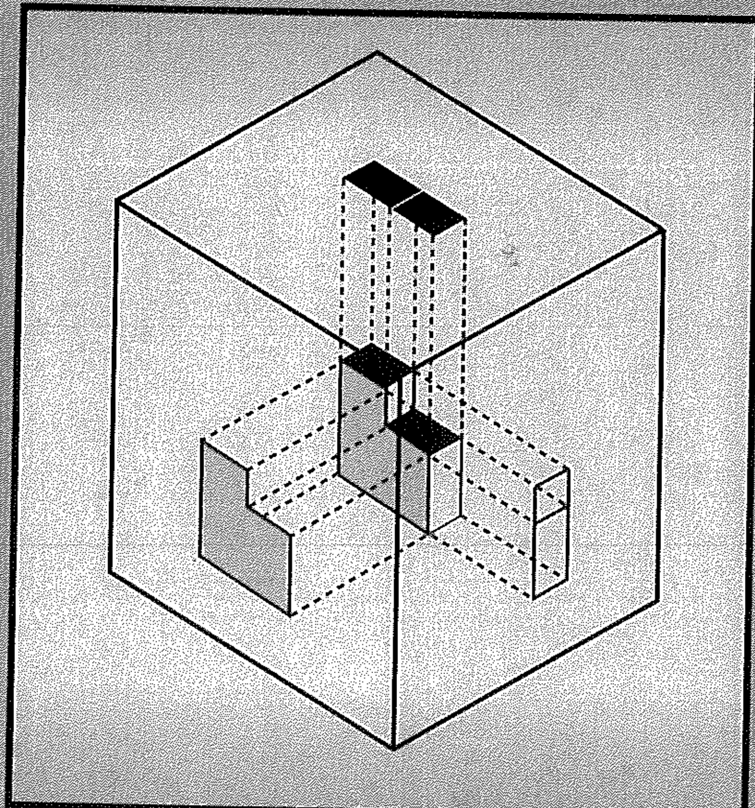
INTRODUCTION TO 3-D SPATIAL VISUALIZATION



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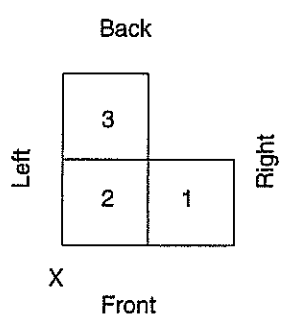
2.1 CONSTRUCTION AND ISOMETRIC DRAWINGS OF BUILDINGS

To develop 3-D spatial sense, one must first construct 3-D objects, observe these objects, and then draw them to scale from different viewpoints. As one's spatial sense develops, it no longer becomes necessary to construct an object before drawing it. A mental image of the object is sufficient to create the drawing. Hence, initially we will work from the concrete object to the more abstract drawing, but ultimately we want to be able to visualize the object and create an accurate drawing of it from this mental image. To become an engineer, one must achieve this level of spatial ability. For example, a mechanical engineer must be able to visualize a machine part and understand how that part will function within a system of parts. The engineer must then be able to communicate the concept for this part with a drawing so that it can be manufactured.

Cubes will be used in the following examples to construct model buildings. The plan for each building will be given by drawing the shape of the top (or base) of the building on square grid paper. Each square will be coded with a number to represent how high the stack of cubes on that square should be. For example, Figure 2.1.1 shows a coded plan and the corresponding building constructed from cubes as viewed from corner X.



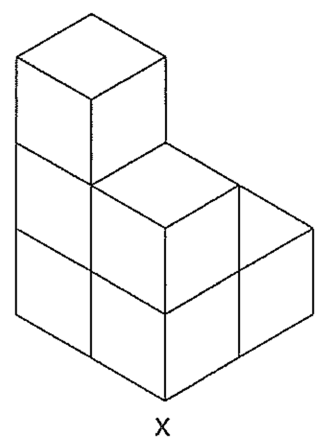


Figure 2.1.1

A corner view of a building, such as the one shown in Figure 2.1.1, is called an **isometric** view of the building. Such views are easy to draw on isometric dot paper. Isometric dot paper has dots spaced an equal distance apart in a triangular pattern. An important feature of isometric dot paper should be mentioned. When rotated 90°, isometric dot paper does not have the same properties for drawing that it did with its original orientation. Figure 2.1.2 shows Figure 2.1.1 drawn on isometric dot paper. Note that Figure 2.1.2 has fewer lines than Figure 2.1.1. When drawing a building, it is not necessary to outline each cube; rather a line is drawn only where there is an edge to the building. An **edge** can be defined as a line that results from the intersection of two plane surfaces. Isometric drawings are useful for showing a 3-D representation of a building on a flat (2-D) piece of paper.

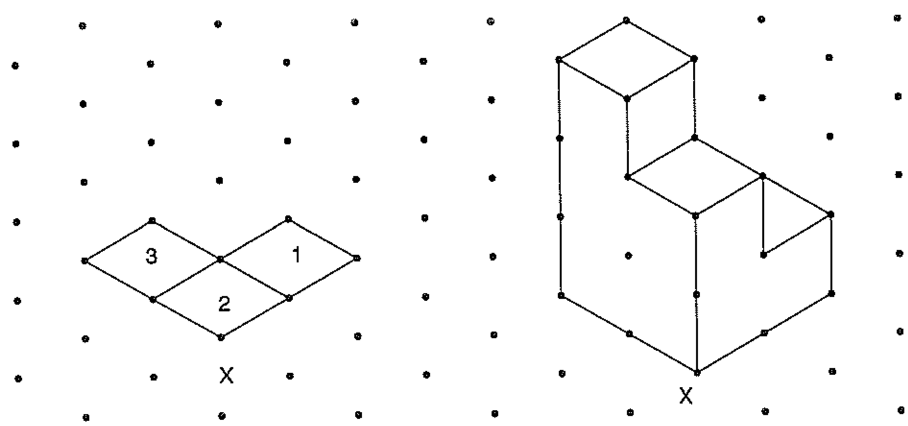


Figure 2.1.2

Sometimes it is easier to think of an object as a collection of surfaces. The isometric drawing of the object can then be made by sketching each visible surface. This process is demonstrated in Figure 2.1.3. In this figure, each surface on the object is drawn individually until all visible surfaces are drawn.

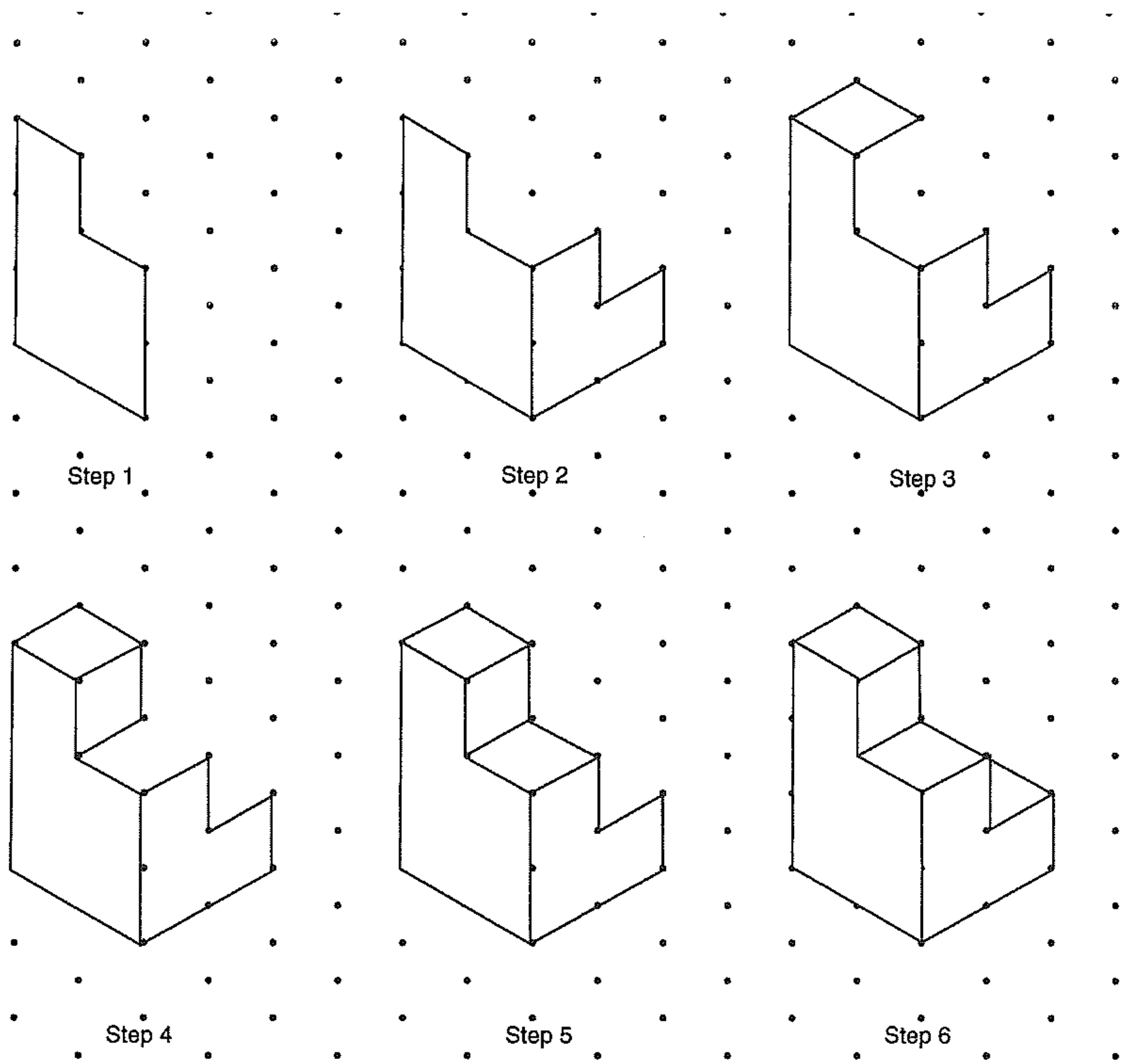


Figure 2.1.3

Figure 2.1.4 shows another coded plan, the corresponding building constructed from cubes, and the final isometric drawing of the building. This time the building is being viewed from corner Y.

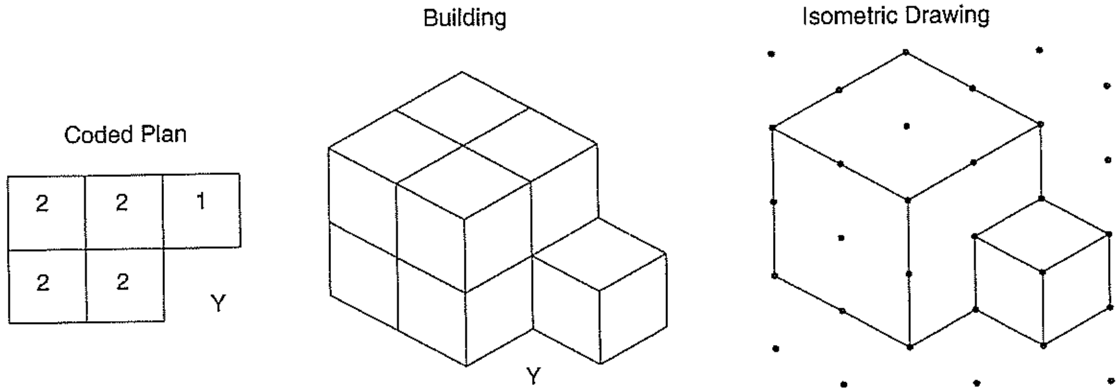


Figure 2.1.4

One way to visualize corner views without disturbing the cubes in your building is to construct the building on 2 cm×2 cm grid paper (sometimes called a *mat*) and then to rotate the mat. Figure 2.1.5 shows the coded plan of a building on a mat being viewed from corner X and from corner Y by rotation of the mat. The mat could also be rotated so that the building could be viewed from corner W or from corner Z.

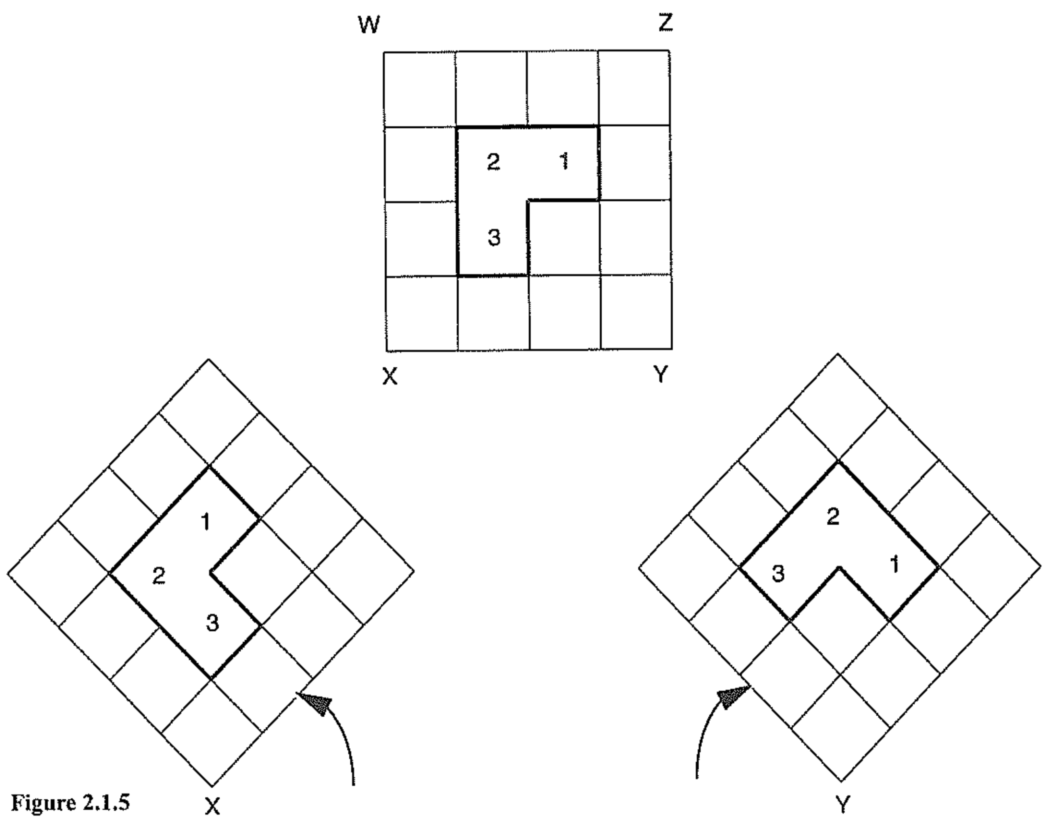


Figure 2.1.5

Isometric grid paper is a popular tool in engineering for drawing isometric views of buildings. One can construct isometric grid paper from isometric dot paper by connecting the dots that lie in the same diagonal lines and in the same vertical lines. Figure 2.1.6 shows isometric grid paper being constructed from isometric dot paper. There is really no

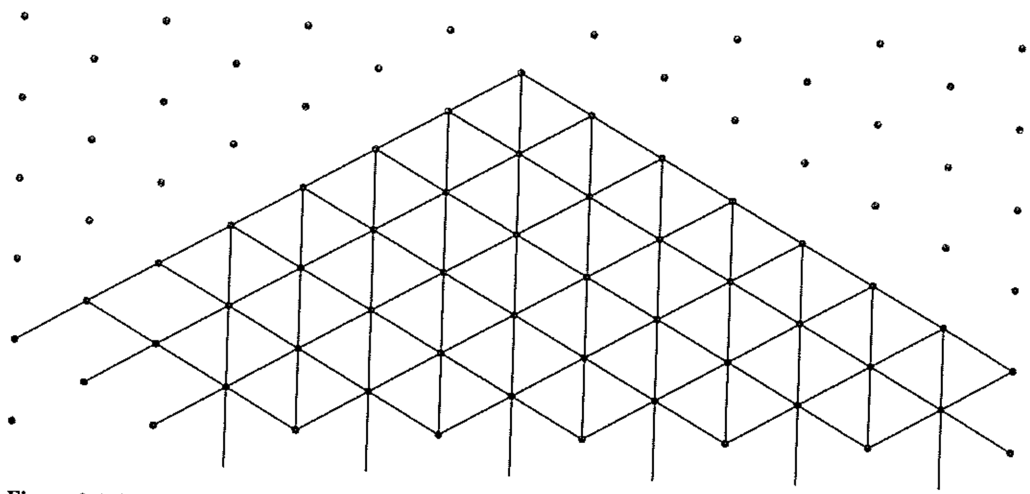


Figure 2.1.6

need to construct your own isometric grid paper—it is commercially available. The motivation for showing the relationship between the two types of paper is to make it easier for a student who can draw buildings on isometric dot paper to transfer those skills to isometric grid paper. Isometric views of buildings can be drawn either directly on isometric grid paper by using a dark marker or on a piece of tracing paper or Vellum placed over the isometric grid paper.

Figure 2.1.7 shows the four corner views of a building on isometric grid paper. The coded plan for the building can be completely determined by viewing the building from its corners, as shown in Figure 2.1.8.

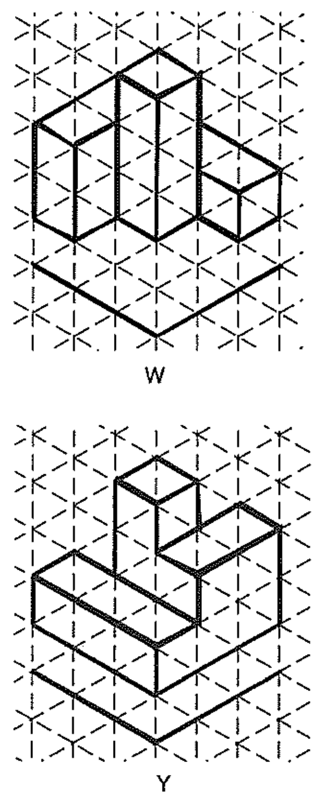


Figure 2.1.7

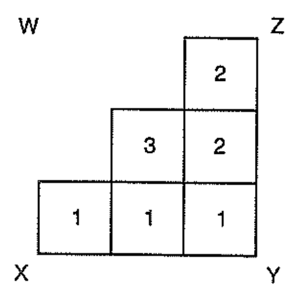


Figure 2.1.8

2.2 ORTHOGRAPHIC DRAWINGS

Isometric sketches are useful for showing a 3-D representation of a solid object on a flat (2-D) piece of paper. However, there are many instances where isometric sketches do not adequately display information in an understandable form. As an example of this, consider a house. An isometric view of the house would show *qualitatively* what the house looked like from the outside. If, however, one wanted to show the interior of the house and the layout of the rooms on each floor, an isometric view would be particularly confusing because the walls from the rooms would run into each other and overlap. Thus, in order to display the layout of the rooms, an orthographic or plan view is normally used. A **plan view** is drawn as if one is located at some point in space above the floor looking down on it. In this way, one is able to accurately view the sizes and relative locations of all the rooms on a particular floor of a building.

This illustrates an important feature in creating views of a building or an object. In general, the object remains fixed in space, and one "moves" around the object in order to "see" what it looks like from different angular perspectives. An isometric view is created as if one is looking straight down a diagonal of a given cube. By looking down the diagonal, one sees all three dimensions (height, width, and depth) of the object. In a plan view of a house, the observer is located at a point above the floor—the house remains stationary. In this way, only the width and the depth of the floor plan are visible; the height is not.

In general, views that show only two dimensions of an object are called **orthographic** views. Typically, the *top* view (sometimes referred to as *plan view*) is one where the object's width and depth are displayed; the *front* view shows the width and the height of an object; and the *side* view of an object shows its depth and height. Figure 2.2.1 illustrates the relationship between dimensions and orthographic view (consider depth as the dimension perpendicular to the plane of the paper.). Note that any two views will display all of the necessary information associated with a given object, but a third view is usually added for clarity.

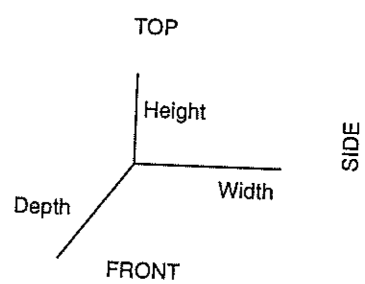


Figure 2.2.1

Figure 2.2.2 shows how orthographic views are created from the geometry of a 3-D object. In creating orthographic views, one imagines that the object is surrounded by a

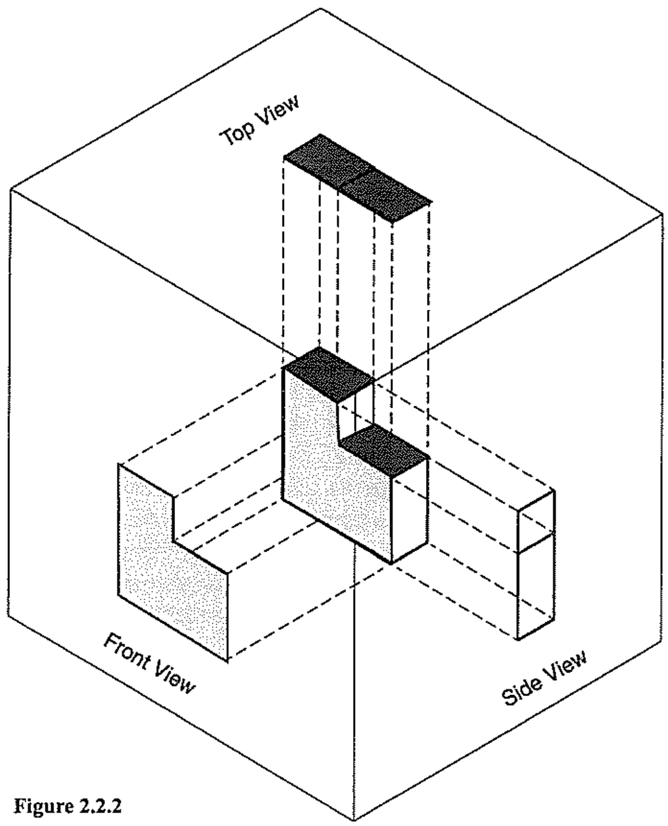


Figure 2.2.2

glass cube. Each of the orthographic views is created by projecting an edge of the object onto one of the panes of glass. The edges are projected so that the "projection rays" are perpendicular to the panes of glass (the term *orthographic* comes from the Greek *ortho*, meaning perpendicular). These projection rays outline the front and side views on vertical panes of the glass cube and the top view on a horizontal pane. Once the object has been projected onto the three panes of glass in the surrounding cube, it is common practice to "unfold" the cube to display the three views of the object in a standard layout. Figure 2.2.3 shows this practice.

In the system of orthographic projection, there are six principal views labeled front, top, back, bottom, and right and left side views. Once the transparent cube is unfolded, the orthographic views of the object are shown in a standard drawing layout. This layout

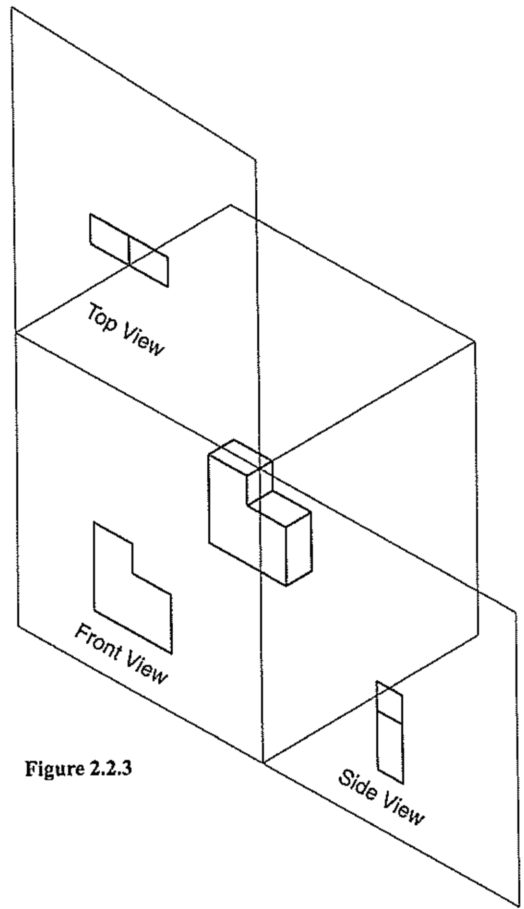


Figure 2.2.3

typically consists of the top, front, and right side views of the object. Figure 2.2.4 shows the standard drawing layout for the three orthographic views of the object in Figure 2.2.3. Note that in this system of orthographic projection, the edges from one view project perpendicularly into the adjacent views.

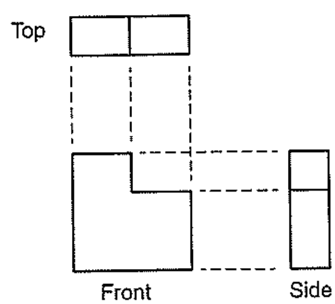


Figure 2.2.4

When objects are built out of blocks, all surfaces on the building are normal surfaces. **Normal surfaces** are defined as those parallel to either the front, side, or top orthographic views. Note that a surface parallel to the front view is perpendicular to both the top and the side views; a surface parallel to the top view is perpendicular to the front and side views; and a surface parallel to the side view is perpendicular to the front and top views. A normal surface parallel to the front view is seen in the front view in true size and shape, and is seen as an edge (line) in both the top and side views. Figure 2.2.5 illustrates this principle.

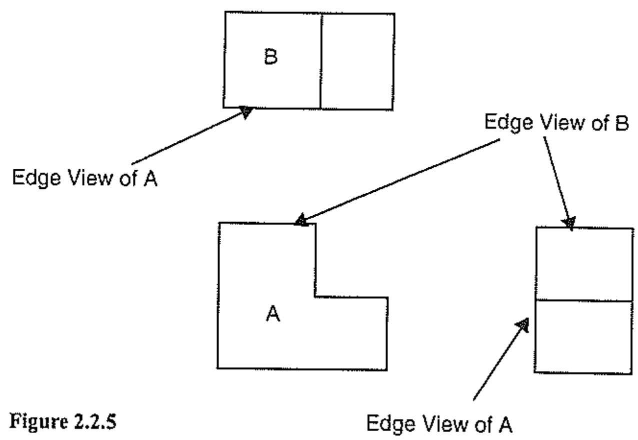


Figure 2.2.5

In this figure, surface A is parallel to the front view and is seen there in its true shape and size. It is seen as an edge in both the top and the side views, as labeled in the figure. Similarly, surface B is seen true size in the top view and is seen as an edge in both the front and the side views.

One of the advantages of using orthographic views to describe an object is that the object appears undistorted, i.e., the planes appear true size and true shape, and the angles appear true size. Thus, one is able to measure the relative sizes of angles and lengths. This is not the case in isometric drawings. As an example, consider the case of a cube. In reality, we know that all of the faces of the cube meet at right angles. However, when an isometric view of a cube is constructed, if one was to use a protractor to measure the angle between the faces, the angle would be either 60° or 120°; whereas, in orthographic views, the angles between sides would all measure 90°. The reason for this is that with orthographic projection, the faces of the cube are parallel to the viewing plane. In isometric drawings, however, none of the faces of the cube is parallel to the viewing plane. Figure 2.2.6 graphically shows the difference between measured angles in isometric and orthographic viewing.

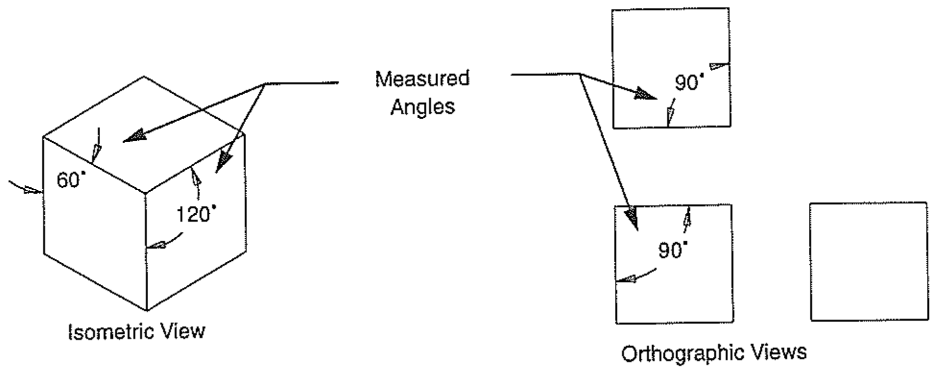


Figure 2.2.6

As in writing, where rules of grammar are needed for effective written communication, rules for making orthographic drawings are needed for effective graphical communication. One of the rules to be followed is that the orthographic views of an object should be aligned with one another. Figure 2.2.7 illustrates this principle.

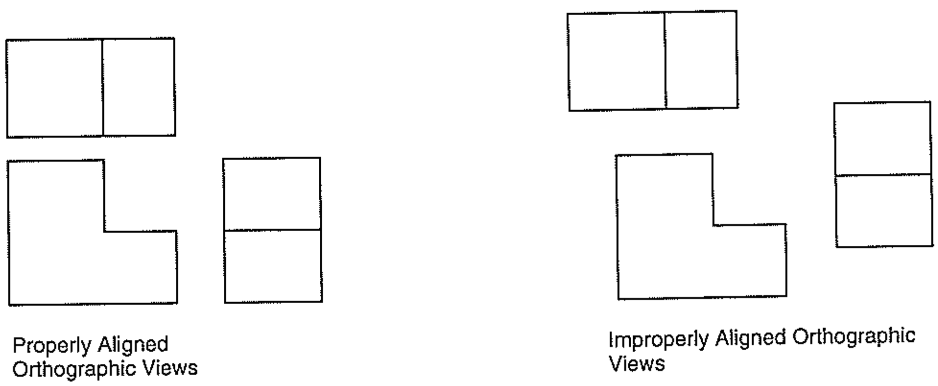


Figure 2.2.7

When creating an orthographic drawing or sketch, lines are drawn at the edges of the object. Sometimes when constructing an engineering drawing, there are edges of an object that are hidden from a particular viewing angle. These hidden edges are drawn as dashed lines and are referred to as **hidden lines**; whereas the visible edges are drawn as solid lines. Solid lines are also referred to as **object lines**. In standard drawing practice, if an object line coincides with a hidden line, then only the object line is shown.

Two orthographic views of an object are adequate to communicate what a 3-D object looks like because each orthographic view gives a different pair of dimensions. For example, a top view will show the length and depth, and a front view will show the length and height, so all three dimensions are represented and the object is completely defined. When an object has an unusual feature, such as an inclined surface (see Section 2.3), it will be accurately defined by two orthographic views if and only if those two views are carefully chosen—not just any two views will do. In Figure 2.2.8, five orthographic views of a building are drawn on square dot paper. Note the use of hidden lines and the use of object lines in this drawing. An isometric view of the building is shown in Figure 2.2.9.

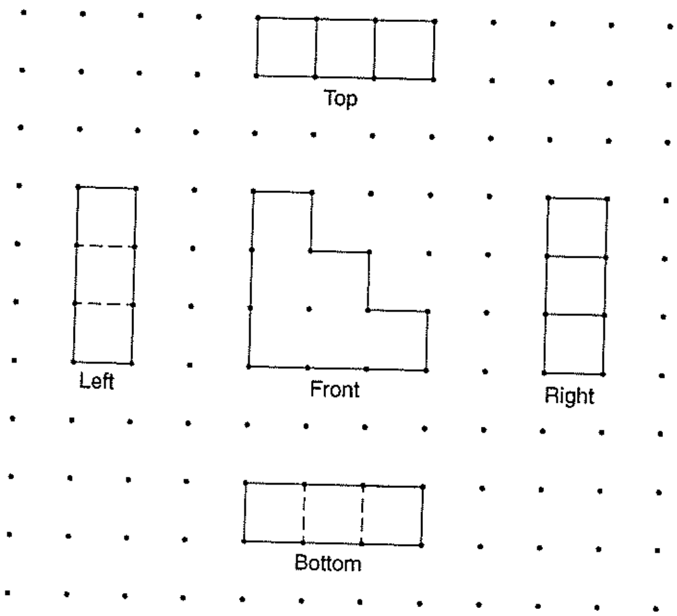


Figure 2.2.8

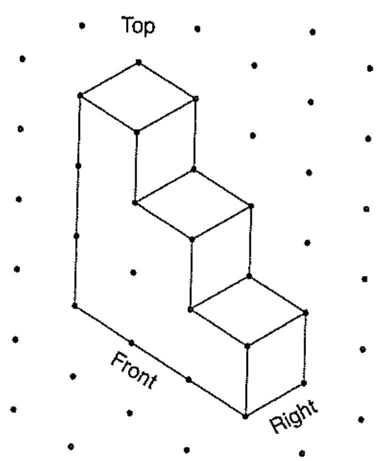


Figure 2.2.9

Many times only two orthographic views of an object are given, and one is expected to draw the third view. This process is easier if one visualizes the way each of the surfaces of the object appears in the third view. For example, suppose the two views of the object shown in Figure 2.2.10 were given and the third (right side) view was required.

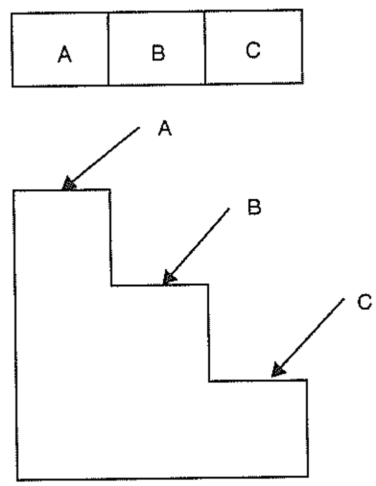


Figure 2.2.10

The surfaces visible in the top view have been labeled A, B, and C. These surfaces are seen as edges in the front and side views because they are normal surfaces. To draw these surfaces in the side view, project them directly into that view from the front view.

The size of these surfaces in the side view can be obtained from the depth dimension shown in the top view. This is illustrated in Figure 2.2.11.To complete the right side view of the object, fill in the front, back, and bottom surfaces. In this example, the back surface is identical to the front surface, otherwise hidden lines would be visible in the front view. Figure 2.2.12 shows the completed drawing of the object.

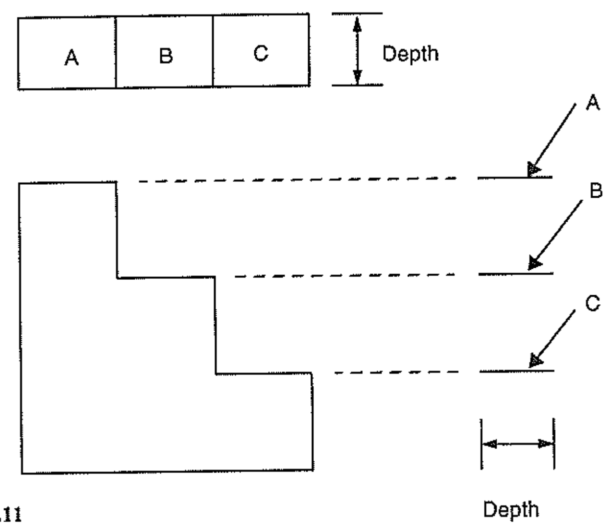


Figure 2.2.11

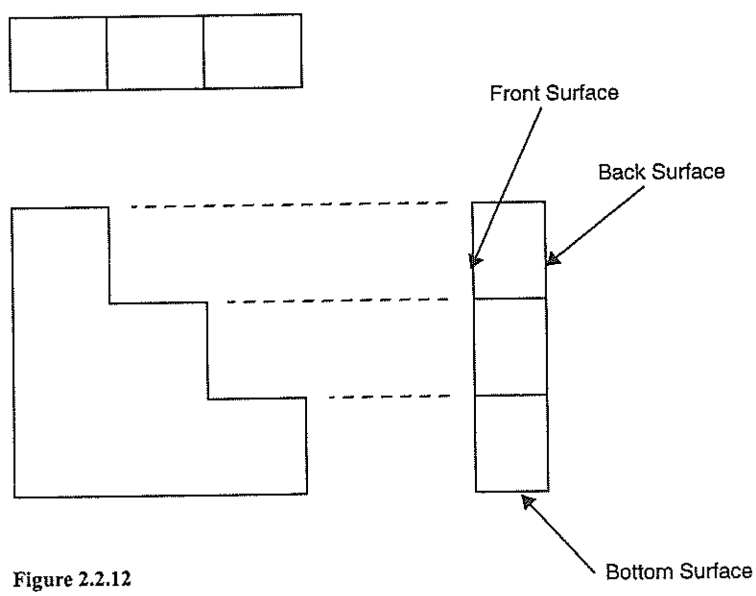


Figure 2.2.12

On other occasions, one is given the three orthographic views of an object and is required to create an isometric drawing of it. This can be accomplished by using the *box method*. When creating an isometric drawing by this method, first sketch a box on isometric grid paper. The dimensions of this box are the overall dimensions of the object as seen in the orthographic views. This step is shown in Figure 2.2.13.

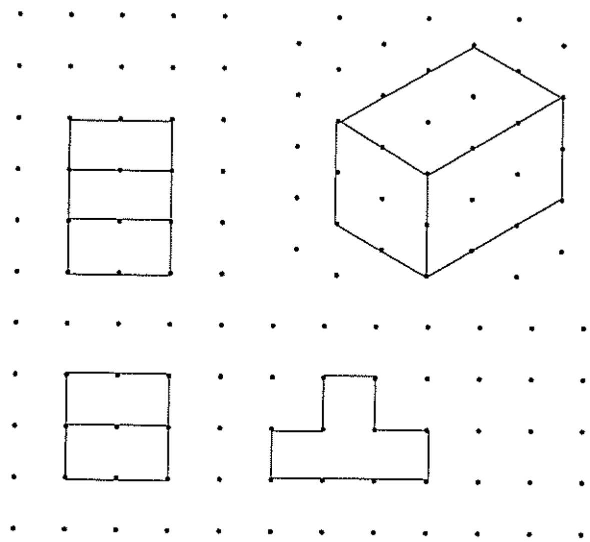


Figure 2.2.13

After sketching the defining box, draw each of the orthographic views of the object on the corresponding faces of the box, as illustrated in Figure 2.2.14. Remove and add lines from this box until all of the features in the orthographic views are shown. This results in the final isometric view of the object shown in Figure 2.2.15.

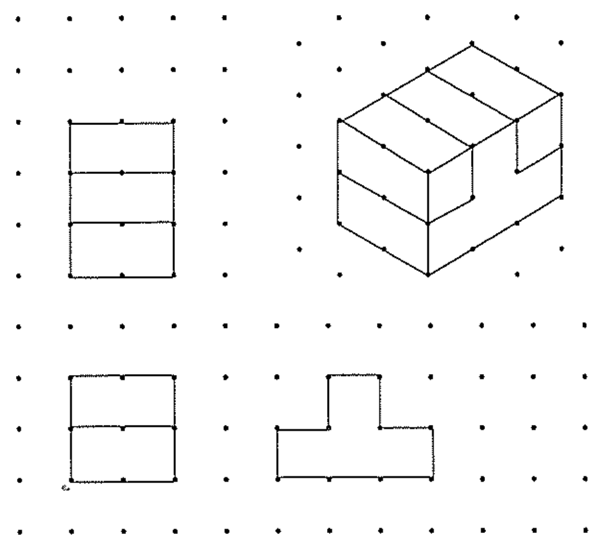


Figure 2.2.14

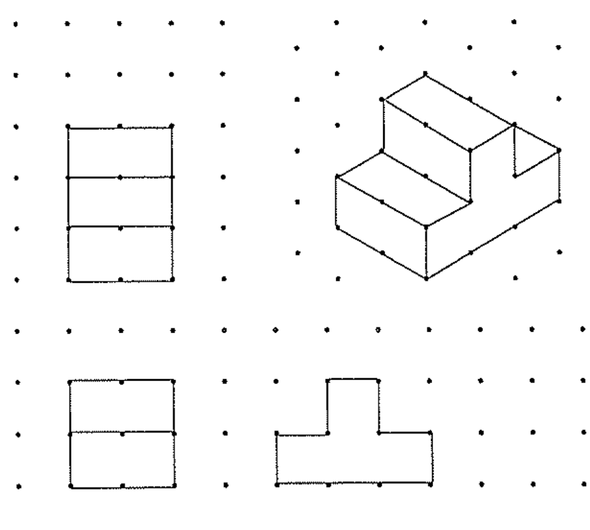


Figure 2.2.15

2.3 INCLINED SURFACES

So far in our discussion of isometric and orthographic drawings, we have limited our consideration to normal surfaces only. Although normal surfaces alone can be used to demonstrate the principles of constructing orthographic and isometric views of an object, their primary disadvantage is that very few "real life" objects are made up entirely of normal surfaces. In contrast with normal surfaces, **inclined surfaces** are defined as those surfaces that meet two of the orthographic views at an angle and are perpendicular to the third orthographic view. Thus, inclined surfaces appear as a surface in two of the orthographic views and as an edge (line) in the third view. Because inclined surfaces are not parallel to any of the orthographic views, they do not appear as true size in any of the orthographic views. Figure 2.3.1 illustrates an inclined surface in an object and the corresponding projected views.

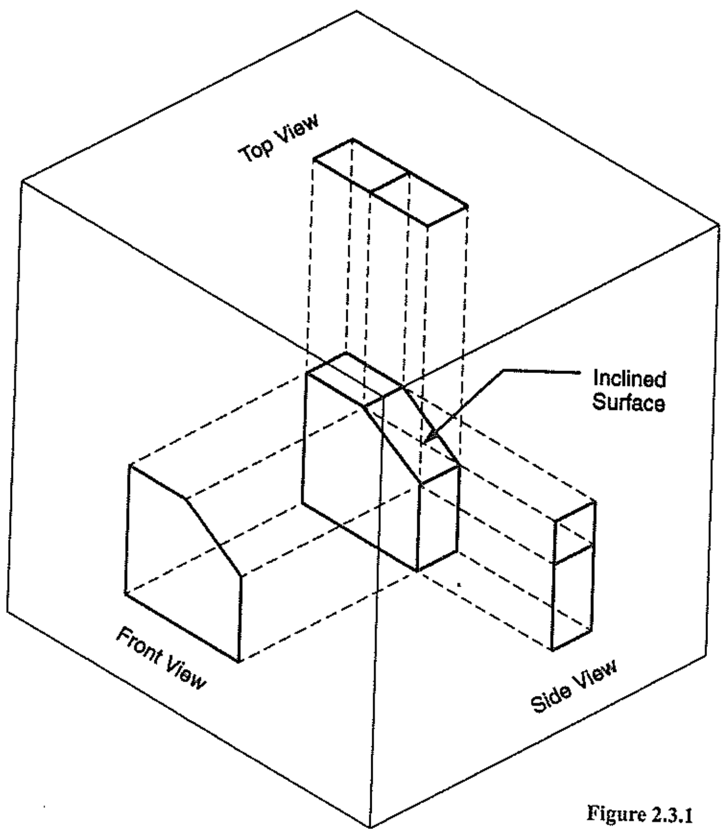


Figure 2.3.1

Figure 2.3.2 shows the orthographic views for the object in Figure 2.3.1 and the orthographic views for the object in Figure 2.2.2. As can be seen from this figure, the top and side views for the two objects are identical, and the general shapes of the objects are

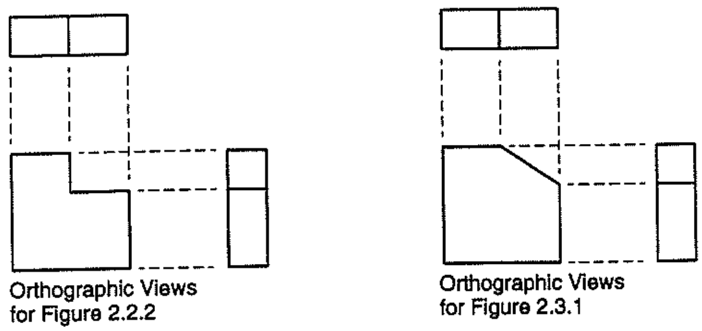


Figure 2.3.2

shown in the corresponding front views. Note that the front views are absolutely necessary for the complete description of the objects: without them, one would not be able to tell exactly what the objects look like. Note also that the size of the inclined surface in the right-side view is different from its apparent size in the top view. Neither of these views shows the surface in true size, because the surface is not parallel to either view. The size of the surface in both views is smaller than the actual size of the surface. When inclined surfaces are projected into orthographic views, they become *foreshortened.*

To construct an inclined surface in an isometric drawing, one typically locates the two endpoints of each inclined edge and draws a straight line between them. Figure 2.3.3 illustrates how inclined edges are located in isometric views, and Figure 2.3.4 shows the resulting isometric drawing of the object.

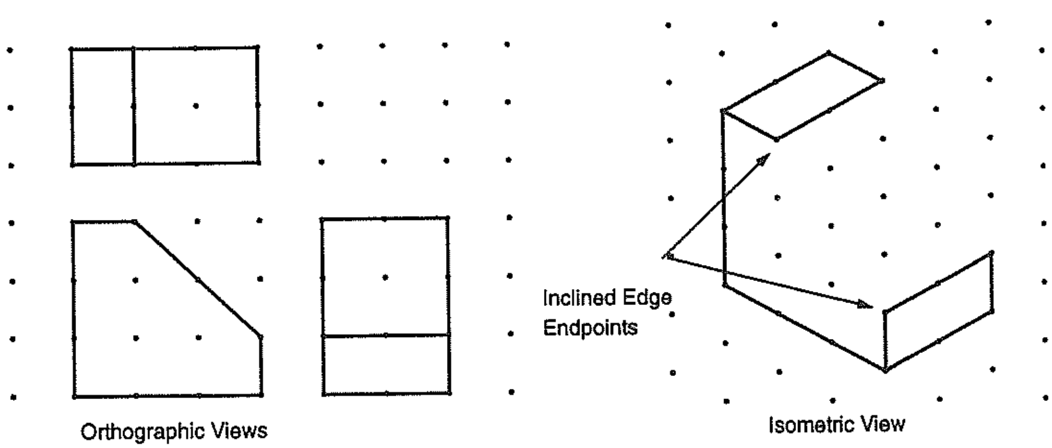


Figure 2.3.3

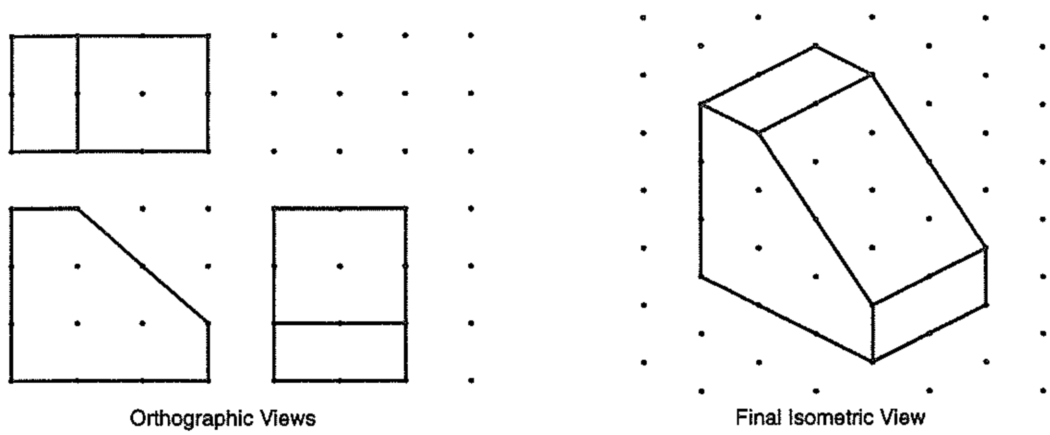


Figure 2.3.4

When constructing isometric views of objects that contain inclined surfaces, one should be careful to select an orientation of the object that makes the inclined surface appear as a surface and not as an edge. Figure 2.3.5 shows the two possible orientations of the object shown in Figure 2.3.4. As can be seen from Figure 2.3.5, the view labeled Isometric 1 shows the inclined surface as a surface, whereas the view labeled Isometric 2 shows this surface as an edge. The second view does not present a clear representation of the appearance of the object. This uncertainty should be avoided to achieve effective graphical communication.

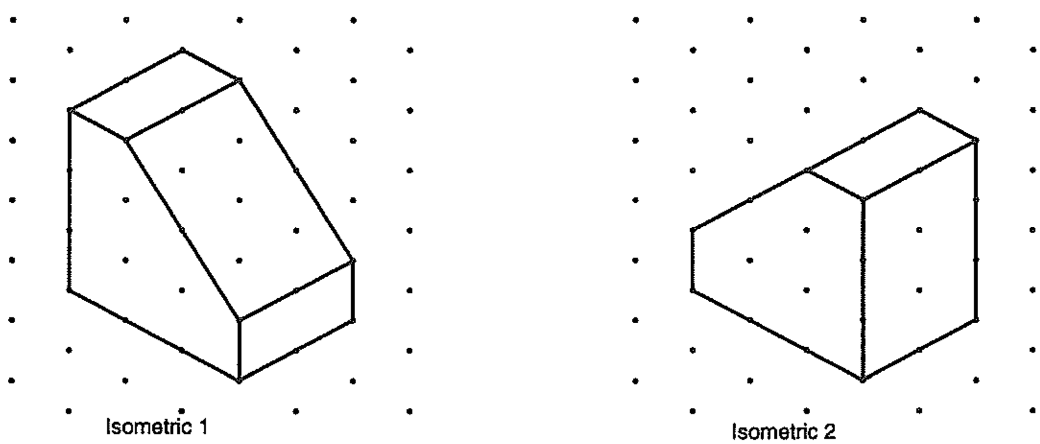


Figure 2.3.5

2.4 SINGLE-CURVED SURFACES

Many objects contain surfaces that are curved in space, and it is important to be able to graphically communicate curved surfaces in an orthographic projection system. **Single-curved surfaces** are defined as those with curvature about one axis only. Typically, this kind of surface is found on a cylindrically shaped object such as an aluminum can. A double-curved surface is spherical in shape, like a basketball. In this text, we will limit our discussion of curved surfaces to single-curved surfaces only.

When single-curved surfaces are drawn, only the outer limits of the curved surface are projected into orthographic views. The curvature of the surface will be visible in an adjacent view. Thus, a cylinder will project as a circle in one orthographic view and as a rectangle in the other two orthographic views. This is illustrated in Figure 2.4.1.

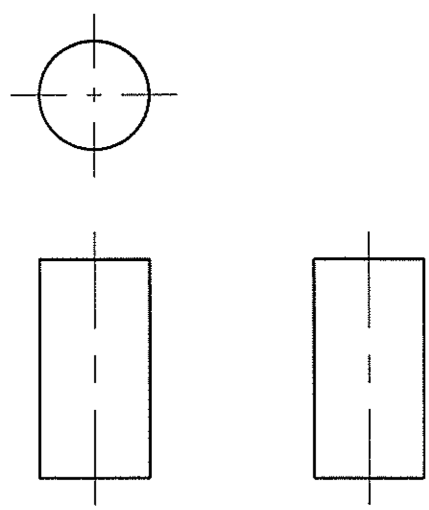


Figure 2.4.1

Because single-curved surfaces do not show their curvature in all of the orthographic views, it is customary to use **centerlines** to designate the location of the center of curvature for the surfaces. Centerlines are shown as a long dash followed by a short dash followed by a long dash, as illustrated in Figure 2.4.1. In this case, two centerlines are included in the view of the cylinder that shows the circular end (top view) and one centerline is shown in each of the views where the curved surface appears as a rectangle (front and side views).

Most of the time, single-curved surfaces will appear as interior, cylindrical holes in objects. The principle involved in drawing these interior surfaces is the same as in drawing exterior surfaces, except that they now appear as hidden features on the drawing. Figure 2.4.2 shows a three-view drawing of a block with two holes in it. One hole extends all the way through the object, but the other hole does not.

Single-curved surfaces will appear as ellipses in isometric views. An ellipse can usually be sketched as four circular arcs which are tangent to each other. To sketch a cylinder using isometric dot or grid paper, begin by drawing the visible or upper ellipse.

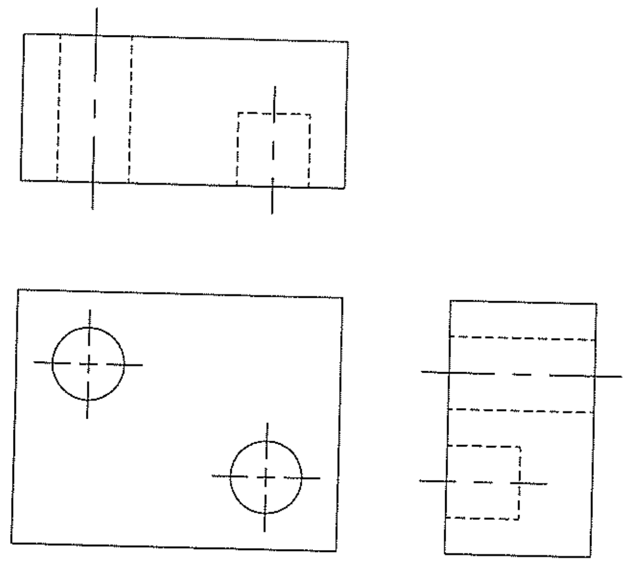


Figure 2.4.2

Locate the four points that correspond to the radial limits of the circular surface. This is shown in stage 1 of Figure 2.4.3. Then sketch in the two longer elliptical arcs as shown in stage 2 of Figure 2.4.3. Finish by sketching in the remaining two arcs to form the complete ellipse. The remaining arcs will be tangent to the first arcs and will go through the other two radial points. This is shown in stage 3 of Figure 2.4.3. To finish the isometric sketch of the cylinder, show the outer limits of the curved surface with straight lines "perpendicular" to the circular surface. Once the straight edges are drawn, sketch in a half ellipse at the bottom of the cylinder, as shown in stage 4 of Figure 2.4.3. Sketching ellipses in isometric views may require some practice before you can achieve acceptable results.

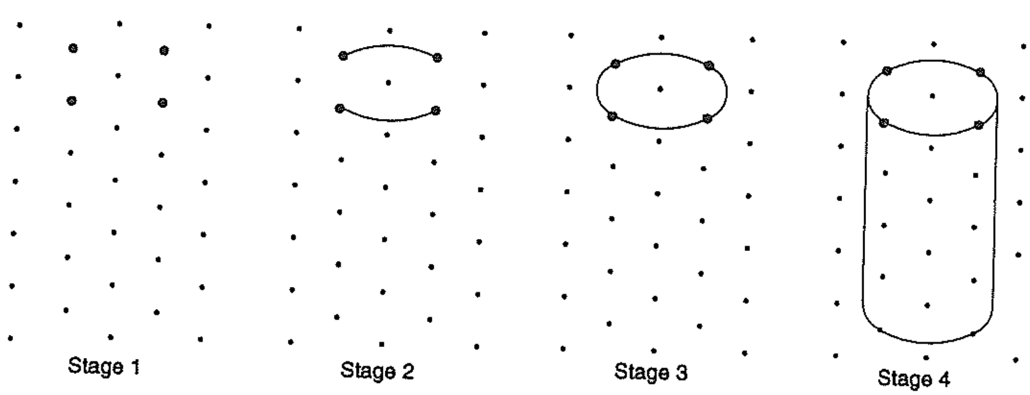


Figure 2.4.3