Chapter Objectives

- **Locate** points in three-dimensional (3D) space.
- **Identify** and describe the three basic types of lines.
- **Identify** and describe the three basic types of planes.
- **Solve** descriptive geometry problems using board-drafting techniques.
- **Create** points, lines, planes, and solids in 3D space using CAD.
- **Solve** descriptive geometry problems using CAD.

**Plane Spoken** Rutan’s unconventional 202 Boomerang aircraft has an asymmetrical design, with one engine on the fuselage and another mounted on a pod. What special allowances would need to be made for such a design?
Efficient travel through space has become an ambition of aeronautical engineer, Burt Rutan. “I want to go high,” he says, “because that's where the view is.” His unconventional designs have included everything from crafts that can enter space twice within a two week period, to planes that can circle the Earth without stopping to refuel.

Designed by Rutan and built at his company, Scaled Composites LLC, the 202 Boomerang aircraft is named for its forward-swept asymmetrical wing. The design allows the Boomerang to fly faster and farther than conventional twin-engine aircraft, having corrected aerodynamic mistakes made previously in twin-engine design. It is hailed as one of the most beautiful aircraft ever built.

**Academic Skills and Abilities**
- Algebra, geometry, calculus
- Biology, chemistry, physics
- English
- Social studies
- Humanities
- Computer use

**Career Pathways**

Engineers should be creative, inquisitive, analytical, detail oriented, and able to work as part of a team and to communicate well. They must have a bachelor's degree in engineering and be licensed in the state in which they work.

Go to glencoe.com for this book’s OLC to learn more about Burt Rutan.
Connect  Understanding basic geometric constructions prepares you to use geometry in solving design problems. You have already learned how to solve design problems using auxiliary views. How do you think geometric constructions will help you?

Content Vocabulary
- descriptive geometry
- slope
- bearing
- azimuth
- grade
- point projection

Academic Vocabulary
Learning these words while you read this section will also help you in your other subjects and tests.
- structure
- identify

Graphic Organizer
Use a chart like the one below to organize notes about points, lines, and planes.

<table>
<thead>
<tr>
<th>Points</th>
<th>Lines</th>
<th>Planes</th>
</tr>
</thead>
</table>

Go to glencoe.com for this book’s OLC for a downloadable version of this graphic organizer.
Elements of Descriptive Geometry

What are the basic elements of descriptive geometry?

The designer who works with an engineering team can help solve problems by producing drawings made of geometric elements. Geometric elements are points, lines, and planes defined according to the rules of geometry. Every structure has a three-dimensional (3D) form made of geometric elements (see Figure 10-1). To draw three-dimensional forms, you must understand how points, lines, and planes relate to each other in space to form a certain shape. Problems that you might think need mathematical solutions can often be solved instead by drawings that make manufacturing and construction possible.

Descriptive geometry is one method a designer uses to solve problems. It is a graphic process for solving three-dimensional problems in engineering and engineering design. In the eighteenth century, a French Mathematician, Gaspard Monge, developed a system of descriptive geometry called the Monge method. Its purpose was to solve spatial problems related to military structures. The Monge method has changed over the years, but engineering schools throughout the world still teach its basic principles. By studying descriptive geometry, you develop a reasoning ability that helps you solve problems through drawing.

Most structures that people design are shaped like a rectangle. This happens because it is easy to plan and build a structure with this shape. But this chapter presents a way to draw that lets you analyze all geometric elements in 3D space. Learning to see geometric elements this way makes it possible for you to describe a structure of any shape. See Figure 10-2 for examples of the basic geometric elements and some of the geometric features commonly found in engineering designs.

### Points

How do points help solve problems regarding drawing lines?

A point is used to identify the intersection of two lines or the corners on an object. A point can be thought of as having an actual physical existence. On a drawing, you can indicate a point with a small dot or a small cross. Normally, a point is identified using two or more projections. In Figure 10-3 on page 334, the normal reference planes are shown in a pictorial view with point 1 projected to all three planes. The reference planes are shown again in Figure 10-4 on page 334. When the three planes are unfolded, a flat two-dimensional (2D) surface is formed. V stands for the vertical (front) view; H stands for the horizontal (top) view; and P stands for the profile (right-side) view.

Points are related to each other by distance and direction as measured on the reference planes. In Figure 10-5, you can see the height dimensions in the front and side views,
Figure 10-2
Basic geometric elements and shapes

Figure 10-3
Locating and identifying a point in space

Figure 10-4
The point from Figure 10-3 identified on the unfolded reference planes
location only, a line has location, direction, and length. You can determine a straight line by specifying two points or by specifying one point and a fixed direction. However, plotting irregular curves is somewhat more difficult and must be done very carefully.

**The Basic Lines**

Lines are classified according to how they relate to the three normal reference planes. The three basic types of lines are normal, inclined, and oblique.

**Normal Lines**

A *normal line* is one that is perpendicular to one of the three reference planes. It projects onto that plane as a point (see Figure 10-6). If a normal line is parallel to the other two reference planes (see Figure 10-7), it is shown at its *true length* (TL).

**Inclined Lines**

An *inclined line*, like a normal line, is perpendicular to one of the three reference planes. However, it does not appear as a point in that plane but at its true length (see Figure 10-8). In all other planes, it appears foreshortened.
Oblique Lines

An oblique line appears inclined in all three reference planes as in **Figure 10-9**. It forms an angle other than a right angle with all three planes. In other words, it is not perpendicular or parallel to any of the three planes. The true length of an oblique line is not shown in any of these views. Also, the angles of direction cannot be measured on the normal reference planes.

True Length of Oblique Lines

Normal lines and inclined lines project parallel to at least one of the normal reference planes. A line parallel to a reference plane shows true length in that plane. Because an oblique line is not parallel to any of the three normal reference planes, you must use an auxiliary reference plane that is parallel to the oblique line to show its true length (see **Figure 10-10**). The auxiliary reference plane must be perpendicular to its normal reference plane, as shown in **Figure 10-11**.

**Figure 10-8**

Inclined lines are parallel to one reference plane and show their true length in that plane only.

**Figure 10-9**

Oblique lines appear inclined in all projections, so their true length cannot be determined from the normal reference planes.

**Figure 10-10**

The true length of an oblique line can be found by auxiliary projection. Reference planes can be placed parallel to the vertical projection (A), the profile projection (B), or the horizontal projection (C).
**Reading Check**

**Contrast** How do a normal line and an inclined line differ?

**Parallel Lines**

See Figure 10-12 for the relationship of parallel lines in a three-view study. Line projections are parallel if they appear parallel in all three reference planes. See Figure 10-13 for an example in which the lines seem parallel in the front and top views but are not parallel in the side view.

**Intersecting Lines**

If two lines intersect, they have at least one point in common. Refer to Figure 10-14 for the alignment needed to check the point of intersection of two straight lines. Lines 1-2 and 3-4 intersect at point O because point O aligns vertically in the H and V projections. Now look at lines 5-6 and 7-8 in Figure 10-15. Do the two lines intersect? They do not because the points of intersection in the H and V projections are not aligned. The intersection appears to be at point X in the V projection, but it appears to be at point Y in the H projection. Thus, the two lines do not intersect in 3D space.
Perpendicular Lines

To determine whether two lines are perpendicular, you must find the true length of one of the lines. In the projection in which one of the lines is at true length, the angle between the lines appears in its true size. Therefore, you can see whether the angle between the lines is actually a right angle.

For example, in Figure 10-16A, line 1-2 is parallel to two principal reference planes, so it appears at true length in the vertical projection. In this projection, you can see that line 1-2 and line 3-4 are indeed perpendicular.

In Figure 10-16B, lines 1-2 and 2-3 are oblique in the H and V projections. You must use an auxiliary projection to view one of the lines at true length. In Figure 10-16B, line 2-3 is shown at true length in an auxiliary projection. In the auxiliary, you can see that the two lines are truly perpendicular.

Industrial Applications of Lines

It may seem that lines drawn on paper mean little and are worth little. However, they do reflect real things, and industry at all levels uses them every day. For example, in areas such as navigational, architectural, and civil engineering, drafters refer to the slope, bearing, azimuth, and grade of a line.

Slope

A line’s slope is its angle from the horizontal reference plane. Slope is measured in degrees. In Figure 10-17, the true slope of a line is shown in the front view when the line is at true length. To find the slope of an oblique line at true length, use an auxiliary projection perpendicular to a horizontal reference plane. Slope is often used to describe nonvertical or nonhorizontal walls and other features that are not parallel to the normal reference planes.

Azimuth and Bearing

You may have heard the terms bearing and azimuth in connection with aviation. People who use navigational instruments use these terms to describe the position and direction of aircraft in the air. The angle a line
makes in the top view with a north-south line is its bearing. See Figure 10-18A. The north-south line is generally vertical, with north at the top. Therefore, right is east and left is west. Make the measurement in the horizontal projection. Dimension it in degrees (see Figure 10-18B).

A measurement that defines the direction of a line off due north is the azimuth. It is always measured off the north-south line in the horizontal plane. It is dimensioned in a clockwise direction (see Figure 10-19).

### Grade

The percentage by which land slopes is known as its grade. Architectural, civil, and construction engineers specify the grade of land prepared for specific purposes. For example, civil engineers must make certain that the grade of roads built in mountainous areas is not too steep. See Figure 10-20 for the scale for a highway with a +12% grade. The grade rises 12’ (3.6 m) in every 100’ of horizontal distance.
Planes
What are the important characteristics of planes?

As a line moves away from a fixed place, its path forms a plane. In drawings, planes are thought of as having no thickness. Like true lines, they are infinite—they extend forever in each direction.

A plane can be determined by any of the following combinations:

- intersecting lines
- two parallel lines
- a line and a point
- three points not in a straight line
- a triangle or any other planar (2D) surface, such as a 2D polygon

The Basic Planes

Planes are classified according to their relation to the three normal reference planes. The three basic types of planes are normal, inclined, and oblique planes. As you read the following descriptions, notice that they closely parallel the descriptions of normal, inclined, and oblique lines.

Normal Planes

A normal plane is parallel to one of the normal reference planes and perpendicular to the other two. Planes appear as edge views when they are perpendicular to a reference plane. Recall that the edge view of a plane appears as a line.

See Figure 10-21 for three examples of normal planes. In Figure 10-21A, plane 1-2-3 is parallel to the vertical reference plane and perpendicular to the horizontal and profile.
perpendicular to the horizontal and profile planes. In **Figure 10-21B**, the plane is parallel to the horizontal reference plane and perpendicular to the vertical and profile planes. In **Figure 10-21C**, the plane is parallel to the profile reference plane and perpendicular to the vertical and horizontal planes.

**Inclined Planes**

An *inclined plane* is perpendicular to one reference plane and inclined to the other two. It is perpendicular to the reference plane in which it shows as an edge view. In the other two reference planes, it appears as a foreshortened surface.

**Figure 10-22** shows examples of inclined planes. In **Figure 10-22A**, inclined plane 1-2-3 is perpendicular to the vertical reference plane. It is inclined to the horizontal and profile planes, where it is foreshortened. **Figure 10-22B** shows an inclined plane that is perpendicular to the horizontal reference plane, where it shows as a line. The other two reference planes show the plane foreshortened. In **Figure 10-22C**, the inclined plane is perpendicular to the profile reference plane, where it shows as a line. The plane shows as a foreshortened surface in the other two reference planes.

**Oblique Planes**

An *oblique plane* is inclined to all three reference planes. An example is shown in **Figure 10-23A** on page 342. Because the oblique plane is not perpendicular to any of the three main reference planes, by definition it cannot be parallel to any of those planes. Thus, it shows as a foreshortened plane in each of the three regular views. **Figure 10-23B** on page 342 shows the same oblique plane in a 3D pictorial rendering.

**Reading Check**

Explain how the characteristics of normal, inclined, and oblique planes differ.

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**Figure 10-22**

Inclined planes perpendicular to the vertical plane (A), horizontal plane (B), and profile plane (C)
Board-Drafting Techniques

What must you know to solve problems in descriptive geometry?

Now that the basic geometric constructions have been described, you may concentrate on using the geometry to solve problems. The board drafting techniques for solving problems in descriptive geometry are much different from the CAD techniques. The difference is due to the CAD software's ability to work in three dimensions. But it is important to be able to solve 3D problems without the aid of a computer.

This section begins with rather simple operations and proceeds to describe the solutions to more complex problems. It should become clear as you work through the problems that Chapters 9 and 10 are closely related. Almost all problems in descriptive geometry can be worked out using auxiliary planes. You can solve problems by knowing how to find the following:

- true length of a line
- point projection of a line
- edge view of a plane
- true size of a plane figure

The ability to understand and solve these problems will build the visual powers necessary for moving on to design problems.

Point on a Line

In Figure 10-24A, line AB on the vertical plane has a point X. To place the point on the line in the other two reference planes, project construction lines perpendicular to the folding lines, as shown in Figure 10-24B.

Note that by using just one view, you cannot tell whether a point is located on a line. It may seem to be on a line in one view, but another view may show that it is really
view may show that it is really in front, on top, or in back of the line (see Figure 10-25).

**Line in a Plane**

A line lies in a plane if it (1) intersects two lines of the plane or (2) intersects one line of the plane and is parallel to another line of that plane. In Figure 10-26A, line RS must be a part of plane ABC because R is on line AB and S is on BC in all three reference planes. You know that line RS is an oblique line because it is not parallel to any of the normal reference planes and is clearly not perpendicular to the reference planes.

In Figure 10-26B, horizontal line MN is constructed in the vertical projection of plane ABC. A line that is horizontal in the vertical projection is known as a *level line*. Projecting MN to the other reference planes shows that it is an inclined line. The top view shows the true length.

In Figure 10-26C, line XY is constructed parallel to the H/V folding line in the horizontal reference plane. Projected into the vertical plane, it shows as an inclined line in true length. This line is called a *frontal line* because it is parallel to the vertical plane.
**Figure 10-26D** shows vertical line EF constructed within the plane ABC. It is called a *profile line* because it is parallel to the profile reference plane. Projecting line EF to the profile reference shows the line in true length.

**Point in a Plane**

To locate a point in a plane, project a line from the point to the edges of the plane in which it lies. In **Figure 10-27A**, point O is on plane ABC. Project line AX, which contains point O, as shown in **Figure 10-27B**. Then project line AX to ABC in the horizontal reference plane, as shown in **Figure 10-27C**. Locate point O on the line by drawing a vertical projection to line AX in the horizontal reference plane.

**Point View of a Line**

A normal line projects as a point on the plane to which it is perpendicular. In **Figure 10-28A**, line AB is a normal line—it is parallel to the horizontal and profile reference planes. It therefore shows as a point in the vertical reference plane. In **Figure 10-28B** and C, the same conditions exist. The line projects as a point on the horizontal plane (B) and in the profile plane (C).

An inclined line projects as a point to an auxiliary plane (see **Figure 10-29A**). Place a reference plane perpendicular to the inclined line at a chosen distance and label it H/1 as in **Figure 10-29B**. Transfer distance D as shown for a vertical or a horizontal auxiliary projection.

To project an oblique line as a point, use two auxiliary projections. Set up the first auxiliary reference plane parallel to the oblique line (see **Figure 10-30A**). Then find the true length. Place the secondary auxiliary reference plane perpendicular to the true-length line of the first auxiliary. Locate the point projection by transferring distance X (see **Figure 10-30B**).
Distance Between Parallel Lines

**Point projection** is one way to show the true distance between two parallel lines. In Figure 10-31, the parallel lines MN and RS are oblique. Two auxiliary projections are needed to find the point projections. The first auxiliary reference plane H/1 is parallel to MN and RS. In this plane, lines MN and RS are shown at true length. The second auxiliary reference plane H/2 is perpendicular to the true-length lines in the first auxiliary. The distance between the point projections of the lines is a true distance.

See Figure 10-32 for a second way to find the distance between two parallel lines. Think of lines AB and CD as parts of a plane. Connect points A, B, C, and D to form the plane. Draw a horizontal line DX in the top view and project point X into the vertical view. Then draw line DX in the vertical plane. Draw...
the first auxiliary plane V/1 perpendicular to DX in the vertical view. Find the edge view of plane ABCD by transferring distances 1, 2, 3, and 4 as shown. The secondary auxiliary V/2 shows the true lengths of AB and CD because plane ABCD is in true size in this view. Measure the true distance between the lines perpendicularly from AB to CD as shown.

**Distance Between a Point and a Line**

To find the shortest distance from a point to a line, project the line as a point. In Figure 10-33, project point A and oblique line CD into the first auxiliary projection H/1. In H/1, label the true length of line CD. Place the secondary auxiliary H/2 perpendicular to line CD, and project line CD as a point in this plane. As shown, the distance between points in this projection is true length.

**Shortest Distance Between Skew Lines**

In Figure 10-34A, lines AB and CD are skew lines. That is, the two lines are not parallel, do not intersect, and are both oblique. The shortest distance between these two lines is a perpendicular line between one line and the point view of the other line.

To find the shortest distance between lines AB and CD in Figure 10-34, first find the true length of CD in the first auxiliary. Do this by placing a V/1 reference line parallel to line CD. See Figure 10-34B. Place the secondary auxiliary reference 1/2 perpendicular to the true length of line CD. Find the point projection of line CD and extend line AB as shown. Then construct a perpendicular line from the point projection of CD to line AB. Extend line AB so that it intersects the perpendicular line at point X. Then transfer the intersecting projection back to the first auxiliary, as shown on the extension of line AB.

**True Size of an Inclined Plane**

In Figure 10-35, plane ABC shows as an edge view in the top view. Place the auxiliary reference plane H/1 parallel to the edge view and make perpendicular projections. Transfer the distances X, Y, and Z as shown to find the true size of the plane in the first auxiliary projection.
**True Size of an Oblique Plane**

When plane ABC in **Figure 10-36A** is projected onto a plane perpendicular to any line in the figure, it shows an edge view in the first auxiliary. In the top view, draw a line BX parallel to the reference plane. Place reference line V/1 perpendicular to the front view of BX. Project the front view of BX into a point projection in the first auxiliary. The point projection is in the edge view of plane ABC as shown. Place the second auxiliary reference line V/2 parallel to the edge view, as shown in **Figure 10-36B**. The projection of plane ABC in the secondary auxiliary shows the true size.

**True Angles Between Lines**

When two lines show at true length, the angle between them appears in its true value. In **Figure 10-37A**, the two lines show as an inclined plane. This is so because the vertical view shows that lines AB and AC coincide, or lie, in a single line. Place the V/1 auxiliary reference parallel to the two lines in the vertical view. The auxiliary view shows the two lines at true length, so it also shows the true angle between the lines.
In Figure 10-37B, oblique lines MS and NS do not show in an edge view. To find the angle between the lines, use two auxiliary planes. The first reference plane is perpendicular to the plane formed by lines NA and MS. The second reference plane is parallel to the first auxiliary view. That is, it is parallel to the edge view of lines MN and NS. The secondary auxiliary view shows MN and NS at true length, so the angle between the two lines is in true size.

**Section 10.1 Assessment After You Read**

**Self-Check**

1. **Explain** how to identify points in three-dimensional (3D) space.
2. **List** and describe the three basic types of lines.
3. **List** and describe the three basic types of planes.
4. **Describe** how to use board techniques to solve descriptive geometry problems.

**Academic Integration Mathematics**

5. **Calculate Grade** George is working as an assistant drafter to a civil engineer working on a new road that will go up a mountain. If he is allowed a +12% grade to keep the road from becoming too steep, how much can the grade rise over a horizontal distance of 6,500′?

   Use Variables and Operations

   If a 12% grade equals a 12′ rise for every 100′ feet of horizontal distance, then the problem can be solved with the equation $12x = 6,500$, where $x$ is the distance the grade will rise.

   **Drafting Practice**

6. In Figure 10-38, find the true length of line AB. Determine the true length and slope of line CD. This problem is laid out on a grid. Assume that the size of the larger squares is .5″. Some of the .5″ squares have been subdivided into .125″ squares.

   **Figure 10-38**

   Go to glencoe.com for this book’s OLC for help with this drafting practice.
Connect As you read this section, use notetaking methods to organize information and then develop an outline of important points.

Content Vocabulary
- user coordinate system

Academic Vocabulary
Learning these words while you read this section will also help you in your other subjects and tests.
- previous

Graphic Organizer
Use a chart like the one below to organize notes about solving descriptive geometry problems using CAD.

Academic Standards

English Language Arts
Use written language to communicate effectively (NCTE)

Mathematics
Geometry Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships (NCTM)
Measurement Apply appropriate techniques, tools, and formulas to determine measurements (NCTM)
Using 3D Coordinate Systems with CAD

What advantage does CAD have over board drafting in solving descriptive geometry problems?

You can use CAD in two ways to solve descriptive geometry problems. First, you can use a CAD system to solve problems exactly as you do using board techniques. That is, you can create 2D auxiliary views and revolutions to solve the problems. To use this technique, you can use the commands and techniques you learned in previous chapters. Follow the directions given in Section 10.1 to solve the problems.

However, it is more practical to use the full power of the CAD system to solve descriptive geometry problems. CAD programs have several commands that allow you to perform location and identification procedures without building elaborate geometric constructions. To solve descriptive geometry problems using CAD, create a 3D model and simply apply the appropriate commands.

As you may recall from Chapter 6, working in 3D space requires the addition of a depth axis to the standard 2D Cartesian coordinate system. Figure 10-39 shows the relationship of the X, Y, and Z coordinates used in 3D drawing.

The World Coordinate System

By default in AutoCAD’s 2D workspaces, the computer screen is parallel to the plane formed by the X and Y axes, and the Z axis is perpendicular to the screen. The origin (intersection of the axes) is at the bottom left corner of the drawing area. In other words, the top right quadrant (quadrant I) of the Cartesian coordinate system is visible. The shaded portion of Figure 10-39 represents quadrant I. This default viewing configuration is known in AutoCAD as the world coordinate system (WCS).

User Coordinate System

Most CAD programs allow you to define new coordinate systems as necessary. In AutoCAD, a user coordinate system (UCS) is a user-defined orientation of the X, Y, and Z axes of the Cartesian coordinate system. Using the UCS command, you can align a new UCS with any planar object, which means that you can create a special UCS to use with any auxiliary plane you may need.

Two of the most often used options of the UCS command are the Origin option and the 3 Points option. Both options are available on the UCS toolbar. The Origin option allows you to move the origin (coordinates 0,0,0) to any point in 3D space without changing the orientation of the axes. The 3 Points option allows you to specify a new origin and a new UCS by choosing a point on the positive X axis and a point on the positive Y axis.

UCS Icon

Notice the X and Y arrows at the bottom left corner of the drawing area. They make up the UCS icon. Its purpose is to show the current orientation of the coordinate system. The lines and arrows show the position of the X, Y, and Z axes. When the WCS is the current system, you cannot see the Z arrow because it points straight back perpendicular to the screen. However, the UCS icon can be very useful when you have defined one or more user coordinate systems. It helps keep you oriented to the current system.
Drawing in Three Dimensions

Why is drawing objects in 3D space helpful for solving descriptive geometry problems in CAD?

CAD programs provide many ways to draw objects in 3D space. In AutoCAD, these include:

- drawing objects with a specified thickness
- extruding 2D objects
- specifying XYZ coordinates
- using solid primitives (solid shapes that are predefined in the software)

Specifying Thickness

AutoCAD’s THICKNESS command provides an easy method to create 3D objects. THICKNESS adds a specific depth to a two-dimensional object (see Figure 10-40). However, it is not strictly a drawing command. Instead, it is used to set the thickness of an object before beginning to draw. Then you can use many of the same commands you would use to draw a 2D object.

Practice using the THICKNESS command by creating a 5 × 5 × 5-inch cube. Create a practice drawing file, set Snap and Grid to .5, and ZOOM All. Then follow these steps:

1. Enter the THICKNESS command. Notice that the default thickness is 0. This setting creates 2D objects. To create the cube, change the thickness to 5.
2. Use the LINE or PLINE command to draw a 5-inch square.
3. Reenter the THICKNESS command and set the thickness to 0.

Because the thickness is set to 5, you have created a 5-inch cube. It looks like a simple square because you are viewing it from the default viewpoint. Next you will change the viewpoint to see the entire cube.

Setting the Viewpoint

To view the cube you just created from a different angle, you can use one of AutoCAD’s preset views or create a new viewpoint manually. Follow these steps to explore the preset view options.

1. From the View menu at the top of the screen, select 3D Views and then SE Isometric. This displays the cube from a southeast isometric position (see Figure 10-41). Notice the position of the grid in this view.
2. Repeat step 1, but this time select one of the other preset views. Experiment until you are familiar with the various preset opportunities.
3. To return to the default view, enter the PLAN command and select W for WCS. Enter ZOOM All to see the entire drawing area. This view is known as the plan view.

The other way to specify a viewpoint is to use the 3DORBIT command. This command provides more flexibility. You can view the object literally from any point in 3D space. Just enter the 3DORBIT command, pick with the mouse, and move the cursor slowly to view the object from any direction.

Summarize How do you use CAD's THICKNESS command to create 3D objects?
Extruding a 2D Object

It is also possible to extrude a 2D object to give it depth. This method is similar to specifying a thickness, but there are some differences. Unlike the THICKNESS command, AutoCAD’s EXTRUDE command works on objects that have already been created. Also, the EXTRUDE command allows you to specify a taper. Figure 10-42 shows the effect of extruding an object with and without a taper. In addition, EXTRUDE works with RECTANGLE and POLYGON as well as LINE and PLINE. This makes the extrusion process more flexible than simply specifying a thickness.

The following procedure provides practice in extruding an object and forms the basis for a descriptive geometry problem later in the chapter. Follow these steps:

1. From the View menu, select 3D Views and SE Isometric. This will allow you to see what you are doing in 3D.
2. Use the POLYGON command to create a pentagon inscribed in a Ø.7 circle.
3. Enter the EXTRUDE command and select the pentagon. Specify an extrusion height of 2 and a taper of 5.

Specifying Individual Coordinates

Another way to create 3D objects is to determine the XYZ coordinates of each defining point on the object and then draw the lines individually. This method is extremely time consuming for complex mechanical assemblies and should be used only if there is a very good reason for not using a different method used instead. However, for geometric problem solving, coordinate specification is the perfect way to locate points in a drawing.

The following procedure uses the coordinate method to define a plane that is oblique to the standard view.

1. Enter the LINE command. At the prompt, enter the following sets of absolute XYZ coordinates, pressing Enter after each set. Do not type spaces between the commas and numbers.
   5,1,.5  
   4,2,1.5  
   7,6,2  
   8,5,0  
   5,1,.5
2. Use 3DORBIT or a series of preset views to view the plane from several angles. As you can see, the plane is oblique to the X, Y, and Z axes.
3. Enter PLAN and W to return to the plan view. The plane looks like a slightly out-of-kilter rectangle in this view.

Recall What effect does extrusion have on a 2D object?
Solving Descriptive Geometry Problems

How do CAD commands help to solve descriptive geometry problems?

Once you have created a 3D object in a CAD system, solving descriptive geometry problems is a fairly easy task. Next you will use the pentagonal solid and the plane you just created to solve some representative problems.

Locating Points

To identify the exact location of a point in 3D space, use the ID command. This command identifies the exact X, Y, and Z coordinates of the point you specify. To demonstrate this, enter the POINT command and use the Endpoint object snap to snap to one of the endpoints of the oblique plane you created earlier. Watch the Command line. The X, Y, and Z values AutoCAD displays should match one of the points you specified when you created the plane (see Figure 10-43).

Points can exist as single entities in AutoCAD. If you are attempting to locate a single point that is not on a defined line, you must change the setting of PDMODE so that you will be able to see the point. PDMODE is a system variable in AutoCAD that controls how points are displayed on the screen. Follow these steps:

1. Enter the POINT command. At the prompt, enter a coordinate value of −1,5.8,3 to place the point at that location.
2. Enter ZOOM All to be sure you can see the entire drawing. Can you see the point? Probably not. If you can see it at all, it is just a tiny speck on the screen.
3. Enter PDMODE and then a value of 3. This changes the point display to an X that is more easily visible. Now the position of the point is clear.
4. View the point from several viewpoints. What effect does the negative X value have on the position of the point?

You can use ID to identify the exact location of single points. To do so, be sure to use the Node object snap. ("Node" is another term for point.)

Determining the True Length of a Line

The true length of any line in 3D space can be determined easily in AutoCAD. Simply use the DIMALIGNED dimensioning command (Aligned Dimension button on the Dimension toolbar or Dashboard). Select the line whose true length you want to find, and place the dimension. The dimension text gives you the true length. After you have determined the true length, you can erase the dimension.

This method works from any viewpoint, but it is usually easier to see the result if you return to the plan view. Notice that you do not have to create complex auxiliary views to find the true length of a line in AutoCAD.

Determining Distances

AutoCAD’s DIST command provides a great deal of information about the relative positions of two points in 3D space. Follow these steps to find the true distance between two points on the oblique plane you created earlier.

1. Enter the DIST command.
2. For the first point, use the Endpoint object snap to snap to one of the endpoints of the plane.
3. For the second point, snap to the endpoint diagonally across the plane from the first point. The result is displayed on the Command line.

Note: If you cannot see the distance, press the F2 key to display a text screen. Review the information that is provided. You will then know the exact distance between the two points, the change (delta) on the X, Y, and Z axes, and the angles in and from the XY plane.

Section 10.2  Solving Descriptive Geometry Problems with CAD  351
Finding the Shortest Distance Between Skew Lines

As you will recall, skew lines are lines that are not parallel and do not intersect. The method for determining the shortest distance between two skew lines is similar to the method used in board drafting. Obtain the point view of one of the lines, and then draw a line from the point view to the other line. Use the Perpendicular object snap to ensure that the new line is perpendicular to the second line.

Identifying Piercing Points

Using AutoCAD, you can find the point at which a line pierces a plane regardless of the plane’s orientation. The following procedure creates an oblique plane and a line that passes through the plane and then demonstrates how to find the piercing point. Refer to Figure 10-44 and follow these steps:

1. Save the first practice drawing as directed by your instructor, and begin a new drawing.
2. Be sure that your UCS is set to World and that you are viewing the plan view. Then create an oblique plane ABC by specifying the following coordinate values:
   - 3,1,−2
   - 1,2,−3
   - 2,4,1
   - 3,1,−2
3. To create line MN piercing plane ABC, first move the UCS icon parallel to plane ABC. To do this, enter the UCS command and then enter 3 to enter the 3 Points option. (Recall that you can use three points to define a plane.) Locate the endpoints of plane ABC by snapping to point B, then point C, and then point A. The UCS icon jumps onto the lower left corner of the plane, which is now located at point B.
4. Create a line starting in front of plane ABC at coordinates 1.6,2,2 and ending at 1.6,2,−2. Notice that the only coordinate that changes is the Z coordinate. Drop line AP from the endpoint of A perpendicular to line MN. Enter the ID command and select the intersection of lines MN and AP, or select the point P. The coordinate value of that point should be 1.6,2,0. This is the point at which line MN intersects plane ABC.
5. To return to the WCS, enter the PLAN command and then W (for World).

Locating the Angle Between Intersecting Planes

The procedure for finding the angle between intersecting planes is similar to the procedure for finding the true length of a line. You can use the dimensioning command DIMANGULAR (the Angular button on the Dimension toolbar or Dashboard) to find the angle directly. You do not need to create auxiliary views.

Viewing the True Shape and Size of a Plane

Using AutoCAD’s dimensioning commands, you can dimension a plane correctly without actually seeing the plane in its true size and shape. However, you may find it necessary at times to view the true size and shape of an inclined or oblique plane. The easiest way to accomplish this is to define a user coordinate system that lies on the plane.

None of the five sides of the pentagonal object created earlier in this chapter is parallel to a normal viewing plane. To see the true shape and size of one of the sides, follow these steps:

1. Switch to the NE Isometric view of the drawing.
2. Enter the HIDE command to remove hidden lines. (This is not absolutely necessary, but it makes it easier to see and select the
points in the following steps. You may also want to move any interfering objects out of the way before you continue.)

3. Enter the UCS command. Enter N to create a new UCS. When the list of creation options appears, enter 3 (for 3point).

4. For the origin of the new UCS, use the Endpoint object snap to pick the bottom of one of the sides as in Figure 10-45A. For the point on the positive X axis, pick the bottom of the other side of the planar surface. For the point on the positive Y axis, pick the top of the line on which you specified the origin. Notice that the UCS icon moves to the new origin.

5. Enter the PLAN command, and enter C for Current UCS. You can see by the grid that the planar surface is now parallel to the screen. You are now viewing the true size and shape of the surface, as shown in Figure 10-45B.

Note: To return to the plan view of the WCS, enter the PLAN command and enter W for World.

Figure 10-45
Create a new UCS using the 3-point method. Specify the points as shown in (A). The plan view of the new UCS is aligned with the screen and shows one face of the solid at its true size and shape (B).

Section 10.2 Assessment After You Read

Self-Check

1. Summarize how to create points, lines, planes, and solids in 3D space with CAD.

2. Explain how to solve descriptive geometry problems with CAD.

Academic Integration English Language Arts

3. This section refers to the Cartesian coordinate system (p. 348). In your own words, define the system, using research resources if necessary, and explain how it can be viewed in AutoCAD.

Drafting Practice

4. In Figure 10-46, locate point D in the plan view (horizontal projection). Determine the length of line AD.

Figure 10-46
Go to glencoe.com for this book’s OLC for help with this drafting practice.
Chapter Summary

Section 10.1
- A point is used to identify the intersection of two lines or corners on an object.
- The basic types of lines are normal (perpendicular to one of the three reference planes), inclined (perpendicular to one of the three reference planes but does not appear as a point in that plane), and oblique (inclined in all three reference planes).
- The basic types of planes are normal (parallel to one of the normal reference planes and perpendicular to the other two planes), inclined (perpendicular to one reference plane and inclined to the other two), and oblique (inclined to all three reference planes).
- Understanding basic geometric constructions is crucial to solving 3D problems in descriptive geometry.

Section 10.2
- CAD programs allow drafters to work directly in 3D space, offering an alternative to traditional geometry methods.
- Preparation for solving descriptive geometry problems using CAD involves creating a 3D model and applying the appropriate commands related to the specific problems.
- Methods of drawing objects in 3D space using CAD include drawing objects with a specified thickness, extruding 2D objects, specifying XYZ coordinates, and using solid primitives.
- In AutoCAD, a user coordinate system command can be used to align a new UCS with any planar object, allowing you to create a special UCS to use with any auxiliary plane you need.

Review Content Vocabulary and Academic Vocabulary

1. Use each of these content and academic vocabulary terms in a sentence or drawing.

Content Vocabulary
- descriptive geometry (p. 333)
- slope (p. 338)
- bearing (p. 339)
- azimuth (p. 339)
- grade (p. 339)
- point projection (p. 345)
- user coordinate system (UCS) (p. 350)

Academic Vocabulary
- structure (p. 333)
- identify (p. 333)
- previous (p. 350)

Review Key Concepts

2. Explain how to locate points in three-dimensional (3D) space.
3. Describe the three basic types of lines.
4. Describe the three basic types of planes.
5. Summarize how to solve descriptive geometry problems using board-drafting techniques.
6. Outline how to create points, lines, planes, and solids in 3D space with CAD.
7. Explain how to solve descriptive geometry problems with CAD.
Technology

8. Discovering New and Emerging Technologies
Staying informed about new technologies is essential when working in a career such as mechanical drawing, which relies heavily on computers and digital imaging tools. What are some strategies to use when studying new technologies? Where can you find information about emerging trends that can enhance your career? How can you find more information about software updates from companies such as Autodesk? Using a word processing template, create a chart that shows types of technology in mechanical drawing along with resources to use to help stay up-to-date.

9. Information Processing
Most large companies have human resources departments that deal with personnel functions, such as recruiting, performance evaluation, and compensation. Contact a human resources professional at a local staffing agency and ask what responsibilities he or she has. How does an efficient human resources department benefit a company? Write a one-page summary of your findings.

Mathematics

10. Making Conversions
Imagine that you are working for a design firm that regularly uses English standard measurements. One of the firm’s clients needs to see measurements in metric. This client has asked you to convert the total length of the order from feet to meters. The total length in feet is 244. How many meters is this?

Conversions
Feet multiplied by 0.3048 equals an equivalent length in meters. Multiply the total length in feet by 0.3048 to get the length in meters.

Multiple Choice Question
Directions Choose the letter of the best answer. Write the letter for the answer on a separate piece of paper.

11. The icon whose purpose is to show the current orientation of the coordinate system is the
a. WCS  
b. plan view  
c. UCS  
d. skew line

TEST-TAKING TIP
Even though the first answer choice you make often is correct, do not be afraid to revise an answer if you change your mind after thinking about it.

Win Competitive Events

12. Effective Communication
Organizations such as SkillsUSA offer a variety of architectural, career, and drafting competitions. Completing activities such as the one below will help you prepare for these events.

Activity Work in groups of five or six. Have two or three members of the group, at different times, stand behind the group and slowly describe an object that is unknown to group members. Members may take notes during the description and then must try to draw the object.

Go to glencoe.com for this book’s OLC for more information about competitive events.
Drafting Problems

The problems in this chapter can be performed using board-drafting or CAD techniques. Each problem is laid out on a grid. Assume the size of the larger squares to be .5". Some of the .5" squares have been subdivided into .125" squares. Use this information to complete the problems. If you are using a CAD system, recreate the geometry in the CAD system and then use the appropriate CAD techniques to complete the problems.

1. In Figure 10-47, determine the angle LM makes with the vertical plane. What is the bearing?

2. In Figure 10-48, what is the bearing of line NO located on plane XYZ? Determine the true size of plane XYZ.

Figure 10-47

Figure 10-48
3. In Figure 10-49, complete the plan view of plane ABCD and develop a side view.

![Figure 10-49](image)

5. In Figure 10-51, complete the three views showing the intersection of AB and EF.

![Figure 10-51](image)

4. In Figure 10-50, find the edge view of plane ABCD and determine the angle it makes with the horizontal plane.

![Figure 10-50](image)

6. In Figure 10-52, draw the front view of line AB, which intersects line CD. What is the distance from C to A?

![Figure 10-52](image)
7. In Figure 10-53, create a location for plane 1-2-3 in the vertical plane.

8. In Figure 10-54, determine the true size of oblique plane ABC. Draw line XY parallel to plane ABC in the plan view.

9. In Figure 10-55, draw the true size of plane ABC and dimension the three angles of the plane.

10. In Figure 10-56, find the true angle between lines AB and BC.
11. In Figure 10-57, determine whether line MN pierces the plane.

![Figure 10-57](image)

Design Problems
Design problems have been prepared to challenge individual students or teams of students. In these problems, you should apply skills learned mainly in this chapter but also in other chapters throughout the text. The problems are designed to be completed using board drafting, CAD, or a combination of the two. Be creative and have fun!

**Challenge Your Creativity**

1. Design a set of collapsible sawhorses using steel components. They are to be 25.00" (635 mm) high. The top is to be 4.00" (100 mm) wide by 38.00" (965 mm) long. Design the sawhorses to fold into the smallest possible size. Have the legs spread at an oblique angle to the top member. Use adequate bracing to make them stable. Make a complete set of working drawings and a materials list.

**Teamwork**

2. Work as a team to design a piece of playground equipment for children. The basic design should include round steel or aluminum tubing with welded joints. (See Chapter 15 for more information about welding drafting.) Each team member should first work independently to develop basic design sketches. Design the apparatus to give children a safe and enjoyable experience. Each member of the team should be responsible for the development of some aspect of the final set of drawings and a materials list.
Customize Your Workspace

**Your Project Assignment**

Use what you have learned in Chapters 6–10 to create a complete set of drawings for an original design of your own. Your challenge is to:

- Design a custom desk organizer to hold your board-drafting supplies.
- Choose the shape and number of compartments for your organizer.
- Measure your organizer to be less than \( \frac{1}{5} \), or 20 percent of the surface size of your desk.
- Make sure that your organizer can hold a minimum of three drafting supplies.

**TIP!** Basic supplies might include a calculator, pencils, or clips. What other items do you wish to store?

- Draw a complete series of design views to illustrate the various dimensions of your organizer.
- Create a three- to five-minute presentation in which you discuss the steps you took to complete your drawings, the materials you recommend using for the organizer, and the drafting principles involved in formalizing your design.

**Applied Skills**

- Write a brief description of the item you are creating.
- List the steps you will take to complete your final drawing.
- Explain how you arrived at the appropriate measurements and dimensions for your organizer.
- Research and recommend the specific materials needed to construct your organizer.
- Draw your plans to match your specs!

**The Math Behind the Project**

The primary math skills you will use to complete this project are geometry modeling, algebra, and measurement. To get started, remember these key concepts, and follow this example:

**Geometry – Calculating Area**

The area of a figure is the number of square units, or in this case, inches, needed to cover a surface. To find the area of your desk, first measure the length and width and then calculate the area using the formula \( A = lw \), where \( l \) represents the length, \( w \) represents width, and \( A \) represents the area of the rectangle of your desk.

For example, if the width of your desk is 16” and the length is 24”, the total area would be:

\[
\text{Area} = 16” \times 24”
\]

\[
288 = 16 \times 24
\]

The surface area of the desk is 384 in\(^2\).
Algebra—Calculating Percentage

To calculate the 20 percent of the surface area available for your holder, use the formula \( P \text{ (Percentage)} = R \text{ (Rate)} \times B \text{ (Base)} \) where the rate of 20% is the same as \( \frac{1}{5} \) or .20.

\[
P = .20 \times 384 \\
20\% \text{ of 384 is } 76.8
\]

**TIP!** Because in this example you have no more than 76.8 in\(^2\), you should estimate to a round number less than 76.8.

Determining Measurement

Then, to calculate the size of your holder, you can determine the length and width by using the area formula again.

\[
A = lw \\
A = 75 \text{ in}^2
\]

To find a length and a width measurement that can be multiplied to equal a number close to 75. Two possibilities would be:

- 75 in\(^2\) = 5” wide \times 15” long
- 75 in\(^2\) = 6” wide \times 12.5” long

**Ergonomics**

You have probably seen the word ergonomics used to describe office equipment such as desks and chairs. Ergonomics is an applied science concerned with designing and arranging things people use so that they interact most efficiently and safely. Ergonomics is sometimes referred to as human factors engineering.

A human factors engineer who designs workspaces would consider many ergonomic factors, such as:

- human anatomy and psychology
- lighting and noise
- human/computer interaction

**Research Activity**

Research the terms ergonomics and human factors engineering. How are they similar and different? In what ways might ergonomics affect the design of your desk organizer? Write a one-page summary of your findings.

**Bonus!**

Incorporate your findings into the design of your desk organizer and explain what you have done.

Go to this book’s OLC at glencoe.com for more information on ergonomics and human factors engineering.
Project Steps: Get Ready, Get Set...Draw!

**STEP 1 Research**

- Explain the objectives you want to accomplish through your design. What will you store in your organizer? Would you rather use an organizer with a round shape or a square or other shape? Why?
- List the steps you will complete to make your final drawing.
- Research elements of your design object that will influence the way you set up your drawings.
- Investigate possible materials you might use in the construction of your organizer.

**TIP!** You can conduct research online, skim periodicals specializing in design, or visit a store that carries desk organizers.

**STEP 2 Plan**

- Define and write out your overall goal for this project.
- Gather the appropriate supplies and tools for board drafting.
- Measure and record the surface area of your desk or tabletop.
- Calculate $\frac{1}{3}$ or 20 percent of this surface to determine the size of your organizer.
- Set up to prepare your drawing file with AutoCAD.

**STEP 3 Apply**

- Create a basic sketch or CAD drawing of your design and write a brief description of the item you are creating.
- Prepare one multiview drawing of your design.
- Prepare one sectional view of your object showing the insides and/or other part(s) not easily seen.
- Add dimensioning and a materials list to your basic sketch or CAD drawing.

**TEAMWORK** Ask a classmate to review your design project drawings before you continue. Ask for feedback on the technical aspects of your drawing as well as the overall concept.

**STEP 4 Present**

Prepare a presentation combining your research with your completed drawings using the checklist below.

**Presentation Checklist**

<table>
<thead>
<tr>
<th>Did you remember to...</th>
<th>✓</th>
<th>✓</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td>state your objectives for the design concept?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>describe the features of your organizer?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>use a presentation program for your slides?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>write notes you might need for your presentation?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>demonstrate the basic sketch or CAD drawing?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>show the multiview and sectional view of your organizer?</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Refer to the math concepts on the previous pages, or go to glencoe.com for this book’s OLC for more information on the math concepts used in this project.
Evaluate Your Technical and Academic Skills

Assess yourself before and after your presentation.
1. Is your research thorough?
2. Did you plan your steps carefully?
3. Did you organize your visuals so that they showcase your ideas?
4. Is your presentation creative and effective?
5. During your presentation, do you make eye contact and speak clearly enough?

Rubrics: Go to glencoe.com for this book’s OLC for a printable evaluation rubric and Academic Assessment.

Highlighting Academic Skills and Achievements
A good portfolio includes samples of coursework in your field of interest. It should also include examples that highlight other aspects of your life such as hobbies, and special skills and interests. Some of these examples might come from work you have created for other classes.

1. **Highlight your communications and math skills:** Potential employers are interested in hiring employees with good writing and math skills. Include in your portfolio any reports you have written in English or history, creative writing, and math and science projects you feel showcase your talents well.

2. **Awards and citations:** If you have received awards or citations for sports or community activities, include them in your portfolio.

3. **Samples of your work:** Now that you have completed the desk organizer design project for this unit, include your drawings as samples of your work in your portfolio.

Save Your Work
In the following units, you will add more elements to your portfolio. Keep the items for your portfolio in a special folder as you progress through this class.