 degrees on the top multi-view view measures only about 32 degrees on the isometric drawing. Note, however, that it is labeled 40 degrees on the isometric drawing. This is because it actually is a 40-degree angle as it would look on a surface plane at the isometric angle of inclination.

1.1.2.4 Circles in Isometric

A circle in a normal multiview view will appear as an ellipse in an isometric drawing. This is shown in Figure 6-41, View A.

Figure 6-40 – Drawing an angle in isometric.

Figure 6-41 – A circle on a normal multi-view view appears as an ellipse in an isometric drawing.
A procedure that maybe used to construct an isometric circle is shown in Figure 6-41, View B. The steps of that procedure are as follows:

1. Draw the isometric center lines of the circle. Then, using those center lines, lay off an isometric square with sides equal to the diameter of the circle.

2. From the near corners of the box, draw bisectors to the opposite intersections of the center lines and the box. The bisectors will intersect at four points (A, A', B, B'), which will be the centers of four circular arcs.

3. Draw two large arcs with radius R, using Points A and A' as centers. Draw the two smaller arcs with radius r, using Points B and B' as centers.

The above discussion should seem familiar, since it is simply an approximation of the fourpoint method you studied in the previous chapter. However, you can use it only when drawing isometric circles on an isometric drawing.

1.1.2.5 Non-Circular Curves in Isometric

A line that appears as a noncircular curve in a normal multi-view view of an object appears as a non-isometric line in an isometric drawing. To transfer such a line to an isometric drawing, plot a series of points by measuring along normal lines in the multi-view view and transferring these measurements to corresponding isometric lines in the isometric drawing.

The upper part of Figure 6-42 shows a two-view multi-view projection of a block with an elliptical edge. To make an isometric drawing of this block, draw the circumscribing rectangle on the top multi-view view; lay off equal intervals as shown, and draw perpendiculars at these intervals from the upper horizontal edge of the rectangle to the ellipse. Then draw the rectangle in isometric, as shown below, and plot a series of points along the elliptical edge by laying off the same perpendiculars shown in the top multi-view view. Draw the line of the ellipse through these points with a french curve.

1.1.2.6 Alternate Positions of Isometric Axis

Up to this point, the isometric axis has been used with the lower leg vertical. The axis may, however, be used in any position, provided the angle between adjacent legs is always 120 degrees. Figure 6-43 shows how varying the position of the axis varies the view of the object.
1.1.2.7 Diagonal Hatching in Isometric

Diagonal hatching on a sectional surface shown in isometric should have the appearance of making a 45-degree angle with the horizontal or vertical axis of the surface. If the surface is an isometric surface (one that makes an angle of 35°16' with the plane of projection), lines drawn at an angle of 60 degrees to the horizontal margin of the paper, as shown in Figure 6-44, present the required appearance. To show diagonal hatching on a non-isometric surface, you must experiment to determine the angle that presents the required appearance.

1.1.2.8 Dimetric and Trimetric Projections

Two other subclassifications of the axonometric projection category are dimetric and trimetric projections; however, these types are used less frequently than isometric projections and will not be discussed further in this training manual.

1.2.0 Oblique Single-Plane Projection

We have seen that you can draw an object showing length and width on a single plane. You can also show depth on this single plane by constructing the receding projection lines of the object at an angle other than perpendicular to the plane of projection.

Figure 6-43 – Various positions of isometric

Figure 6-44 – An example of diagonal hatching in isometric.
Figure 6-45 Oblique and orthographic projections of the same object

There are two types of oblique single-plane projections: cavalier and cabinet.

1.2.1 Cavalier Projection

Cavalier projection is a form of oblique projection in which the projection lines are presumed to make a 45-degree vertical and a 45-degree horizontal angle with the plane of projection. Assume that in Figure 6-46 the line XX' represents a side-edge view of the plane of projection, and that the square ABCD represents a side of a cube placed with its front face parallel to, and its top face perpendicular to, the plane of projection. The projected lengths of AB and AD are the same as the actual lengths.

Now assume that the line XX' in Figure 6-46 represents a top-edge view of the plane of projection, and that the square ABCD represents the top of the cube. You can see again that the projected lengths of AB and AD are the same as the actual lengths.

Figure 6-46 - Angle of projection lines in a cavalier projection.

Figure 6-45 shows the same object by both orthographic and oblique projection. The block is placed so that its front surface (the surface toward the plane of projection) is parallel to the plane of projection. The orthographic projection shows only this surface of the block. The oblique projection, on the other hand, shows the front surface and the top and side surfaces. The orthographic projection shows only two dimensions: length and width. The oblique projection shows three: length, width, and thickness. Oblique projection, then, is one method by which an object can be shown, in a single view, in all three dimensions.
lengths of AB and AD.

In a cavalier projection, any line parallel or perpendicular to the plane of projection is projected in its true length. Figure 6-47 shows a cavalier projection of the cube shown in Figure 6-46. Start by drawing the axis, which consists of the front axes OA and OB and the receding axis OC. The front axes are always perpendicular to each other; the receding axis may be drawn from O at any convenient angle. All three are equal in length, the length being the length of an edge of the original cube (which may be scaled down or up if the drawing is made other than full scale). After you draw the axis, complete the projection by drawing the required parallel lines. All the edges shown in the projection are, like the edges on the original cube, equal in length.

1.2.2 Cabinet Projection

The first thing you notice about the cube shown in Figure 6-47 is the that it doesn’t look like a cube because the depth dimension appears to be longer than the height and width dimensions. The reason is that a cavalier projection corrects a human optical illusion—the one that causes an object to appear to become smaller as its distance from the eye increases. This illusion, in turn, causes receding parallel lines to appear to the eye to be shorter than they really are, and to be converging toward a point in the distance. But receding parallel lines on a cavalier projection appear in their true lengths, and they remain constantly parallel. Also, the far edges of the cube shown in Figure 6-47 are equal in length to the near edges.

The distortion in Figure 6-47 is only apparent. It is sometimes desirable to reduce this appearance of distortion. This can be done by reducing the length of the receding axis (OC in Figure 6-38). This axis can be reduced by any desired amount, but it is customary to reduce it by one half. When the receding axis is reduced by one half, the projection is called a cabinet projection. Figure 6-48 shows a cabinet projection of a cube. The length of the receding axis OC has been reduced by one half. As you can see, this representation looks more like a cube.

Cavalier and cabinet projections are compared in Figures 6-49 and 6-50.
1.2.3 Oblique Drawing Techniques

In an oblique projection drawing of a rectangular object, one face (usually the most prominent or most important) is parallel to the plane of projection. All features appearing on this plane, such as circles or oblique lines, are in their true dimension. However, in the side or top views, these same features are somewhat distorted because of the receding axis angle. When drawing these features, you can use various techniques to aid you in their construction.

For convenience, the angle chosen for the receding axis is 30 degrees, 45 degrees, or 60 degrees because those angles are easily constructed with triangles (Figure 6-51).
Figure 6-51 – Angles of 30 degrees, 45 degrees, and 60 degrees are normally chosen for the receding access in oblique projection because they are easily drawn with triangles.

1.2.3.1 Irregular Lines

An irregular line in an oblique drawing is a line that would be an oblique line in a normal multi-view projection. In the upper part of Figure 6-52, is a two-view multi-view projection of a block; the line AB is an irregular line and will not appear in its true length in an oblique projection. To transfer the line, draw the projection by transferring measurements taken along regular lines; these measurements locate the end points of the irregular line. Figure 6-52 shows the cavalier projection of an irregular line. The procedure for cabinet projection is the same except that all measurements along the receding axis are reduced by one half.

Figure 6-52 – Cavalier projection of an object with irregular lines.
1.2.3.2 Angles in Oblique

In an oblique projection, an angle on the surface that is parallel to the plane of projection will appear in its true size; an angle on any other surface will not. The upper part of Figure 6-53 shows a two-view multi-view projection of a block. It has a 30-degree angle on the top face and another on the front face. In the cavalier projection below, the angle on the front face still measures 30 degrees; that on the top face measures only about 9 degrees. Transfer the top face angle by locating the end points of the line by measurements along regular lines.

1.2.3.3 Circles in Oblique

In an oblique projection, a circle on the surface parallel to the plane of projection will appear as a circle. A circle on any other surface will appear as an ellipse, as shown in Figure 6-54. The upper part of this figure shows a two-view multi-view projection of a block with a circle on its upper face. The lower part of this figure shows a cavalier projection in which the circle appears as an ellipse. Each of the conjugate (joined together) diameters of the ellipse is equal to the diameter of the circle.

Figure 6-53 – Transferring an angle in oblique projection.

Figure 6-54 – Cavalier projection of a circle on a receding surface.
2.0.0 PERSPECTIVE PROJECTION and PERSPECTIVE DRAWING

Perspective projection is achieved when the projection lines converge to a point that is at a finite distance from the plane of projection. Each projection line forms a different angle with the plane of projection, giving the viewer a three-dimensional picture of the object. This type of projection, however, cannot accurately convey the structural features of a building; hence, it is not adequate for working drawings.

On the other hand, of all the three-dimensional single-plane drawings, **perspective drawings** are the ones that look the most natural. At the same time, they are also the ones that contain the most errors. Lines that have the same length on the object have different lengths on the drawing. No single line or angle on the drawing has a length or size that has any known relationship to its true length or size when projected through perspective projections.

Perspective drawing is used only in drawings of an illustrative nature, in which an object is deliberately made to appear the way it looks to the human eye. Most of the drawings you prepare will be drawings in which accuracy, rather than eye appearance, is the chief consideration. Consequently, you will not be concerned much with perspective drawing.

If you are required to prepare perspective drawings, refer to *Illustrator Draftsman, NAVEDTRA 10472*, or civilian publications, such as *Architectural Drawing and Light Construction and Architectural Graphic Standards*.

3.0.0 SKETCHING

The ability to make quick, accurate sketches is a valuable asset in conveying technical information or ideas. Without this ability, you are handicapped in many of your day-to-day situations. Almost every drawing or graphic problem originates with a sketch. The sketch becomes an important thinking instrument, as well as a means of conversing effectively with technically trained people. Sketching is not just another trick of the trade; it is an essential skill and an important part of your training. Sketch at every opportunity to develop your skills; your skills will improve with experience.

A sketch is usually thought of as being made freehand, although in practice you may use graph paper or a small triangle for a straightedge. A sketch may be of an object or an idea or a combination of both. Sketches are used to solve graphic problems before an object or structure is put in final form on a drawing. Preliminary sketches are used to plan and organize intelligently the sheet layout of a complete set of drawings for a construction project, which often includes many views and details. There are no set standards for technical freehand sketching; however, you should use standard line conventions for clarity.

A sketch may be drawn pictorially so that it actually looks like the object, or it can be an orthographic sketch of the object showing different views. The degree of perfection required for any sketch will depend upon its intended use.
3.1.0 Sketching Materials

Sketching requires few materials; basically, you only need pencil and paper. The type of sketch prepared and your personal preferences determine the materials used.

Use a soft pencil in the grade range from F to 3H, H being a good grade for most sketching. The pencil should be long enough to permit a relaxed but stable grip. As you gain experience, you may even prefer to use fine tip felt pens. (Dark- or bright-colored pens should be used.) Felt tip pens work very well on overlay sketches (discussed later).

![Figure 6-55 - Use of cross-sectional paper in technical sketching.](image1)

![Figure 6-56 - Use of specially ruled isometric paper in technical sketching.](image2)

Most of your sketches will be done on scratch paper, which can be any type or size of paper. An experienced draftsman will keep a pad of 3 in. by 5 in. or 5 in. by 8 in. scratch paper handy at all times. Tracing paper is convenient for planning the layout of a drawing. The advantage of sketching on tracing paper is the ease with which sketches can be modified or redeveloped simply by placing transparent paper over previous sketches or existing drawings. Sketches prepared in this manner are referred to as overlay sketches. You can use cross-section or graph paper to save time when you are required to draw sketches to scale. (See Figure 6-55.) You can easily draw isometric sketches on specially ruled isometric paper. (See Figure 6-56.)

While you may use an eraser, you will probably do very little erasing. Sketches usually can be redrawn more quickly than mistakes can be erased.

For making dimensioned sketches in the field, you will need some sort of measuring tape—either a pocket rule or a surveyor’s tape, depending on the extent of the measurements taken. If you are required to collect extensive field data, maintain a sketch notebook. A surveyor’s field notebook works well for this purpose.
3.2.0 Techniques of Sketching

Your sketches should conform to one of the standard types of projection discussed in this chapter. Apply correct proportion whenever possible. When you use cross-section paper, its grid will provide a ready scale that will aid you in sketching proportionally. Do this by counting the squares within the object to be drawn. The size of your sketch depends upon the complexity of the object and the size of paper you are using.

3.2.1 Sketching Straight Lines

In sketching lines, place a dot where you want a line to begin and one where you want it to end. In sketching long lines, place one or more dots between the end dots. Swing your hand in the direction your line should go, and back again a couple of times before you touch your pencil to the paper in order to get the feel of the line. When ready, use the dots to guide your eye and your hand as you draw the line. Draw each line with a series of short strokes instead of with one stroke. Using short strokes, you can better control the direction of your line and the pressure of your pencil on the paper. Hold the pencil about three quarters of an inch to an inch from the point so that you can see what you are doing. Strive for a free and easy movement rather than a cramped finger and wrist movement.

Another useful technique in drawing straight lines is to use the side of the paper, pad, or table as a guide for your hand. Hold the pencil at the desired starting point of the line and place the heel of your hand and one finger on the guide, as shown in Figure 6-57. Move the pencil, in this case, with one uniform stroke to complete the line. Try drawing several light horizontal lines and, after each one is drawn, examine it for straightness, weight, and neatness. If it is too light, use either a softer pencil or a little more pressure.

Vertical lines are usually sketched downward on the paper. The same suggestions for using locator dots, free movement of the entire arm, and guides apply to vertical lines as to horizontal lines.

Slanting lines may be drawn from either end toward the other. For better control, you might find it helpful to rotate the paper, thus placing the desired slanting line in either the horizontal or vertical position.

Figure 6-57 – Use of paper, pad, or table as a guide when drawing straight lines.
To keep your sketch neat, first sketch your lines lightly. Lines not essential to the drawing can be sketched so lightly that you need not erase them. Darken essential lines by running your pencil over them with more pressure. *Figure 6-58* shows line conventions drawn with various types of pencil points.

### 3.2.2 Dividing Lines and Areas Equally

Your ability to divide lines and areas into equal parts is necessary to arrive at many of the common geometric forms required in sketching. The simplest method of bisecting lines is by visual comparison, as shown in *Figure 6-59*. First, observe the entire line and weigh it optically to determine its fulcrum or point of balance. Compare each half visually before placing the bisecting point. This procedure can be repeated any number of times to divide a line into any number of equal divisions, merely by dividing and re-dividing its line segments.

*Figure 6-58* – Line conventions drawn with various types of pencil points.

*Figure 6-59* – Bisecting a line by visual comparison.
You can easily determine centers of rectangular areas drawing their diagonals. If necessary divide the halves with diagonals for smaller divisions, as shown in Figure 6-60.

3.2.3 Sketching Angles

You will be sketching 90-degree angles in the majority of your sketches. Learn to sketch right angles accurately, even if you have to check them with a triangle occasionally. You can frequently use the perpendicular edges of your paper as a visual guide for comparison. Try turning your sketch upside down; non-perpendicular tendencies of horizontal and vertical lines will become evident. Shaping right angles correctly will give your sketch visual stability and increase its effectiveness.

Make a 45-degree angle by dividing a right angle by visual comparison and a 30-degree or 60-degree angle by dividing the right angle into three equal parts. The 30-degree or 45-degree angle may be divided into equal parts in the same manner. (See Figure 6-61.) Always start with the right angle for the most accurate estimation of angle shape.

3.2.4 Sketching Circles and Arcs

Perfectly round circles are the most difficult to draw freehand. Figure 6-62 shows methods of drawing circles and curves using straight lines as construction lines. First, draw two straight lines crossing each other at right angles, as in Figure 6-62, View A. The point at which they cross will serve as the center of the circle. The four lines radiating from this center will serve as the radii of the circle. You can use a piece of marked scrap paper to measure an equal distance on each radius from the center. Sketch a square, with the center of each side passing through the mark defining a radius. (See Figure 6-62, View B.) Now sketch in your circle, using the angles of the...
square as a guide for each arc. When larger circles are required, you can add 45-degree angles to the square to form an octagon. This will provide four additional points of tangency for the inscribed circle.

In Figure 6-62, View C and View D, four lines, instead of two, are sketched crossing each other. The radii are measured as in constructing the other circle, but a square is not drawn. For this method, you will find it helpful to rotate the paper and sketch the circle in one direction.

For drawing large circles, you can make a substitute for a compass with a pencil, a piece of string, and a thumbtack. Tie one end of the string to your pencil near the tip. Measure the radius of the circle you are drawing on the string, and insert your tack at this point. Now swing your pencil in a circle, taking care to keep it vertical to the paper.

Figure 6-62 – Methods of sketching circles.

Figure 6-63 – Proper pencil grip in sketching circles and arcs.

Another technique for drawing circles is shown in Figure 6-63. In Figure 6-63, View A, observe how the pencil is held beneath the four fingers with the thumb. This grip tends to produce a soft or easy motion for sketching large circles or curves and also makes it possible to sketch small circles, as shown in Figure 6-63, Views B and C. Notice in Figure 6-63, View B, that the second finger rests at the center of the circle and forms the pivot about which the pencil lead can swing. The distance from the fingertip to the pencil lead determines the radius of the circle. To draw smaller circles, you need to
assume a somewhat different grip on the pencil, as shown in Figure 6-63, View C, but the principle is the same.

As shown in Figure 6-64, View A, the first step in sketching either large or small circles with the grips shown in the previous figure is placing the second finger on the paper at the center of the proposed circle. Then, with the pencil lightly touching the paper, use the other hand to rotate the paper to give you a circle that may look like the one in Figure 6-64, View B. To correct the slight error of closure shown in View C, erase a substantial section of the circle and correct it by eye, as shown at the right. You now have a complete and round circle, but with only a very light line, which must be made heavier. Do this as shown in View B. Notice that you DO NOT PIVOT on the second finger during this step. Rest your hand on its side and, keeping it within the circle, trace over the light line with your hand pivoting naturally at the wrist. As you work around the circle in this way, rotate the paper counterclockwise so that your hand can work in its most natural and easy position. Of course with smaller circles you cannot work with your hand within the circle, but you can successfully use the same general approach.

Probably one of the best methods to sketch curves connected to straight lines is the six-step method illustrated and explained below.

1. Intersect a vertical and horizontal line, lightly.
2. Mark off on the horizontal and vertical lines the same distance from the intersection.
3. Draw a light diagonal line through the two points marked.
4. Place an x or a dot in the exact center of the triangle formed.
5. Start your curve from one point of the triangle (preferably on the vertical line) touching the x or dot and ending at the other point of the triangle.
6. Erase all unnecessary guidelines and darken the curve and necessary adjoining straight lines.

With a little practice of this method, your ability to sketch curves properly should improve.
Figure 6-66 shows a convenient way to sketch arcs and curves by lightly drawing construction boxes (or blocks).

3.2.5 Construction Lines

When you are sketching an object, such as that shown in Figure 6-67, don’t start at one corner and draw it detail by detail and expect it come out with the various elements in correct proportion. It is better to block in the overall size of the object first, (See Figure 6-67, View A.) Then draw light guidelines at the correct angles for the various outlines of the object. (See Figure 6-67, Views B and C.)

Finish the sketch by first making an outline of the object and then drawing in the details, as shown in Figure 6-67, View D.

Figure 6-67 – The use of construction lines in sketching an object.
3.2.6 Order of Sketching

To make a working sketch, first choose a clean sheet of paper, either plain or ruled. Estimate the size the sketch should be, and select the views that will give the best picture of the object. Then draw the orthographic projections of these views, leaving adequate space between them for dimensions. (Refer to the working sketch in Figure 6-68.) In sketching, progress as follows:

![Figure 6-68 - Progress of a working sketch.]

1. Draw the center lines, as shown in Figure 6-68, View A.
2. Block the views.
3. Draw the outlines, aligning them as in Figure 6-68, View A.
4. Add the details on the surface of the views
5. Darken the lines of the finished sketch.
6. Use an art gum or a kneaded eraser to erase the construction lines, which are no longer needed. If necessary, touch up the lines you may have inadvertently erased.
7. Draw all necessary extension and dimension lines.
8. Letter in the dimensions. (See Figure 6-68, View C)
You can see that a working sketch such as the one shown in Figure 6-68 could easily be followed in preparing a finished drawing of the object. The sketch provides you with all the necessary information needed on the finished drawing.

3.2.7 Pictorial Sketches

Often it will be more convenient, or even necessary, to prepare isometric or oblique pictorial sketches instead of multi-view orthographic sketches. Pictorial sketches provide a quick method of examining tentative construction details. A quick pictorial sketch will also help you in the layout of isometric and oblique drawings.

The principles of pictorial and orthographic sketching are similar, except that in pictorial sketching you will be dealing with volumes rather than flat planes. Pictorial sketches and pictorial drawings are practically the same except for the drawing materials used in their development and the fact that pictorial sketches are not normally drawn to scale. By following a few simple steps, based on pictorial drawing construction principles, you should be able to prepare meaningful pictorial sketches.

3.2.7.1 Isometric Sketches

Select a position (view) that will show the object to the best advantage. You will know what you want included in your sketch, so move either the object or yourself until you can actually see everything you want to show. If the object is something you have in mind or if you intend to sketch an isometric view from an orthographic drawing, you will have to visualize the object and assume a viewing position. In making your isometric sketch, remember that you start by sketching three isometric axes 120 degrees apart, using two angles of 30 degrees and a vertical axis of 90 degrees. Figure 6-69, View A, shows a step-by-step procedure you can use to make an isometric sketch of a wooden rectangular block measuring 1 1/2 inch. by 2 inches by 4 inches.

The first step is to sketch the three isometric axes, as mentioned earlier. The second step is to mark off the 1 ½ inch for height on the vertical axis, the 2 inch width along the left axis, and the 4 inch length along the right axis. The third step is to draw two vertical lines 1 ½ inches high (starting with the marks on the right and left axis), then sketch parallel lines from each of the marks on the sketch. Not that the lines that are parallel on the object are parallel on the sketch. The fourth step is to dimension the sketch. The dimensions on an isometric sketch are placed parallel to the ends or edges. The final step is to check the sketch for completeness and accuracy.

3.2.7.2 Oblique Sketches

Draw the front face or view of an oblique sketch in the same way as an orthographic front view. Using the same wooden block that was sketched isometrically for a model, draw an oblique sketch following the basic steps shown in Figure 6-69, View B.

First, draw a rectangle of the front view (using light lines). Second, draw an oblique base line at a 45-degree angle starting at the corner (intersection) of the horizontal and vertical base lines. Third, sketch the remaining horizontal and vertical lines parallel to the other base lines. Fourth, erase any unnecessary lines, and, fifth, dimension and darken the completed drawing for easier reading. Remember, place the dimensions so they are parallel to the axis lines. The final step is to check the sketch for completeness and accuracy.
Figure 6-69 –Sketching a regular block: (A) Isometric; (B) Oblique.

In the above procedures for development of pictorial sketches, a simple rectangular form was used. All objects may be simplified to their basic geometric forms. These forms are the first consideration in the pictorial sketch. Basic volumetric forms are shown in Figure 6-70. By carefully analyzing any object you sketch, you will see one or more of the forms shown in Figure 6-70. However, at times only a part of a form is present.

Before attempting detailed sketches, practice sketching the basic forms. Then look for these forms in the object you are about to sketch and concentrate on the basic form representation. Enclose the object in a basic form, or build it up with a series of different forms, depending on the nature of the object. Details are added or “carved” from these forms after shape and proportion have been determined.
3.2.8 Overlay Sketches

To make overlay sketches, sketch freehand on transparent paper placed over existing drawings or other sketches. Sometimes when you make overlay sketches, you merely trace, freehand, objects or lines from another drawing or sketch. But more often you will prepare overlay sketches by tracing and then adding supplementary sketched lines or objects.

Usually, when this type of sketch is prepared, only the prominent or desired features are traced. Overlay sketches are primarily used for planning purposes.

A suggested procedure for using overlay sketches as a tool for planning is explained in the following example:

The drafting room is being relocated. You are tasked with developing a proposed furniture and equipment layout. You have the latest prints of the floor plan and an electrical plan, and you know what furniture and equipment will be moved to the new area. The steps you take to develop the proposed layout are as follows:

1. Check the floor plan and electrical plan against the actual room layout. If necessary, check the dimensions. Correct any discrepancies with a dark-colored fine tip felt pen or colored pencil.
2. Place a piece of tracing paper over the floor plan on the print and secure it with small strips of drafting tape.

3. Trace the outline of the walls with single freehand lines (preferably with a dark colored felt tip pen). Terminate the lines, where applicable, to indicate windows and door openings.

4. Remove the tracing paper from the floor plan and place it over the electrical plan, lining the traced wall outlines up with the corresponding walls on the electrical plan. Using appropriate symbols, locate, on the traced floor plan, all electrical outlet locations.

5. You now have a clear overlay sketch of the existing floor plan without the unnecessary dimensions and information on the original print of the floor plan. This is your basic planning overlay. Check your overlay with the original prints to make sure you did not omit relevant lines.

6. Place another sheet of tracing paper over the basic planning overlay. This becomes your second overlay. On this second overlay, sketch in your desired location of all the furniture and equipment. Use simple shapes for each and estimate sizes. Use letters or symbols for identification. Repeating the outline of the walls is not necessary because you can still see the outline from the basic planning overlay.

7. If this first location sketch on the second overlay does not suit you or does not provide an adequate layout, lay another piece of tracing paper over the second layout and sketch another one. Repeat this procedure with additional overlays until you have developed a good layout.

8. Once you have a good layout, trace the wall outlines from the basic planning overlay. This final overlay sketch is your proposed furniture and equipment layout for the new location of the drafting room.

Summary

As an EA, you should be able to clearly represent any given object or structure on paper by applying basic geometric construction to the various projection methods. To show an object’s three dimensions by lines alone, you must use either a system of related views or a single pictorial projection. You must be able to show clearly the shape of the object, give the exact size of each part, and provide necessary information for constructing the object. In the field, freehand sketching is an invaluable tool in preparing quick sketches to convey or develop your ideas.
Review Questions (Select the Correct Response)

1. Parallel projection is divided into two main types of projection: _________ and _________.
   A. orthographic, oblique
   B. perspective, orthographic
   C. perspective, oblique
   D. perspective, first angle

2. A parallel projection in which the lines of projection are perpendicular to the plane of projection is called a(n) _________ projection.
   A. perspective
   B. orthographic
   C. oblique
   D. first angle

3. The position of the observer in relation to the object and the plane of projection is called the _________.
   A. point of sight
   B. parallel point
   C. oblique point
   D. orthographic point

4. The observer views the features of the object through an imaginary _________.
   A. station point
   B. point of site
   C. plane of projection
   D. plane of perspective

5. ________ are the imaginary lines from the eye of the viewer to points on the object.
   A. Images lines
   B. Parallel lines
   C. Planes of projection
   D. Lines of sight

6. ________ projection consists of drawing the essential views of the same object from different angles and projecting the views on a single plane
   A. Perspective
   B. Oblique
   C. Orthographic
   D. Profile
7. Establishing an object's true height, width, and depth requires front, top, and side views, which are called the __________.

A. image planes  
B. principal planes of projection  
C. station points  
D. lines of sight

8. **(True or False)** First-angle projection is commonly used in the United States.

A. True  
B. False

9. A __________ projection of a cube will result with a front view on the vertical plane, a top view on the horizontal plane, and a right side view on the profile plane.

A. first-angle  
B. second-angle  
C. third-Angle  
D. fourth-angle

10. Using a __________ offers a convenient method of laying out a third view while you are in the process of drawing two views.

A. projection line  
B. mitre line  
C. line of sight  
D. projection plane

11. In the American standard arrangement of views, all views are rotated toward the view as though they are hinged; the __________ view always lies in the plane of the drafting surface and does not require any rotation.

A. back  
B. front  
C. left side  
D. right side

12. When creating a balanced drawing, remember that the __________ of the object will determine the space between the views.

A. color  
B. position  
C. size  
D. shape
13. In a third-angle projection, you always presume the plane of projection is __________ the object and the observer, regardless of which view you are considering.

A. in front of
B. behind
C. between
D. in the same place as

14. When numbering a hidden corner point, the number is __________, and for a visible corner point, __________.

A. placed within the outline, outside the outline
B. placed outside the outline, inside the outline
C. circled, not circled
D. not circled, circled

15. A multi-view projection should contain __________.

A. four views
B. only front, side, and back views
C. all possible views
D. only as many views as required to describe the object fully

16. In a multi-view orthographic projection, a __________ is parallel to two of the planes of projection and perpendicular to the third.

A. non-normal line
B. non-normal plane
C. normal line
D. normal plane

17. Views on planes other than the regular planes are called __________ views.

A. auxiliary
B. regular
C. multi-
D. normal

18. A __________ view is a view on one of the three regular planes of projection (horizontal, vertical, or profile).

A. auxiliary
B. regular
C. multi-
D. normal
19. A _________ on a surface that is parallel to the plane of projection will project as a _________.

A. circle, circle  
B. ellipse, circle  
C. circle, ellipse  
D. circle, hidden line

20. An imaginary plane that is parallel with the line or surface we want to project in its true shape that is NOT one of the regular planes is called a(n) _________.

A. non-normal plane  
B. normal plane  
C. auxiliary plane  
D. regular plane

21. (True or False) An auxiliary view is one that is projected on a plane other than one of the regular planes.

A. True  
B. False

22. In a _________, the object is projected on one or more of the regular planes of projection, but instead of being placed in normal position, the object is rotated on an axis perpendicular to one of the regular planes.

A. revolution  
B. auxiliary  
C. rotation  
D. normal plane

23. Use a _________ view when it will better show the object's internal structure than using hidden lines.

A. regular  
B. auxiliary  
C. revolution  
D. sectional

24. When a cutting plane passes entirely through a symmetrical object and divides it into two equal parts, this view is called a _________ section.

A. revolved  
B. full  
C. broken  
D. partial
25. A section consisting of less than half a section is called a _________ section.

A. revolved  
B. full  
C. normal  
D. partial

26. In _________ projection only one plane is used and the projection lines are perpendicular to the plane of projections, but the object is inclined to the plane of projection.

A. regular  
B. sectional  
C. axonometric  
D. partial

27. (True or False) Isometric projection is the most frequently used type of axonomic projection.

A. True  
B. False

28. (True or False) A foreshortened line in a projection is somewhat longer than the actual length of the edge on the object itself.

A. True  
B. False

29. A _________ line is a line that is not parallel to any one of the three legs of the isometric axis. It is not a normal line in a normal multi-view projection of the object.

A. regular  
B. partial  
C. isometric  
D. non-isometric

30. (True or False) In a normal multi-view view of an object, an angle never appears in its true size.

A. True  
B. False

31. (True or False) A circle in a normal multiview view will appear as an ellipse in an isometric drawing.

A. True  
B. False
32. **(True or False)** A line that appears as a noncircular curve in a normal multi-view view of an object appears as a non-isometric line in an isometric drawing.

A. True  
B. False

33. The isometric axis is commonly used with the lower leg vertical. The axis may, however, be used in any position, provided the angle between adjacent legs is always __________ degrees.

A. 120  
B. 90  
C. 45  
D. 60

34. **(True or False)** Diagonal hatching on a sectional surface shown in isometric should have the appearance of making a 90-degree angle with the horizontal or vertical axis of the surface.

A. True  
B. False

35. There are two types of __________ single-plane projections: cavalier and cabinet.

A. abstract  
B. orthographic  
C. oblique  
D. isometric

36. __________ projection is a form of oblique projection in which the projection lines are presumed to make a 45-degree vertical and a 45-degree horizontal angle with the plane of projection.

A. diametric  
B. cavalier  
C. cabinet  
D. trimetric

37. In a __________ projection, then, any line parallel to or perpendicular to the plane of projection is projected in its true length.

A. diametric  
B. cavalier  
C. cabinet  
D. trimetric
38. When the receding axis is reduced by one half, the projection is called a _________ projection.

A. dimetric  
B. cavalier  
C. cabinet  
D. trimetric

39. **(True or False)** In an oblique projection drawing, the angle chosen for the receding axis is either 30 degrees, 45 degrees, or 60 degrees because those angles are easily constructed with triangles.

A. True  
B. False

40. **(True or False)** A regular line in an oblique drawing is a line that would be an oblique line in a normal multi-view projection.

A. True  
B. False

41. **(True or False)** In an oblique projection, an angle on the surface that is parallel to the plane of projection will appear in its true size; an angle on any other surface will not.

A. True  
B. False

42. In an oblique projection, a circle on the surface parallel to the plane of projection will appear as a(n) _______. A circle on any other surface will appear as a(n) _______.

A. ellipse, ellipse  
B. circle, circle  
C. ellipse, circle  
D. circle, ellipse

43. _______ projection is obtained when the projection lines converge to a point that is at a finite distance from the plane of projection.

A. Cavalier  
B. Cabinet  
C. Perspective  
D. Oblique

44. **(True or False)** Of all the three-dimensional single-plane drawings, perspective drawings are the ones that look the most natural.

A. True  
B. False
45. **(True or False)** Sketching is not an important skill for an EA to have.

A. True  
B. False

46. Sketching requires __________.

A. many specialized tools  
B. only pencil and paper  
C. drafting board and a T square  
D. a ball point pen

47. Sketches drawn on transparent paper over existing drawings are known as __________ sketches.

A. overlay  
B. perspective  
C. isometric  
D. cabinet

48. **(True or False)** Your sketches do not have to conform to any kind of standard projection types.

A. True  
B. False

49. **(True or False)** Draw each line with a series of short strokes instead of with one stroke.

A. True  
B. False

50. **(True or False)** Vertical lines are usually sketched upward on the paper.

A. True  
B. False

51. The simplest method of bisecting a line when freehand sketching is __________.

A. using a ruler  
B. using a protractor  
C. using a compass  
D. using visual comparison

52. A 30-degree or 60-degree angle can be made by dividing the right angle into ________ equal parts.

A. 2  
B. 3  
C. 4  
D. 5
53. One convenient way to sketch arcs and curves is by lightly drawing __________.
   A. dotted lines
   B. construction lines
   C. dots
   D. construction boxes

54. (True or False) When sketching an object, it is best to start at one corner and draw it detail by detail.
   A. True
   B. False

55. (True or False) You should draw the center lines of the object first.
   A. True
   B. False

56. (True or False) Pictorial sketches deal with planes and are drawn to scale.
   A. True
   B. False

57. In making an isometric sketch, remember that you start by sketching three isometric axes __________ degrees apart, using two angles of 30 degrees and a vertical axis of 90 degrees.
   A. 90
   B. 120
   C. 60
   D. 30

58. The front face or view of an oblique sketch is drawn the same way as a(n) __________ front view.
   A. oblique
   B. orthographic
   C. auxiliary
   D. non-normal

59. To make __________ sketches, sketch freehand on transparent paper placed over existing drawings or other sketches.
   A. cavalier
   B. cabinet
   C. perspective
   D. overlay
**Trade Terms Introduced in this Chapter**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Broken Section</td>
<td>A part of a drawing showing less than half a section; also known as a partial section.</td>
</tr>
<tr>
<td>Cabinet Projection</td>
<td>A cavalier projection in which the receding axis is reduced by one half of the size of the actual length of the edge on the object itself.</td>
</tr>
<tr>
<td>Foreshortening</td>
<td>In isometric projection, the cube is inclined so that all of its surfaces make the same angle (35°16’) with the plane of projection. A result of this inclination, the length of each of the edges shown in the projection is somewhat shorter than the actual length of the edge on the object itself.</td>
</tr>
<tr>
<td>Full Section</td>
<td>When the cutting plane passes entirely through the object and divides it into two equal parts, a full section results.</td>
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<tr>
<td>Half Section</td>
<td>One half of a full section.</td>
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<tr>
<td>Image Plane</td>
<td>Also called plane of projection; a theoretical transparent plane between the point of sight and the object.</td>
</tr>
<tr>
<td>Line of Symmetry</td>
<td>Center line indicating the division between the section and unsections part of a sectional view.</td>
</tr>
<tr>
<td>Oblique Projection</td>
<td>A type of parallel projection in which the projection lines are parallel to each other but oblique to the plan of projection.</td>
</tr>
<tr>
<td>Oblique Sketch</td>
<td>A sketch which starts with a rectangle of the front view, and has an oblique base line at a 45-degree angle starting at the corner of the horizontal and vertical base lines.</td>
</tr>
<tr>
<td>Overlay Sketches</td>
<td>Sketches created on tracing paper; sketches can be modified or redeveloped simply by placing transparent paper over previous sketches or existing drawings</td>
</tr>
<tr>
<td>Parallel Projection</td>
<td>A projection type in which the projection lines are parallel to each other. May be oblique or orthographic.</td>
</tr>
<tr>
<td>Partial Auxiliary View</td>
<td>Only showing the points or lines needed to project the line or surface desired.</td>
</tr>
<tr>
<td>Perspective Drawings</td>
<td>Most natural-looking of all three-dimensional single-plane drawings, but no single line or angle on the drawing has a length or size that has any known relationship to its true length or size when projected through perspective projections.</td>
</tr>
</tbody>
</table>
Pictorial Sketches  Provide a quick method of examining tentative construction details, deals with volumes rather than flat planes. Normally not drawn to scale.

Plane of Projection  Also called image plane; theoretical transparent plane between the point of sight and the object.

Principal Planes of Projection  The three principal (or primary) planes of projection, known as the vertical, horizontal, and profile planes.

Revolution  The object is projected on one or more of the regular planes of projection and evolved on an axis perpendicular to one of the regular planes.

Secondary Auxiliary View  Used when the shape of the object is such that normal orthographic and auxiliary views will show the true size and shape of a surface. The reference plane for a secondary auxiliary view is located in the orthographic view from which the primary auxiliary view is projected. Usually, the primary auxiliary plane becomes the secondary reference plane.

Section Lining  Diagonal hatching or crosshatching

Station point  Position of the observer in relation to the object and plane of projection. Also called point of sight.
Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.


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Write:       CSFE N7A
             3502 Goodspeed St.
             Port Hueneme, CA   93130

FAX: 805/982-5508

E-mail:      CSFE_NRTC@navy.mil

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