

DESIGN GRAPHICS FOR ENGINEERING COMMUNICATION

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1. Introduction

Technical illustrations provide detailed information about the shape, size, and material of a product or design and they need to be accurate, clear, and unambiguous. Although objects are three-dimensional, representing 3D objects accurately on 2D media, such as paper, is not trivial and requires special care.

The precise representation of an object on a plane (called picture plane or projection plane) from a particular point of view is called true projection. Think of the picture plane as a paper located between the viewer and the object. A drawing is created by connecting the points where the lines of sight from the viewer's position, traveling to the different points on the object, intersect the projection plane (see Figure 4.1). Drawing true projections of objects is a laborious process, so alternative projection methods have been developed to simplify this task. This simplification is accomplished by taking angles and measurements to produce a projection that resembles the true projection of the object.

One of these projection methods has already been discussed in the previous chapter; orthographic drawings use three principal orthographic planes (horizontal, frontal, and profile) as picture planes to produce several views of an object. For each view, the observer is located at infinity in front of the projection plane, hence the lines of sight travel parallel to each other in the direction of the object and hit the picture plane perpendicularly. Each orthographic projection generates a drawing that shows only two dimensions. Therefore, more than one drawing is required to fully describe any object.

Pictorials are a type of technical drawing that shows several faces of an object at once, much as they would be captured by a camera. Pictorial drawings are often more clearly understood than orthographic drawings, especially for non-technical audiences. As opposed to multi-view drawings, where the viewer

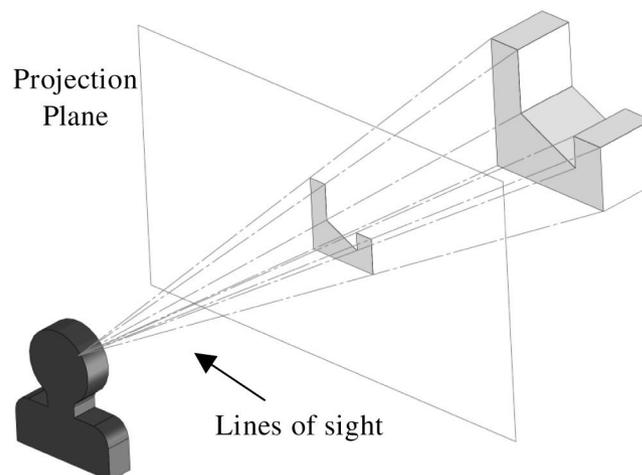


Figure 4.1 True projection of an object

is required to mentally visualize and combine the individual views into one 3D object, pictorials show all three dimensions of an object in one single drawing. Pictorial drawings are commonly used in conjunction with orthographic drawings. They are very useful in the early stages of the design process, as they mimic the way we represent objects in our mind and how we visualize spatial relationships.

2. Types of Projections

There are four major projection techniques used in engineering: orthographic, axonometric, oblique, and perspective, as shown in Figure 4.2. Axonometric, Oblique, and Perspective projections are pictorials, showing all three dimensions of an object in a single drawing. Orthographic projections require multiple 2D drawings to describe any object. Orthographic, Axonometric, and Oblique projections are parallel projections, which means that lines that are parallel on the real object will remain parallel on the drawing as well. This simplification is a result of theoretically locating the viewer infinitely far away from the picture plane and assuming that the lines of sight travel parallel to each other and perpendicular to the projection plane.

Perspective projections are non-parallel projections: lines that are parallel in the real object are not necessarily shown as parallel in the perspective drawing. Perspective projections reproduce the effect that distant objects appear smaller than objects that are closer to the observer and represent how an eye perceives the world. Lines that are parallel in nature appear to converge towards a single point, depending on the position of the viewer.

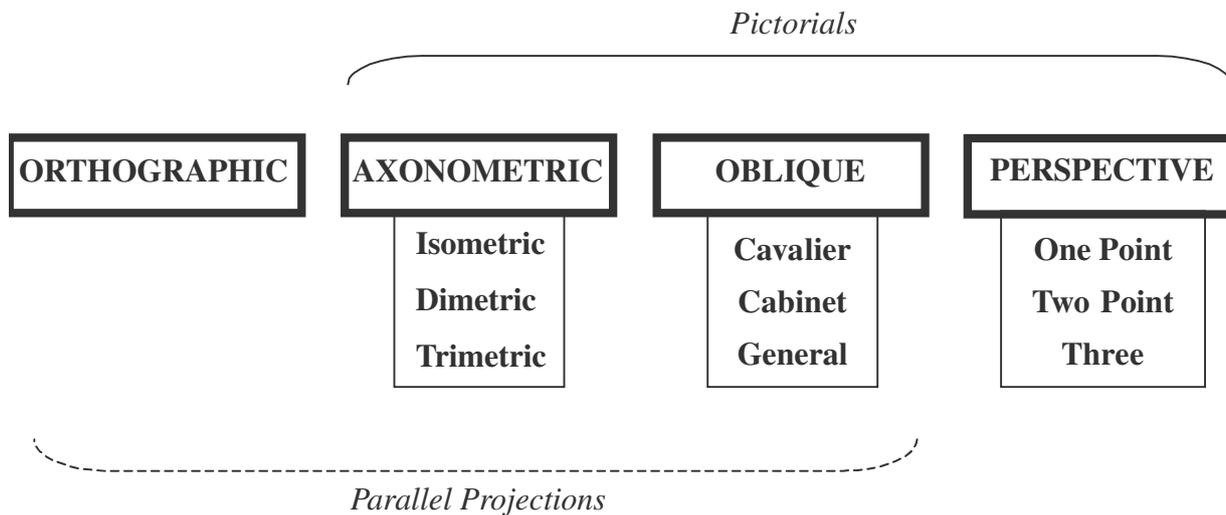


Figure 4.2 Classification of projection techniques

3. Axonometric Projections

Axonometric projection is a type of parallel projection where the observer is theoretically located at infinity and the object is rotated and tilted around an axis (called an axonometric axis) relative to a projection plane in order to display all three dimensions (see Figure 4.3). There are infinite numbers of angles and rotations that can be used to draw objects using this type of projection, but only a few of these angles are useful in practice. Such angles are optimized and standardized so the process of creating axonometric drawings is simple and fast and the results are accurate and reasonably realistic. In this case, the term “reasonably realistic” refers to visual realism, or how close the drawing resembles what our eyes see. Unlike perspectives, axonometric projections make distant objects appear the same size as nearby objects. This simplification is not representative of how humans perceive the world, but by sacrificing “visual realism” and making the drawing appear distorted, an advantage is gained: the actual dimensions of the real object can be measured directly from the drawing if the scale is known.

Axonometric projections are classified by the orientation of the primary axes relative to the projected face of the object. This orientation determines the amount of distortion for each dimension. When an axis is oriented parallel to the projected face, dimensions along that axis are shown true size. Otherwise, dimensions appear shorter than their true length. The closer an axis comes to being perpendicular to the projected face, the shorter it becomes. This orientation can be observed through the three angles formed by the primary axes on the projected object. If all three angles are equal (120°) an Isometric projection is created. If two of the angles are equal, the projection is Dimetric. If all three angles are different, the projection is Trimetric. See Figure 4.4 for an example of axonometric projections using a cube, and then using a more complex object. Notice in the isometric drawing of the object how a basic cube can still be used to identify the primary axes.

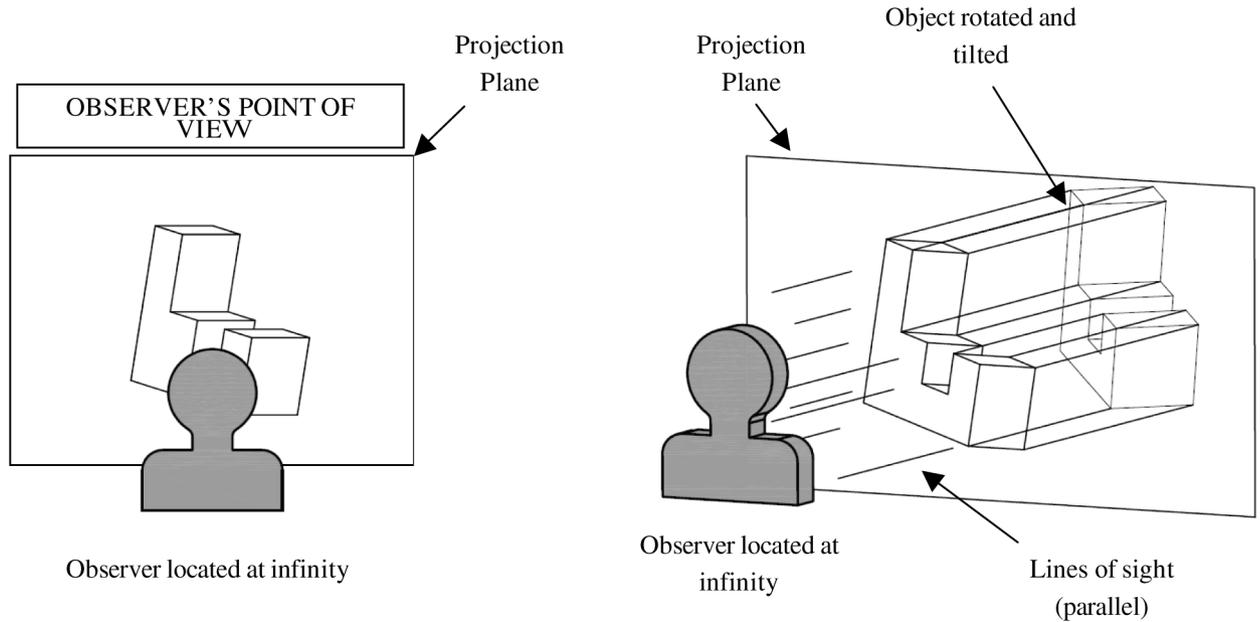


Figure 4.3 Axonometric projection

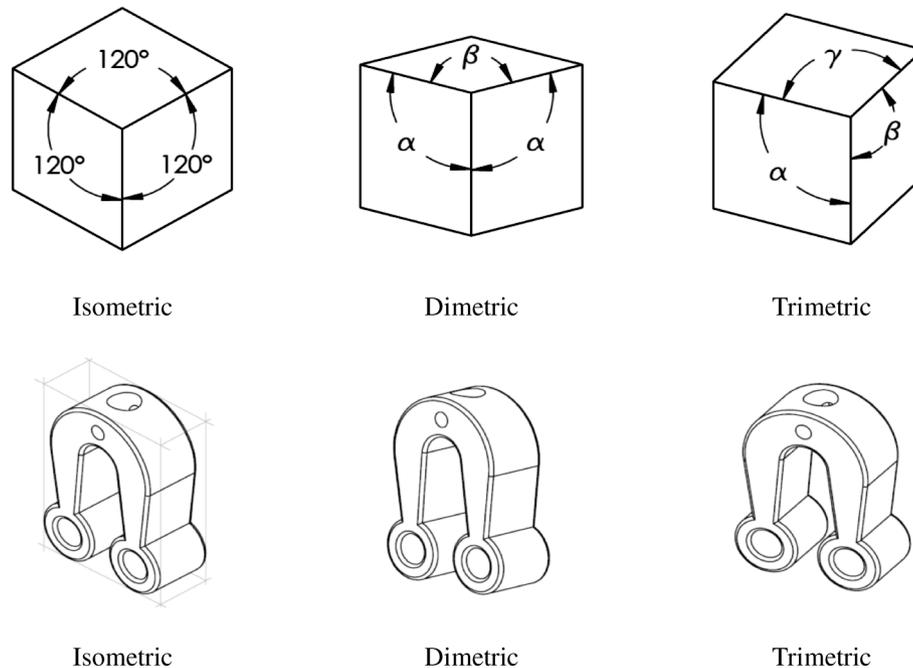


Figure 4.4 Three types of axonometric projections

3.1 Standard Practices for Axonometric Drawings

Orientation There are many different ways axonometric axes can be oriented relative to the projection plane and still maintain the relationships and angles. In general, axonometric projections are drawn with the main axes above the horizontal. The same rules used in orthographic projections to select the most descriptive orientation apply to axonometric drawings. Examples of different orientations of the same object using an isometric projection are shown in Figure 4.5.

Lines In axonometric drawings, hidden lines often create more confusion than they provide information, especially for complex models (see Figure 4.6 for an example). Hidden lines are normally omitted in axonometric drawings unless the features they represent are absolutely required to fully illustrate the object. As it happens with orthographic drawings, the use of hidden lines can generally be minimized by selecting the correct orientation for the object. Center lines are also omitted, unless additional clarity is needed to show concentricity. As a rule, only axonometric drawings with dimensions and/or tolerances for manufacturing purposes will include center lines. Tangent edges are normally omitted on orthographic drawings, because they can mislead the viewer by giving the false impression of a visible line. However, tangent edges are typically shown in axonometric projections. Omitting tangent edges in axonometric drawings often has severe effects on the quality of the drawing and how the information is perceived (see Figure 4.6 for an example). Most 3D CAD applications will show tangent edges by default when axonometric pictorials are created.

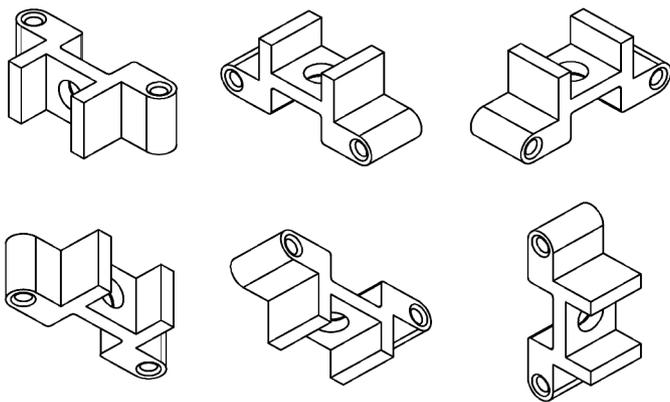
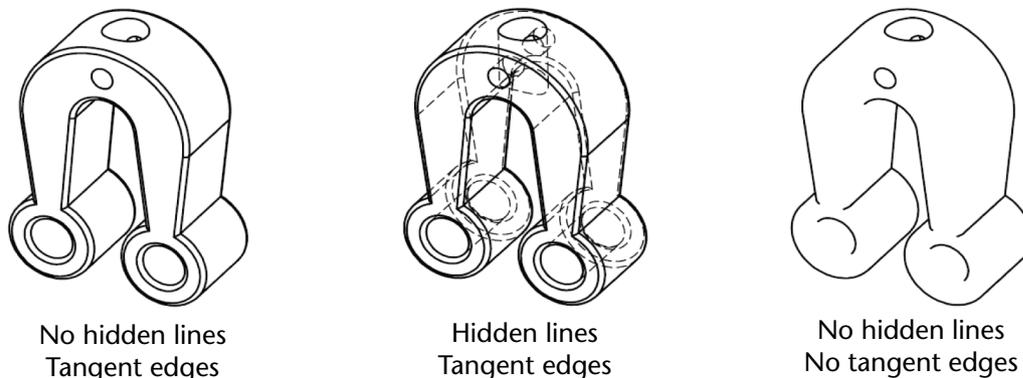


Figure 4.5 Different orientations of the same object using isometric projections

Dimensions It is a common practice in production drawings to include orthographic drawings and pictorials of all the parts of a design. Normally, dimensions are included only in the orthographic views and pictorials are used as an illustration tool to assist with the visualization of the object.

Occasionally, axonometric drawings need dimensioning and general dimension standards apply. All elements of a dimension must be positioned on the same plane (normally axonometric planes) as the line that is being dimensioned. Dimensioning practices will be discussed later. See Figure 4.7 for an example of a dimensioned isometric drawing.



No hidden lines
Tangent edges

Hidden lines
Tangent edges

No hidden lines
No tangent edges

Figure 4.6 Effects of hidden lines and tangent edges on axonometric projections

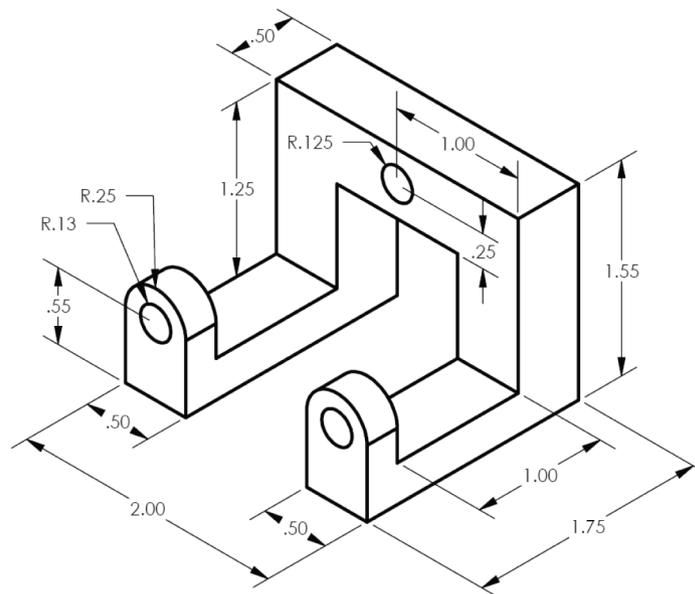


Figure 4.7 Dimensioned isometric drawing

3.2 Isometric Projections

Isometric projection is the most popular type of axonometric projections used in engineering. Because of its popularity, many tools are readily available to assist in the sketching and construction of isometric drawings. Even most computer aided design (CAD) packages nowadays incorporate isometric grids, snaps, viewpoints, cameras, and templates optimized for this type of projection.

Isometric projections are built by locating the observer at infinity looking perpendicular to the picture plane. The object to be drawn is first rotated 45° about a vertical axis and then tilted forward 35.27° as shown in Figure 4.8. These values cause the projected object to be oriented in such a way that the three primary axes (in this case called isometric axes) form equal 120° angles among themselves and 30° angles with the horizontal (see Figure 4.9).

The orientation of the object in isometric projection also causes an overall scale reduction of approximately 80% in the projected drawing. Although this is not a major concern, for practical purposes, a full scale isometric is always preferred, since immediate information about the true dimensions of the object is given. Because of the specific orientation of the axes, isometric projections keep drawings proportionate in size, so drawings do not appear distorted. In addition, lines and edges drawn parallel to the isometric axes will always appear true size.

There are three major disadvantages when using isometric drawings. The first is that all lines and edges that are not parallel to the isometric axes will not appear true size and therefore will not be as easy to draw as isometric lines. The second drawback is that circular features on the real object will

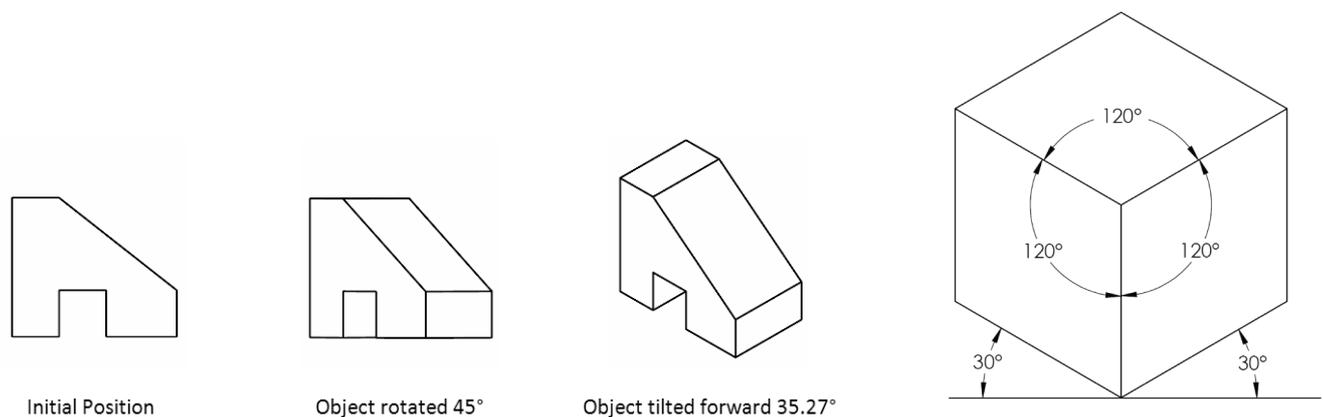


Figure 4.8 Creation of an isometric projection

Figure 4.9 Isometric cube

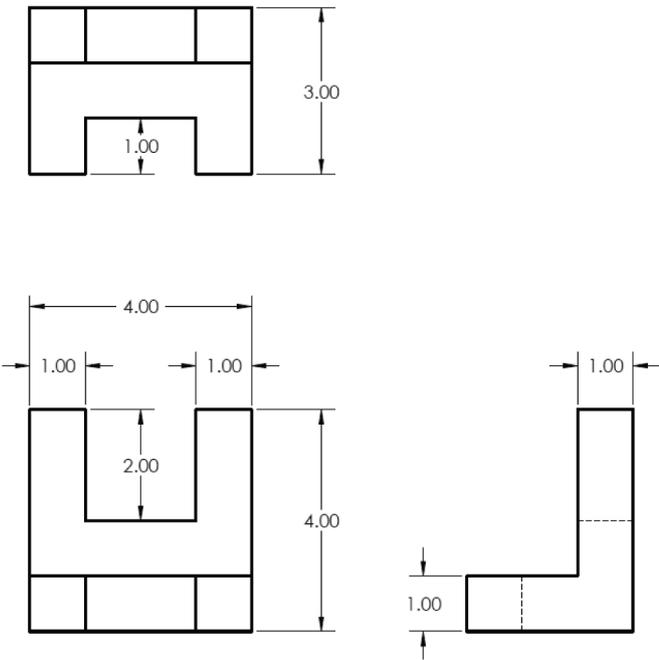
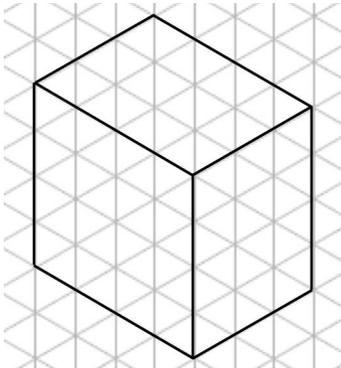


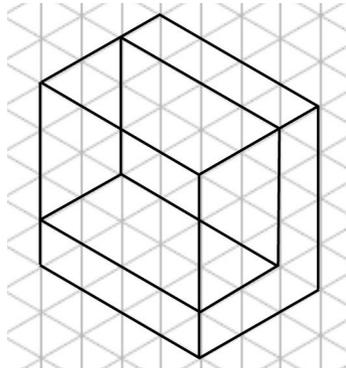
Figure 4.10 Orthographic views of object

appear as ellipses on all faces in the isometric drawing. Although there are templates and tools to assist with the construction of ellipses, it is difficult to draw and orient them correctly in an isometric drawing. Finally, curved surfaces and irregular features on the object must be located with coordinates to properly plot them on the drawing.

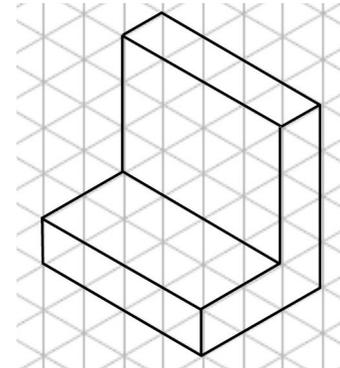
Sketching Techniques for Isometric Drawings The most common technique needed to sketch isometric drawings uses basic cubes or construction boxes as visual aids. Isometric sketching begins with the definition of the isometric axes. Although isometric grids and drafting triangles are commonly used to facilitate the task, several freehand techniques can be employed. Examine the object shown in Figure 4.10 to gain an understanding of this process. Assume an isometric grid where lines are spaced 1 unit from each other.



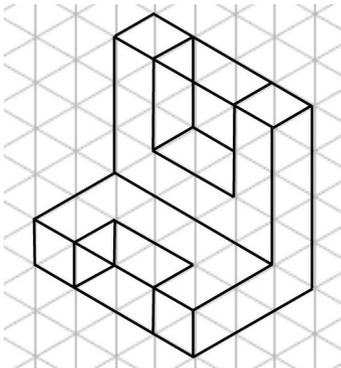
1. Build a box with the overall size of the object to be drawn (in this case $4 \times 4 \times 3$).



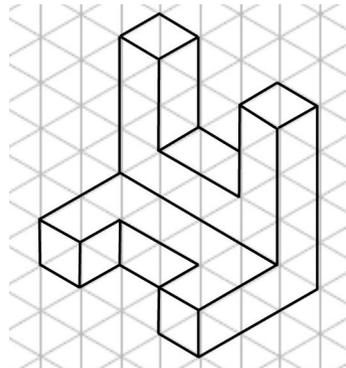
2. Sketch the overall shape or outline using the orthographic views. In this case, the right side view offers great detail.



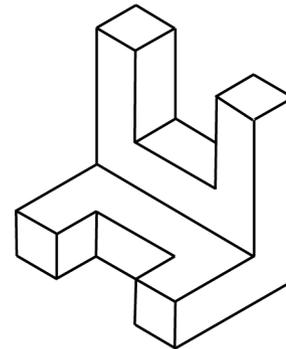
3. Delete the lines that are no longer needed.



4. Add details to the overall shape using the other orthographic views. In this case, front and top views.



5. Delete the lines that are no longer needed.



6. Completed drawing.

Angles and Non-Isometric Lines A non-isometric line is a line that is not parallel to any isometric axis. An observation can be made that any line in an orthographic drawing that is not parallel or perpendicular to an orthographic plane will be a non-isometric line in the isometric drawing. Any angle other than 0° , 90° , 180° , and 270° creates a non-isometric line. In summary, angles always appear true size in multi-view drawings but never in isometric drawings.

A common technique used to represent angles and non-isometric lines in isometric drawings is to start the drawing by sketching all the isometric lines (normal lines in the multi-view drawing, and thus appearing true size in the pictorial). Non-isometric lines can be added by connecting the endpoints of the existing isometric lines with straight lines. This process is illustrated in Figure 4.11.

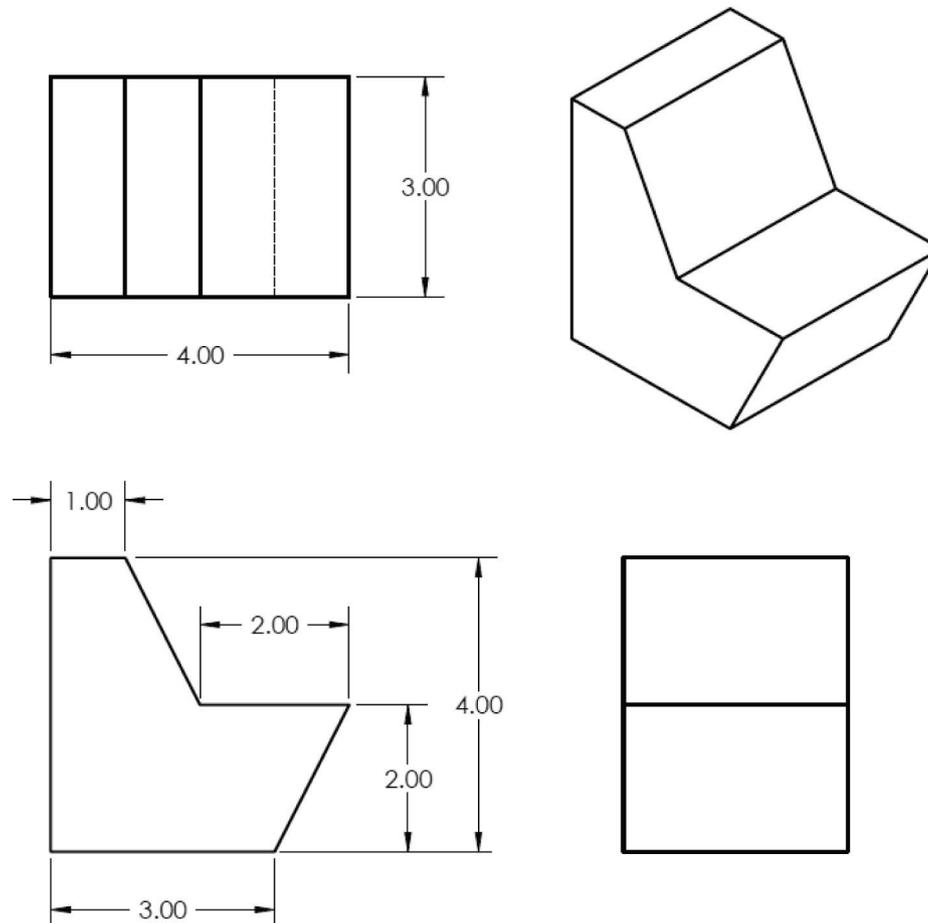
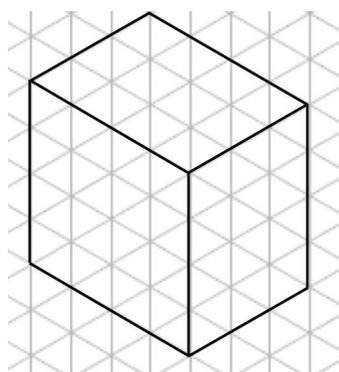
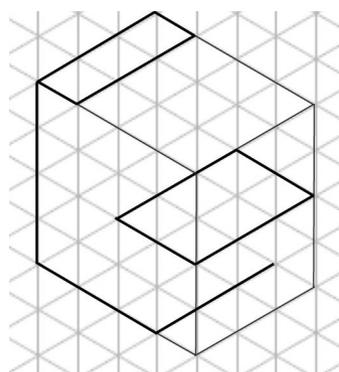


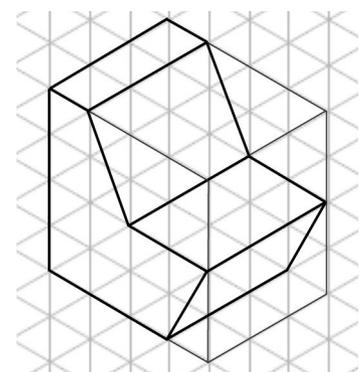
Figure 4.11 Orthographic views of object with angled features



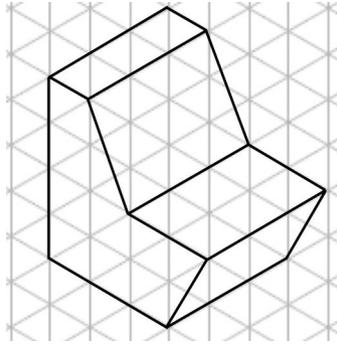
1. Build a box with the overall size of the object to be drawn (in this case $4 \times 4 \times 3$).



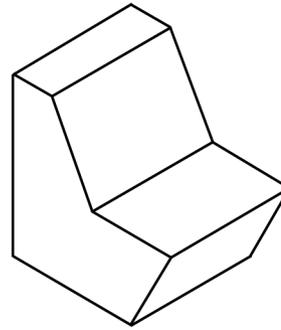
2. Sketch the overall shape or outline (isometric lines only) using the orthographic views. In this case, the front view offers great detail.



3. Connect endpoints of existing lines to create non-isometric lines.



4. Delete the lines that are no longer needed.



5. Completed drawing.

Circles and Curved Features The general method for creating irregular curved features in isometric drawings is the grid method. This method consists of constructing a grid on the orthographic view where the curved feature is shown. The intersections of the curved line with the divisions in the grid give a sequence of control points that can be used to plot the curve on the isometric drawing. See Figure 4.12 for an example.

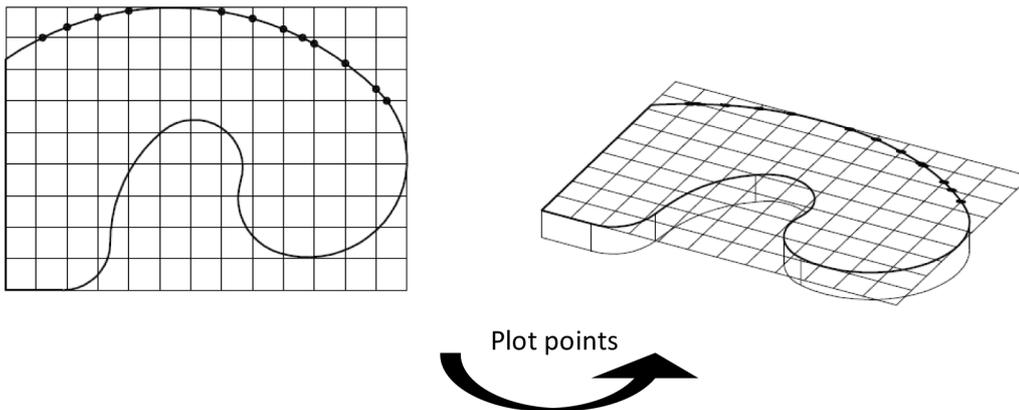


Figure 4.12 Grid method to sketch curves and irregular features

The same technique can be used to sketch full circles in isometric drawings. However, since circles will resemble ellipses (see Figure 4.13) an easier method can be used. An isometric square (construction box) can be created such that each side equals the diameter of the desired circle. The method is based on how isometric ellipses are connected to their construction boxes:

- Ellipses always touch the midpoint of each side of the isometric construction box.
- The major diameter of the ellipse is always aligned with the longest body diagonal of the construction box.

See Figure 4.14 for a representation of an ellipse inside its construction box.

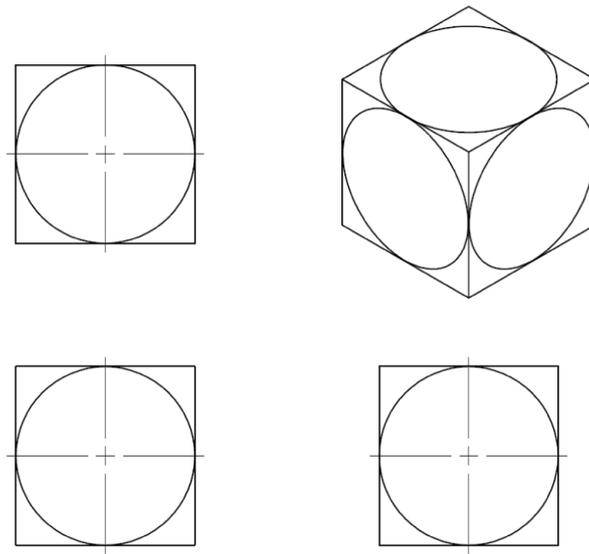


Figure 4.13 Circles appear as ellipses in isometric drawings.

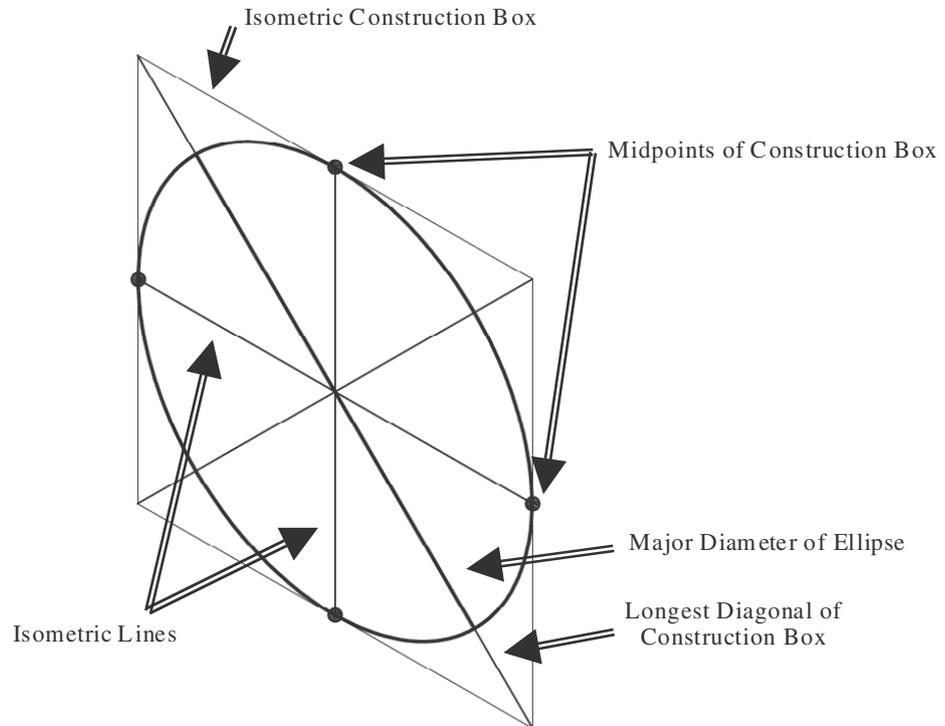
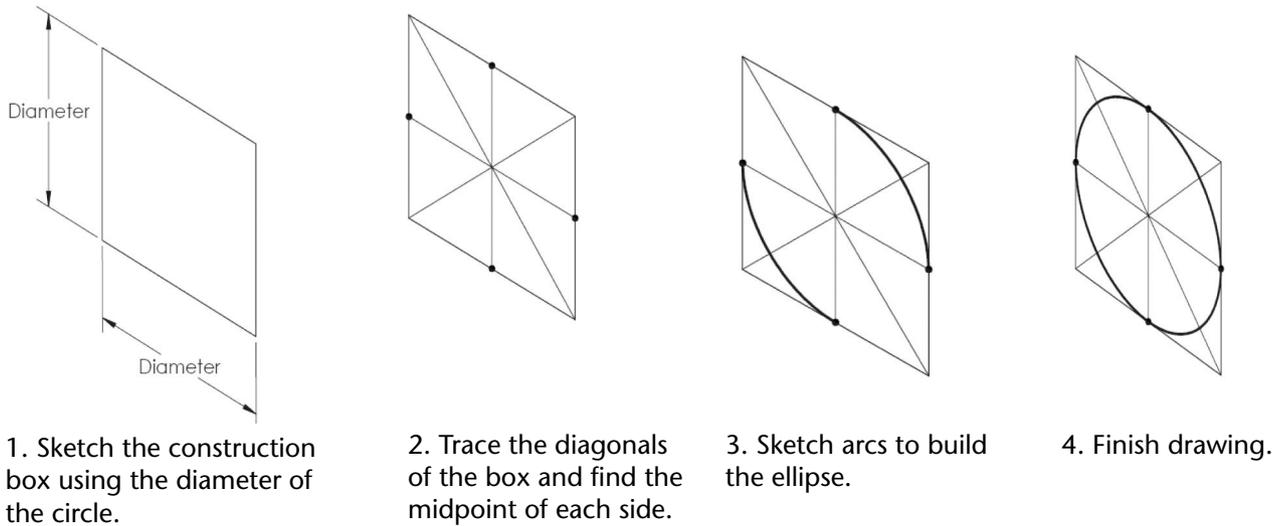


Figure 4.14 Isometric ellipse inside its construction box



Parts with holes and/or cylindrical features are common examples where isometric circles must be sketched. Isometric cylinders are commonly shown standing upright. To sketch these features, begin with a construction box and sketch the ellipses on the top and bottom of the cylinder or hole. Finally, connect the ellipses with tangent lines and delete the construction lines when the drawing is finished (See Figure 4.15).

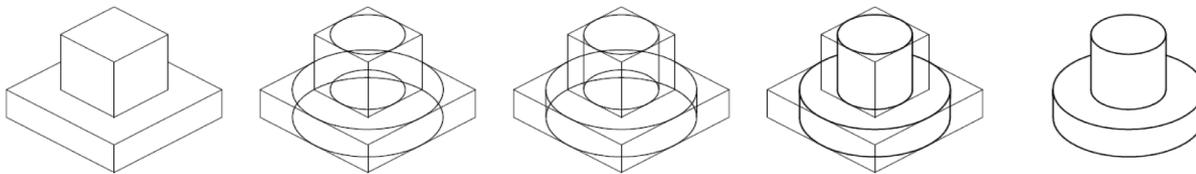


Figure 4.15 Cylindrical features in isometric drawings

3.3 Dimetric Projections

Dimetric projections are constructed by locating the observer at infinity looking perpendicular to the picture plane. The object to be drawn is first rotated about a vertical axis and then tilted forward so that only two of the three primary axes form equal angles with the projection plane. The first rotation of the object before it is tilted occurs at 45° , so that one of the dimetric axes is vertical. This way, the two equal angles will appear on either side of the vertical line creating a symmetric dimetric projection, which provides for easier visualization. If one of the equal angles and the third angle are placed on either side of the vertical, an asymmetric dimetric projection can be produced.

Infinite tilt angles can be used to create dimetric projections. In general, any angle other than 35.27° , which would produce an isometric, is acceptable. The most common configuration uses 105° for the equal angles (thus, 150° for the third angle) and 15° for the receding angles (the angles formed by the dimetric axes and the horizontal). See Figure 4.16 for an example of different dimetric projections.

3.4 Trimetric Projections

Despite the fact that trimetric projections are considered the most visually pleasant type of axonometric projections, they are not frequently used because of the difficulty needed to draw them. Determination of dimensions in trimetric drawings requires three scales because all three axes are oriented at different angles.

Trimetric projections are constructed by locating the observer at infinity looking perpendicular to the picture plane. The object to be drawn is first rotated about a vertical axis and then tilted

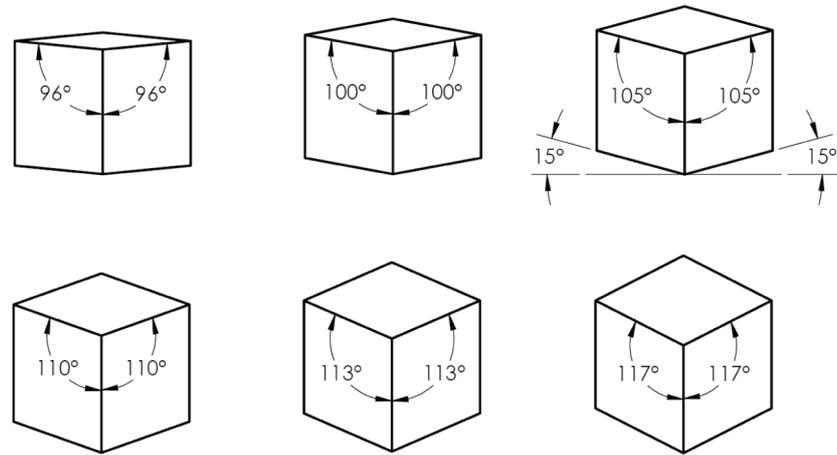


Figure 4.16 Different angles for dimetric projections

forward so that the angles formed by the three primary axes and the projection plane are different. The first rotation of the object before it is tilted can occur at any angle other than 45° , which would produce a dimetric or isometric projection, depending on the tilt angle.

Similar to dimetric projections, infinite tilt angles can be used to generate trimetric projections (see Figure 4.17 for some examples). The most popular orientation uses 105° , 135° , and 120° angles for the axes and 15° and 45° for the receding angles.

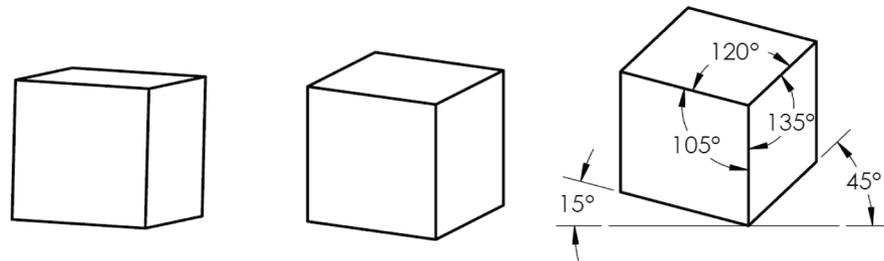


Figure 4.17 Different rotation and tilt angles for trimetric projections. The dimensioned drawing represents the most common trimetric orientation.

4. Oblique Projections

Oblique drawings are a distinctive type of parallel projections where the most descriptive face of the object is projected parallel to the projection plane, thus appearing true size, and depth is represented using angled, parallel lines drawn to one side of the front face.

Oblique pictorials are simple to create, but their use is not as widely extended in production environments as isometric drawings due to the amount of distortion that occurs. The use of oblique drawings is normally limited to simple parts and objects, or complex objects with simple top and side surfaces. However, because of their simplicity, oblique pictorials are a great tool to quickly communicate ideas in early stages of the design process.

All types of oblique projections represent the most descriptive view true size and the depth using any receding angle between 0° and 90° . Similar to dimetric and trimetric drawings, an infinite number of angles can be used to produce oblique drawings. Regardless, angles that are less than 30° or greater than 60° create excessive distortion. Traditionally, 30° , 45° , and 60° angles have been used because of the availability of standard drafting triangles and other drawing instruments that simplified the calculation of angles.

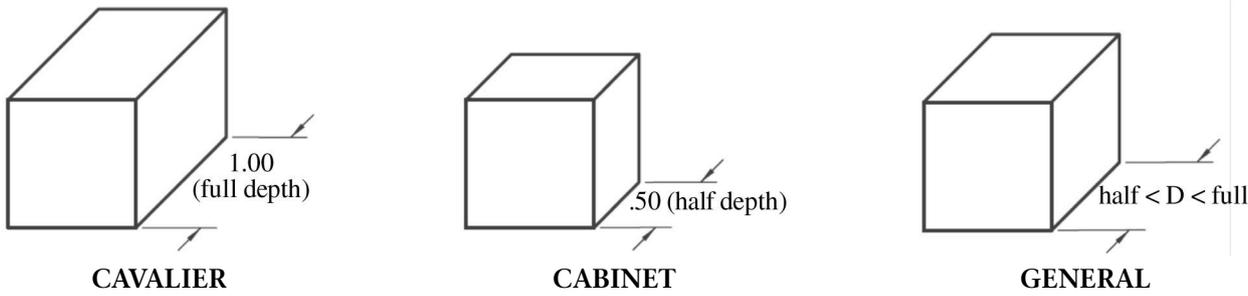


Figure 4.18 Three types of oblique projections

There are three types of oblique pictorials based on how the depth of the object is represented on the drawing (see Figure 4.18). If depth is represented true size, the projection is called cavalier oblique. The advantage of this type of projection is that true sizes can be obtained directly from the drawing. The drawback is that it creates a great amount of distortion due to the absence of foreshortening.

When depth is scaled to half size, a cabinet oblique projection is created. This type of projection reduces the distortion created by the cavalier oblique so the drawing appears more realistic. If depth is shown using any value between half and true size, a general oblique is produced. General oblique pictorials are normally used with specific objects where a cavalier oblique makes the object's depth appear too long and a cabinet oblique makes the object's depth too shallow.

4.1 Standard Practices for Oblique Drawings

Although oblique drawings are easy to draw, general guidelines must be followed to optimize quality and reduce the level of distortion.

Front View As with orthographic projections, the view that gives the most information about the object (shape, size, features, etc) must be selected as the oblique front view. This guideline allows complex features and details to be drawn more easily, accurately, and without distortion. (See Figure 4.19 for an example.)

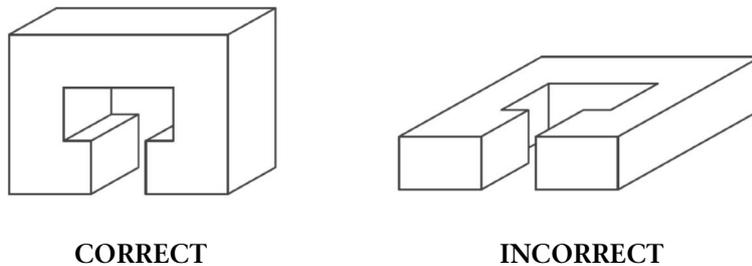


Figure 4.19 Selection of oblique front view

Receding Angle As mentioned earlier, receding angles less than 30° and greater than 60° create severe distortion, especially cavalier projections. Therefore, angles between 30° and 60° should be chosen. (See Figure 4.20 for an example.)

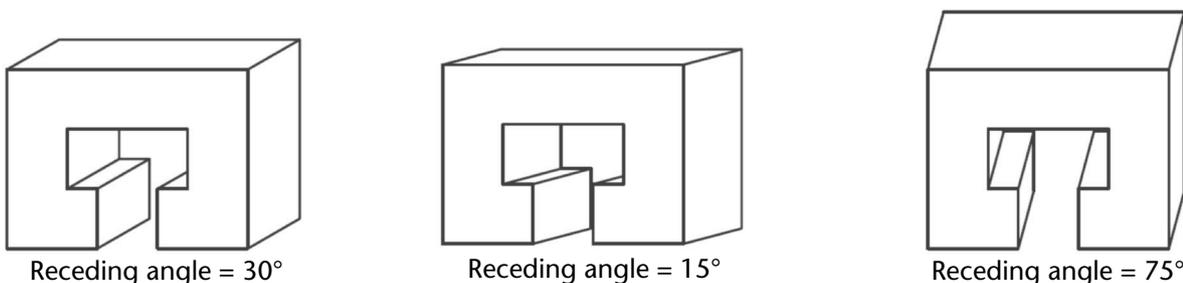


Figure 4.20 Effects of the receding angle in oblique pictorials

Orientation In oblique drawings, irregular and circular features cause more overall distortion than regular faces and shapes. For this reason, such features should be placed parallel to the projection plane whenever possible. (See Figure 4.21 for an example.)

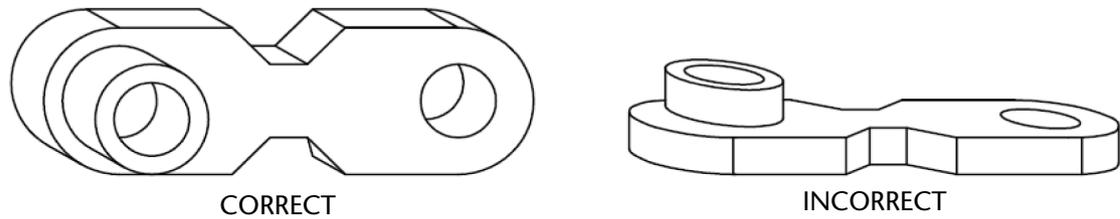


Figure 4.21 Orientation of oblique drawings

Lines The same rules used in axonometric drawings apply to obliques: hidden lines are normally omitted unless the features they represent are required to fully illustrate the object (see Figure 4.22 for an example). Center lines are also omitted unless needed to show concentricity. Tangent edges are typically shown; although in some cases the effect of omitting tangent edges in oblique drawings is not as severe as it is in axonometric drawings.

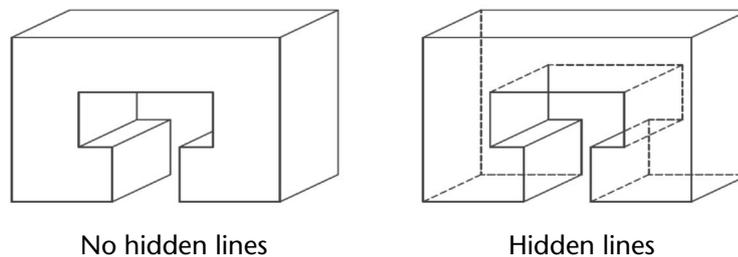


Figure 4.22 Effects of hidden lines in oblique pictorials

Dimensions Since most descriptive features will be placed on the front face of the oblique drawing, most dimensions will also be located on this plane. For those dimensions not in the front plane, the same dimensioning practices used in axonometric drawings apply. (See Figure 4.23.)

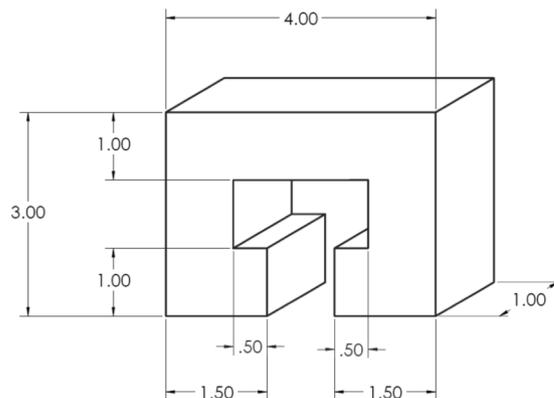


Figure 4.23 Dimensioned oblique pictorial

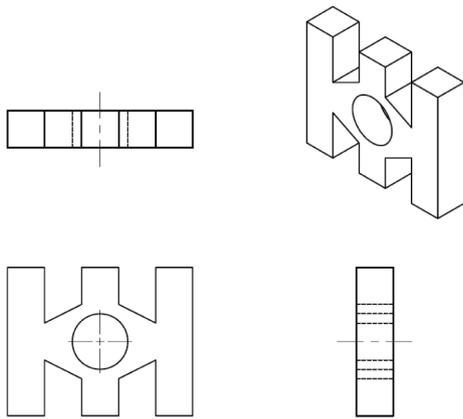
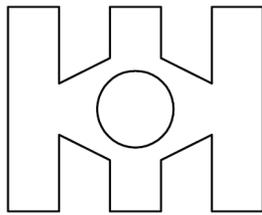


Figure 4.24 Object for oblique pictorial

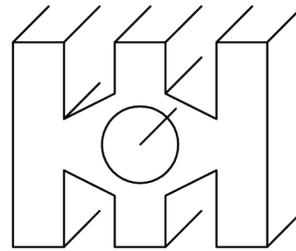
4.2 Sketching Techniques for Oblique Drawings

Oblique sketching begins with the selection of the front view. Although grids and drafting triangles are readily available, several freehand techniques can be employed. The process of creating a cabinet oblique is illustrated in Figure 4.24.

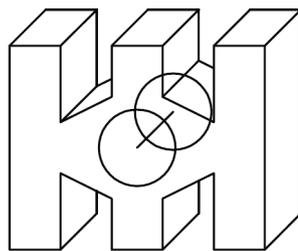
Circles and Curved Features Irregular features in the oblique front view will always appear true size. However, it is difficult to sketch curves and circular features in the receding planes as they appear distorted. The grid method employed to sketch curved features in isometric drawings can also be used in obliques. To avoid distortion, cylinders drawn as obliques are traditionally shown lying on their side. (See Figure 4.25 for an example.)



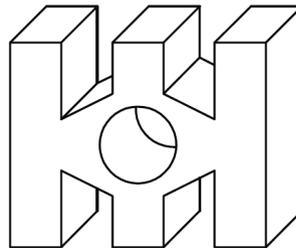
1. Sketch the oblique front view true size using the orthographic views. In this case, the orthographic front view offers the most detail.



2. From every point, sketch lines at the oblique angle selected (in this case, 45°). In this drawing, the lines are half the size of the lines in the multi-view drawing (cabinet oblique).



3. Connect the endpoints of the sketched lines to complete the back side of the object. Also, sketch another circle to determine the visibility of the back of the hole.



4. Delete the lines that are no longer needed.

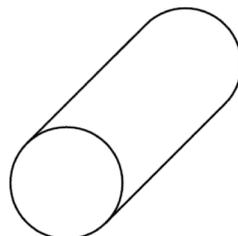


Figure 4.25 Oblique cylinder

5. Isometric vs. Oblique

When representing simple objects with straight edges and flat surfaces, isometric and oblique pictorials look equally good assuming all the general sketching guidelines discussed above are followed. However, oblique pictorials create a great amount of distortion when representing objects with curved and circular features. See Figure 4.26 for an example. In this case, isometric pictorials are preferred.

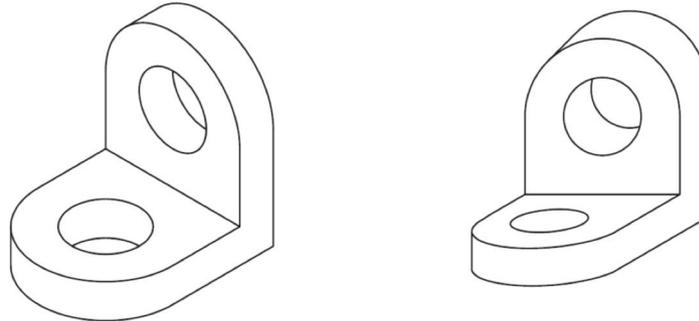


Figure 4.26 Isometric pictorial vs. oblique pictorial

6. Perspective Projections

A perspective projection results when the observer is not located at infinity, but at a finite distance from the projection plane. This projection causes several visual effects on the drawing projected on the picture plane. First, parallel lines in the object will not remain parallel on the drawing. In fact, all lines that are not in a plane parallel to the picture plane will converge toward a single point (called vanishing point). Secondly, objects that are closer to the viewer will appear larger than those further away.

Perspective projections are the most realistic projections. The way objects are represented in perspective projections is the way eyes perceive the world. However, perspective drawings contain the most visual errors of any standard projection method; lines or angles with the same dimension on the object will have different dimensions on the drawing. Perspectives are difficult to construct, especially circular features, and plotting distances and calculating true dimensions in perspective are time consuming tasks. The use of perspectives in engineering is commonly limited to drawings with illustrative and presentation purposes only, where accuracy is not required, and approximations are frequently used in order to simplify the process.

There are different factors involved in producing a perspective drawing. These factors take into account the position of the observer (called station point) relative to the object to be drawn, the position of the ground relative to the horizon, and the position of the object relative to the projection plane (See Figure 4.27). These factors, along with the orientation of the object, will determine how many vanishing points will be used in the drawing. In fact, perspective projections are classified based on the number of vanishing points.

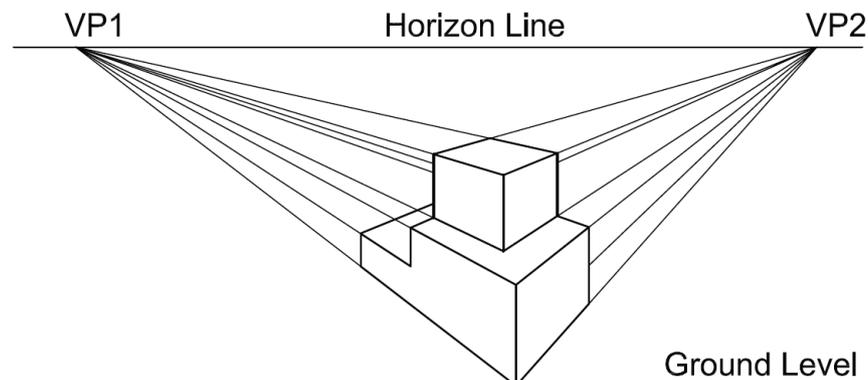


Figure 4.27 Example of perspective projection

6.1 One-Point Perspective

One-Point perspectives show one face of the object in true size (actually, all faces that are parallel to the projection plane). Lines representing depth converge toward one single vanishing point. See Figure 4.28 for an example.

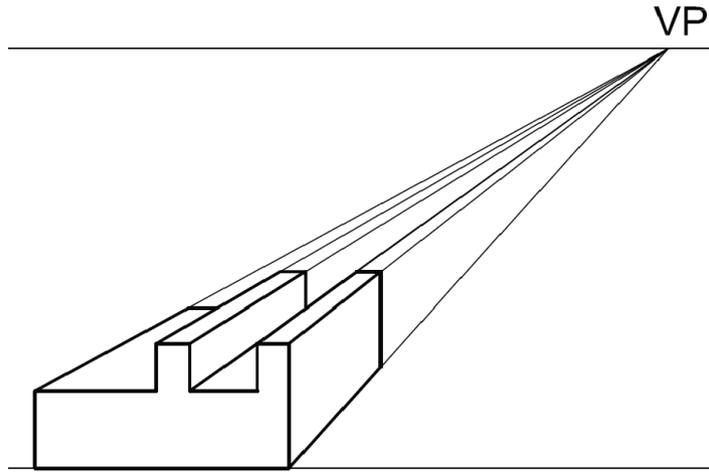


Figure 4.28 One-point perspective

6.2 Two-Point Perspective

Two-Point perspectives show the object positioned at a certain angle relative to the projection plane. Lines representing depth will converge to one of the vanishing points located on the horizon line. In addition, all vertical edges of the object are parallel to the projection plane. See Figure 4.29 for an example.

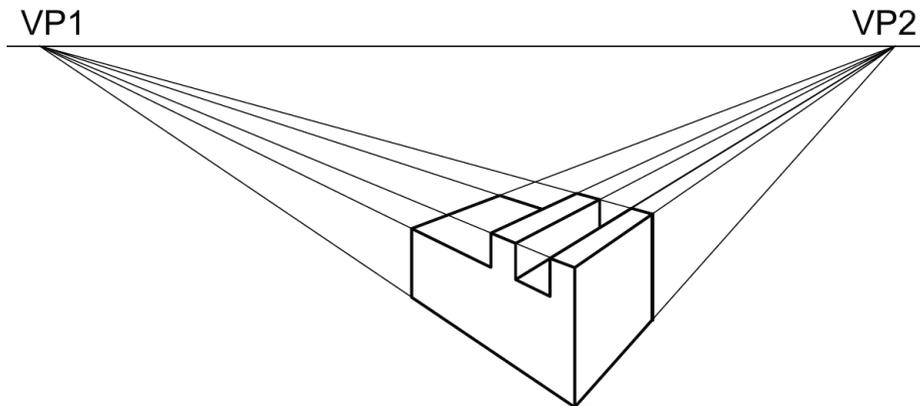


Figure 4.29 Two-point perspective

6.3 Three-Point Perspective

Three-Point perspectives show the object positioned at a certain angle relative to the projection plane, making lines that show depth converge to one of the vanishing points, as with two-point perspectives. In this case, all vertical edges of the object will converge to a third vanishing point located above or below the object. See Figure 4.30 for an example.

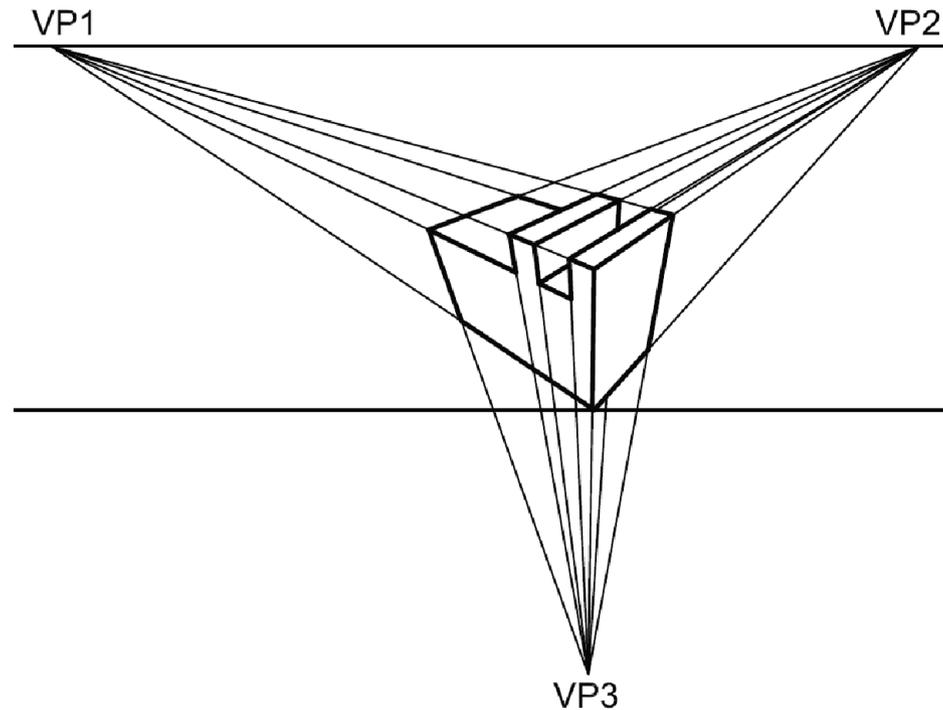
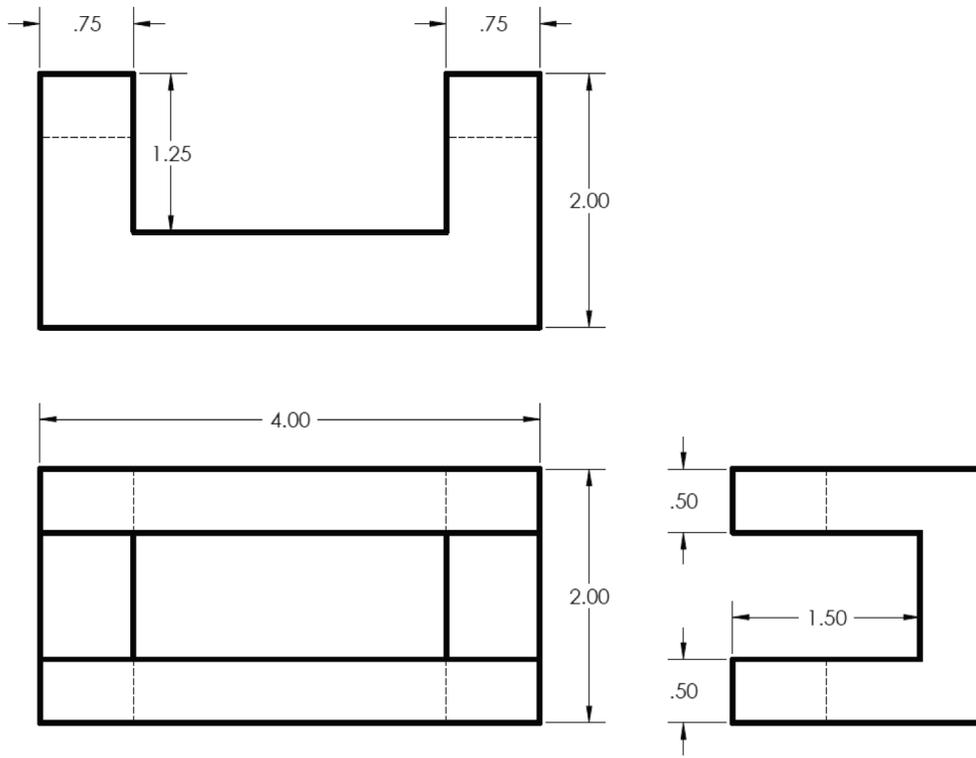


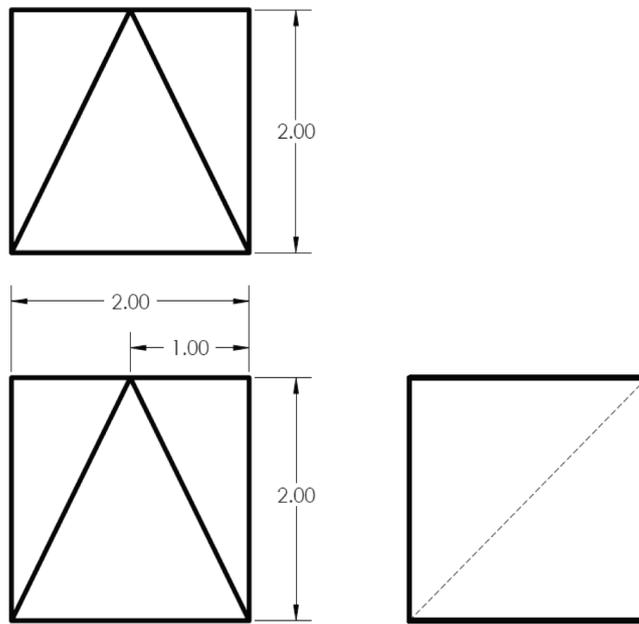
Figure 4.30 Three-point perspective

Practice Test

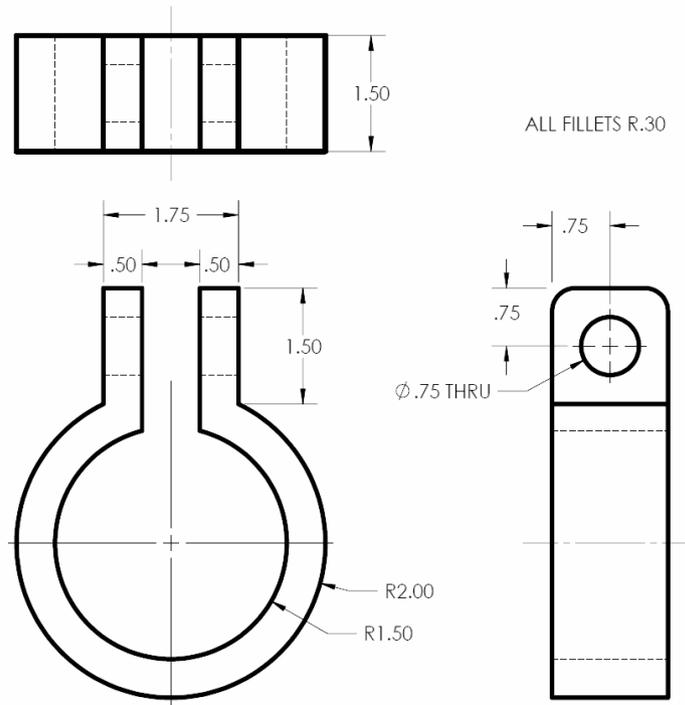
- 1. Which type of sketch is not a pictorial?**
A) Trimetric B) Cavalier oblique C) Multi-view D) One-point perspective E) Axonometric
- 2. Which of the following is not a parallel projection?**
A) Cabinet oblique B) Multi-view C) Dimetric D) Isometric E) Two-point perspective
- 3. In what type of oblique drawing is depth represented true size?**
A) Cavalier B) Cabinet C) General D) Trimetric E) None of the above
- 4. What type of sketch requires the use of vanishing points?**
A) Isometric B) Multi-view C) Perspective D) Oblique E) None of the above
- 5. Which of the following receding angles is not commonly used in oblique drawings?**
A) 30° B) 45° C) 60° D) 90° E) None of the above
- 6. In a dimetric drawing, the lines of sight travel _____ to each other and _____ to the picture plane.**
A) Parallel, parallel
B) Parallel, perpendicular
C) Perpendicular, parallel
D) Perpendicular, perpendicular
E) None of the above
- 7. Circles in a real object will appear as _____ in an isometric drawing.**
A) Circles B) Ellipses C) Depends on the orientation D) Arcs E) None of the above
- 8. What is the value of the isometric axis angle?**
A) 60° B) 90° C) 120° D) 180° E) None of the above
- 9. In isometric drawings, lines that are not parallel to any of the isometric axes will appear _____.**
A) Foreshortened B) True size C) Hidden D) Stretched E) A and D are correct
- 10. Which is the most realistic type of pictorial?**
A) Isometric B) Perspective C) Oblique D) Multi-view E) None of the above



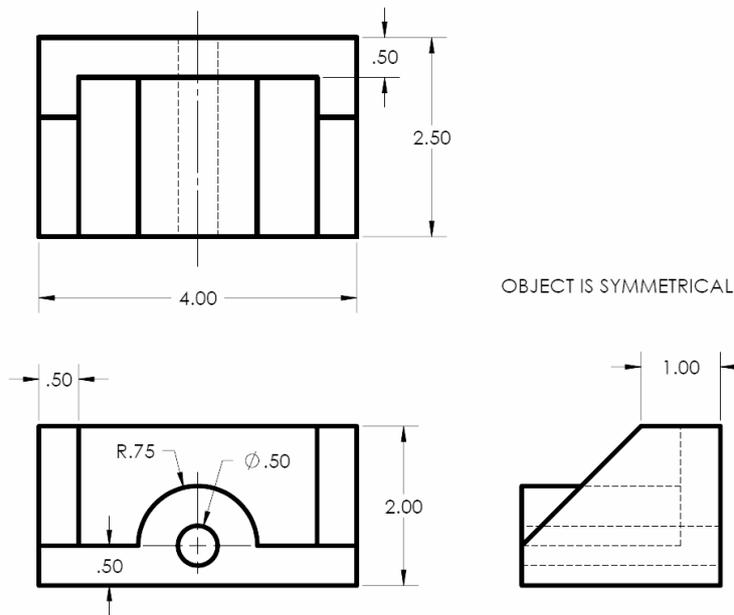
Problem 3



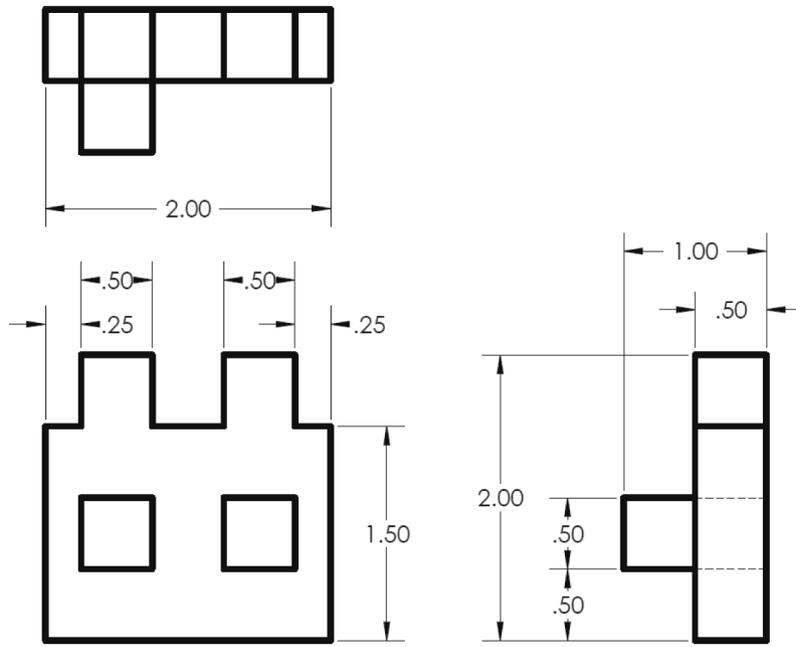
Problem 4



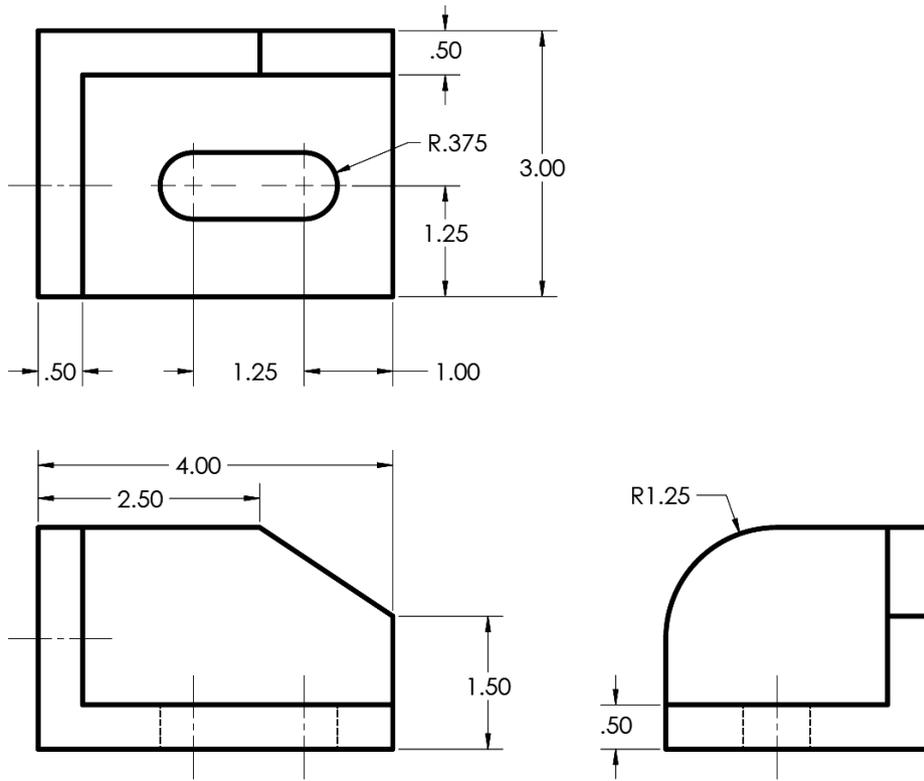
Problem 5



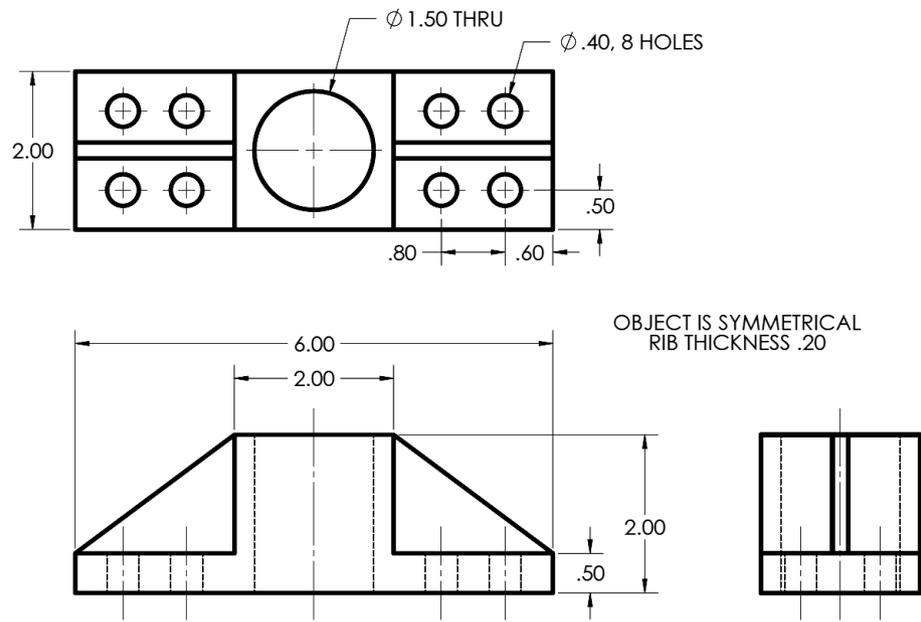
Problem 6



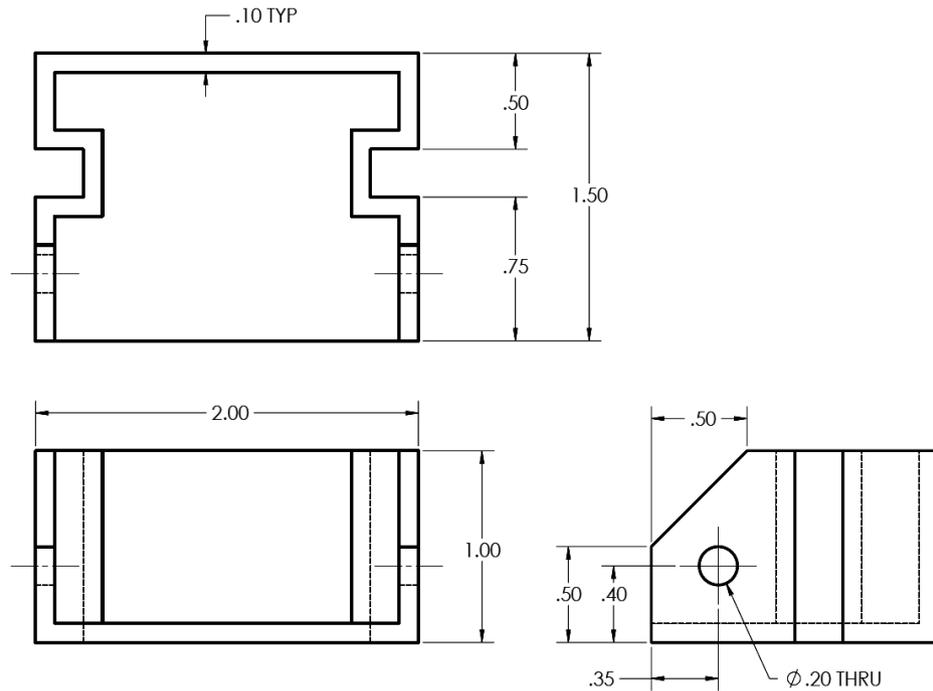
Problem 7



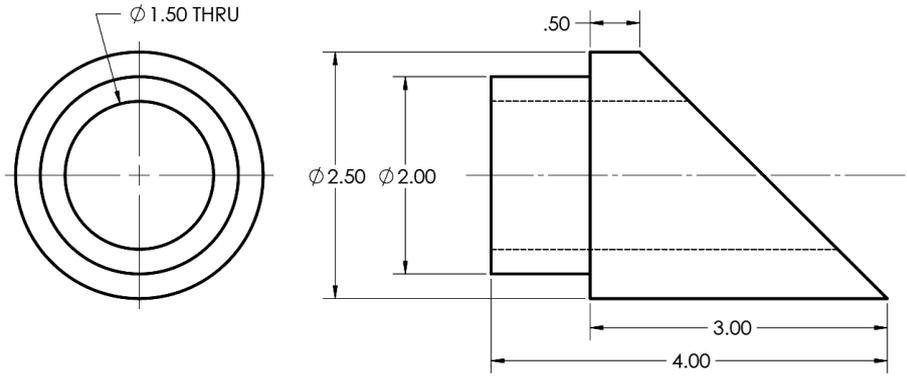
Problem 8—Corner Support



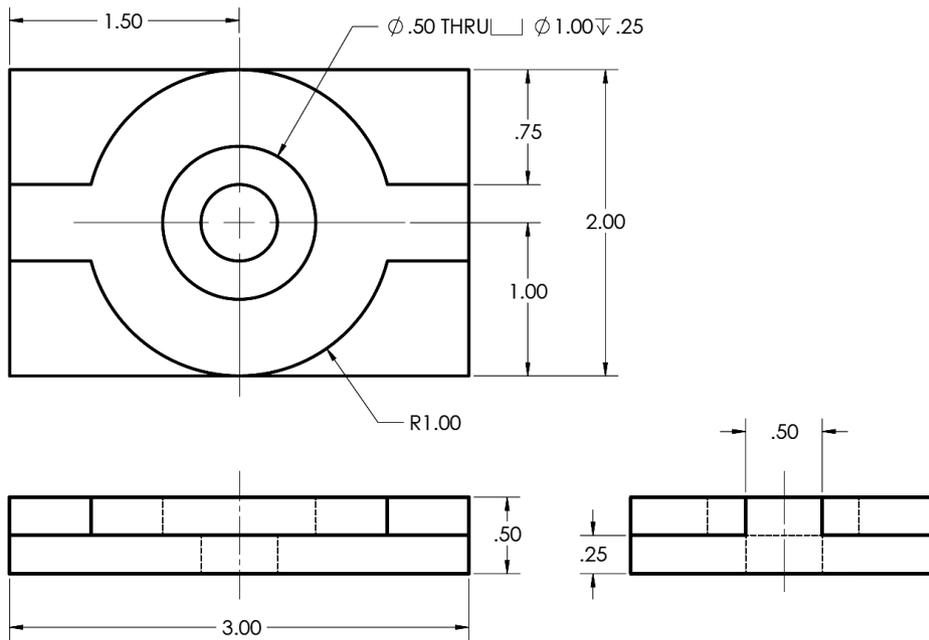
Problem 9—Pole Support



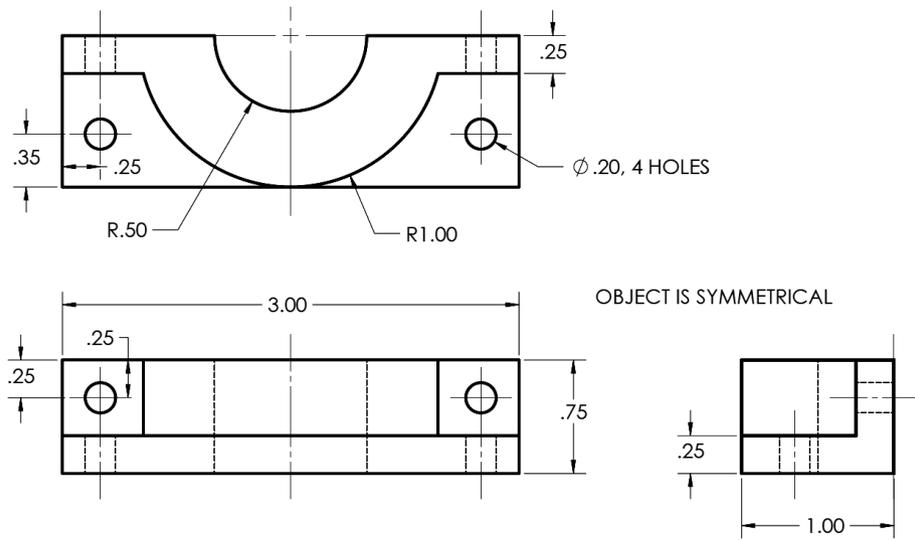
Problem 10—Platform



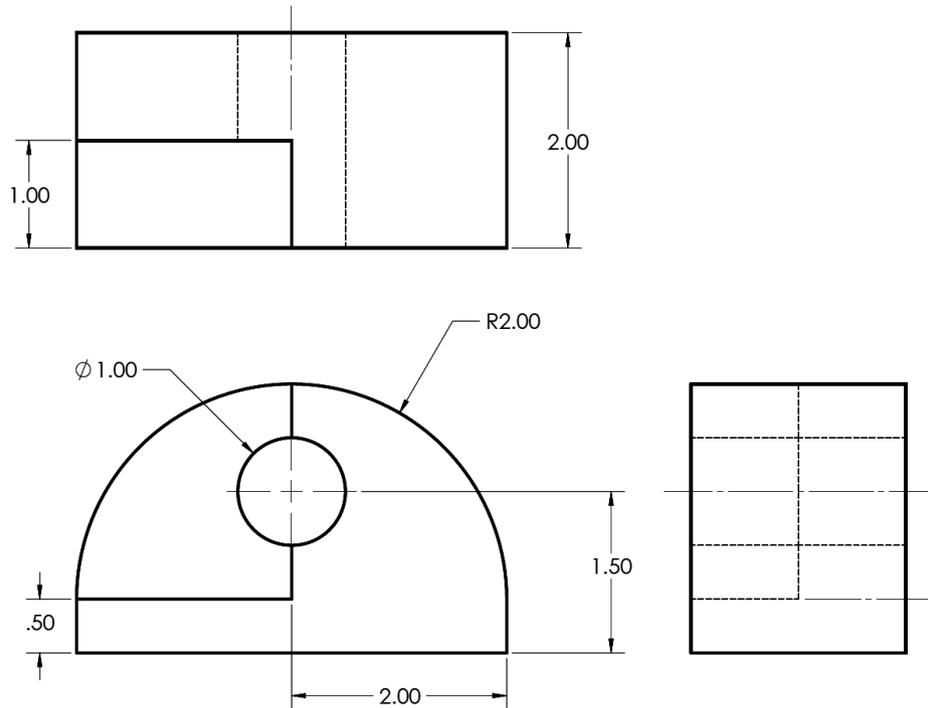
Problem 11—Wedge



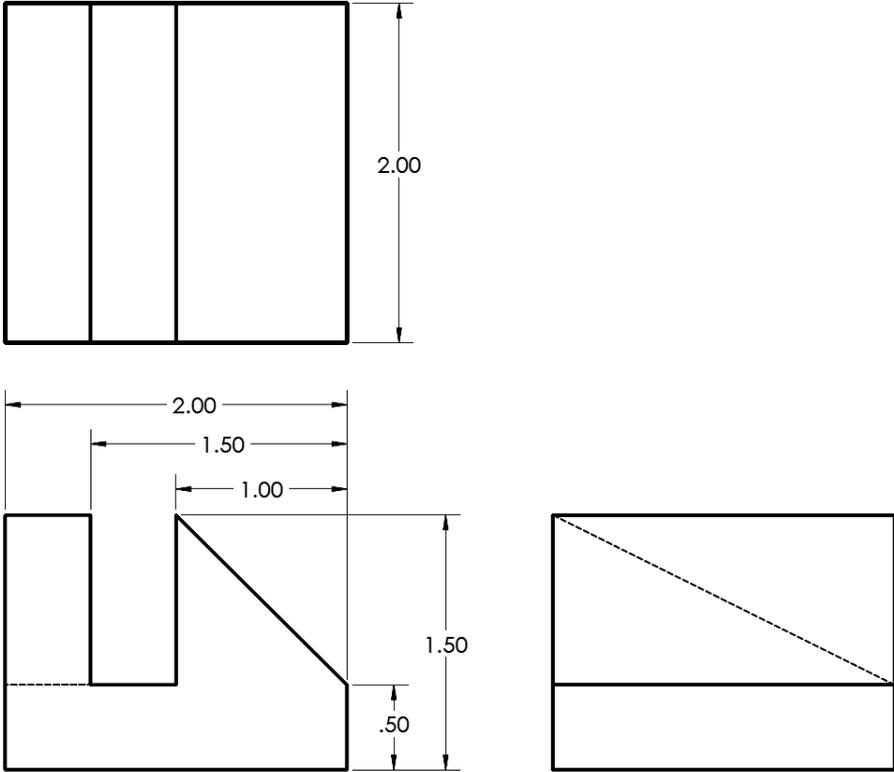
Problem 12—Support



Problem 13—Bracket



Problem 14



Problem 15