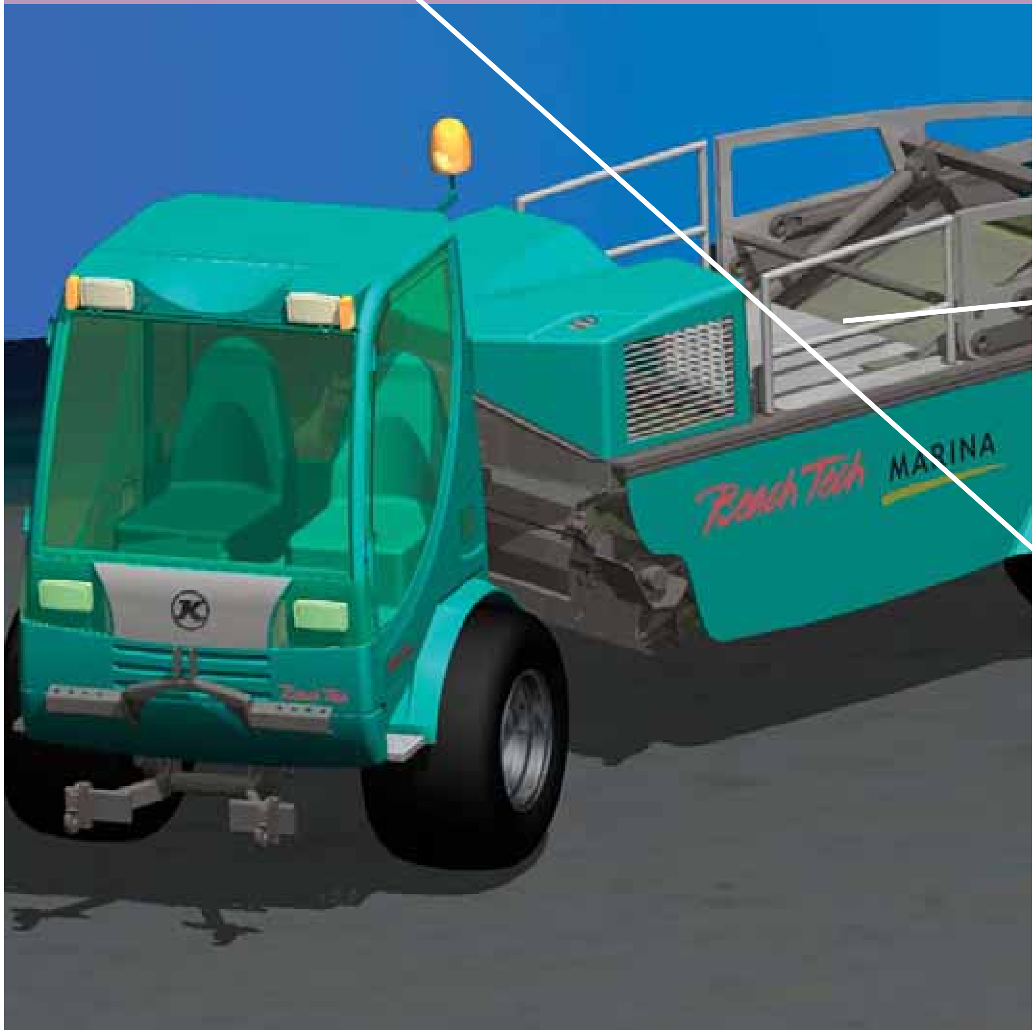

7

Computer-Aided Drafting and Design

OBJECTIVES

After studying this chapter, you should be able to:

- Explain how computer technology is revolutionizing drafting, design, and engineering.
- Describe the basic features and operation of a computer-aided drafting program.
- Explain the various commands used to create objects in CAD.
- Describe the tools used to modify CAD drawings.
- Identify the various display functions used in CAD programs.
- List different types of CAD software and their applications.

DRAFTING VOCABULARY

Absolute coordinates
Array
Attributes
Bitmap graphics
Cartesian coordinate system
Chamfer
Computer-aided design/computer-aided manufacturing (CAD/CAM)
Coordinates
Fillet
Grid
Layers
Linetype
Menu
Object snap
Orthogonal mode
Parametric modeling
Pixels
Polar coordinates
Raster objects
Relative coordinates
Rendering
Resolution
Round
Scanner
Scene
Snap
Solid modeling
Surface modeling
Symbol library
Symbols
Template
User coordinate system
Vector objects
World coordinate system

Computer graphics continues to revolutionize drafting and engineering, **Figure 7-1**. Computer-aided drafting and design systems play an integral part in the entire engineering process, from design and drafting to analysis and presentation. They aid in designing mechanical products, buildings, and other structures.

There are many benefits to using CAD as a design and drafting tool. Traditional drafting tasks, such as drawing basic shapes, lettering, and creating views, are greatly simplified with the electronic tools of a CAD system. CAD programs provide setup tools, drawing and editing commands, and customization methods to maximize accuracy and proficiency. There is a wide range of programs to choose from depending on the nature of the work. This chapter introduces the various applications of CAD drafting and discusses the common tools used to create CAD drawings.

Overview of Computer Graphics and CAD

Computer graphics was first employed for aerospace design in the 1950s. It is now a required tool of industrial technology. Until the advent of CAD, engineers, designers, and drafters had to imagine and then evaluate a three-dimensional object that was drawn in two dimensions on a flat sheet of paper. The only way a design could be verified in three dimensions was to make a wood, clay, plaster, or plastic model. This is an expensive and time-consuming process.

The emergence of CAD provided designers with a dynamic new tool. CAD technology permits more time for creative work because it eliminates the repetitive tasks required in traditional drafting.

CAD is a computer graphics technology that allows users to generate 2D and 3D designs electronically on a display monitor, **Figure 7-2**. Many people are able to use a computer drawing program after a suitable training period. *However, the principles of drafting are fundamental to both traditional drafting and CAD.* A working knowledge of basic drafting standards, techniques, and procedures is absolutely necessary to be an effective CAD drafter.

The main function of a CAD designer or engineer is to define the basic shape of a part, assembly, or product in 2D or 3D form. The

Figure 7-1 Computer-aided drafting systems are used for a wide variety of applications in design and engineering. With the proper CAD program, it is possible to generate realistic three-dimensional models representing complex mechanical assemblies. (Autodesk, Inc.)

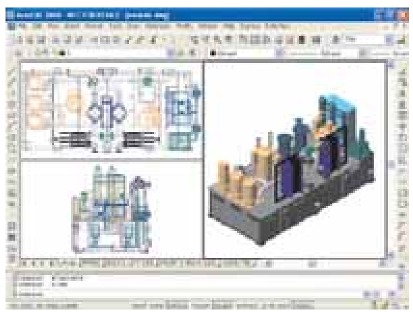

Figure 7-2 A 3D drawing created with a typical CAD system. With the proper tools, 2D and 3D images of the object being designed can be generated. (Autodesk, Inc.)

process involves many changes and refinements before a design is finalized. With a CAD system, design changes can be made and evaluated quickly.

Computer graphics programs fall into one of two classifications. These classifications are based on how the actual images are created. Images in a computer graphics program may be created with ***vector objects*** or ***raster objects***. Drawings created in a CAD program are made up of vector objects. Vector objects are made up of lines (vectors) and arcs and are defined with point coordinates in space. See **Figure 7-3A**.

Raster objects are defined using tiny shapes of data called ***picture elements***, or ***pixels***. See **Figure 7-3B**. Pixels are arranged in a fixed, precise manner. Each pixel is the same size and shape. The number of pixels making up an image defines the ***resolution***, or visual quality, of the image. Raster objects are also known as ***bitmap graphics***. Image editing programs are commonly used to alter bitmap graphics. Televisions and computer monitors are examples of devices that use raster displays.

A vector-based drawing can be converted to bitmap form in several different ways. The most basic way is to export a drawing file from a CAD program as a bitmap file. The file can then be imported into a different program for editing. For example, a 3D model created with a CAD program may be converted to a bitmap file and edited for special effects, such as lighting and shadows. If a vector drawing is output as hard copy, it can be converted to bitmap form with a ***scanner***. A scanner is an automatic digitizing device. It analyzes the lines, circles, and other graphic elements of the drawing and converts the objects into computer data.

Referring to **Figure 7-3**, vector images are edited by modifying the individual lines and arcs making up the drawing. Raster images are modified by editing the individual pixels making up the image. In creating or editing a vector object, such as a line, it can be helpful to visualize the object as an entity defined with coordinates. Most CAD programs provide a drawing grid that can be used to define objects with coordinates. This method of drawing is similar to the graph method used in manual

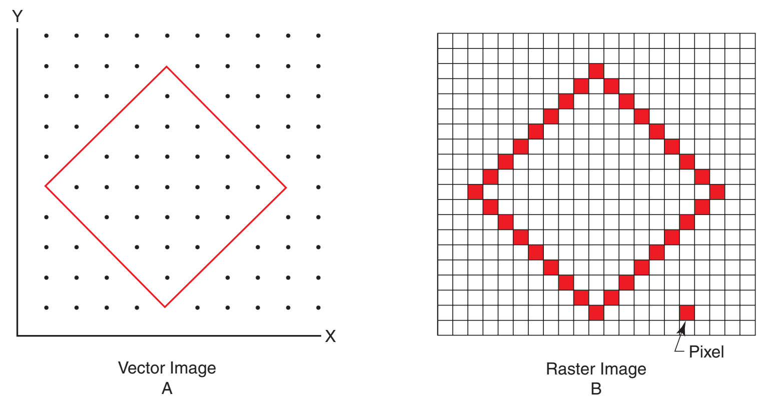

Figure 7-3 A comparison of vector and raster displays.

drafting. The graph method, discussed in Chapter 3, is used to enlarge or reduce drawings with coordinate grids. When using a CAD program, objects can be drawn to the desired size by defining coordinates or other parameters or by scaling an original object to a different size. Coordinate entry, scaling, and other types of drawing functions in CAD programs are discussed later in this chapter.

How CAD Works

A CAD drawing project starts with the generation of a geometric model of the proposed design on the display screen. The outline or profile of the design is created first and then details are added.

Instructions are given to a CAD program through the use of menus and commands. A ***menu*** is a list of options from which the drafter can select to execute the desired procedure. It can appear as a list of commands on a digitizing tablet or as a list of options on the monitor, **Figure 7-4**. Commands can also be entered at the keyboard or picked from toolbars.

Once objects are drawn, they can be altered as needed. For example, an object can be moved, rotated, copied, deleted, or mirrored. These operations are executed with editing commands. An object drawn in CAD can be manipulated in a variety of ways, making it unnecessary to draw the object again. CAD commands are discussed later in this chapter.

Dimensions and text can be added to a CAD drawing by selecting the appropriate menu function and entering the required information. The drafter can define the text size, style, and orientation as needed. CAD functions for creating text and dimensions are discussed later in this text.

After a drawing is completed, it can be output in a number of ways. Drawings converted into hard copy are typically printed on a plotter, **Figure 7-5**. Inkjet plotters are most commonly used to produce CAD drawings. CAD drawings may also be output to a printer, such as a laser printer.

Drawings made in a CAD program may also be converted to an appropriate file format for electronic viewing. For example, a drawing may be posted by a firm on a Web site for clients or for another engineer working on the project. If a drawing file is sent via

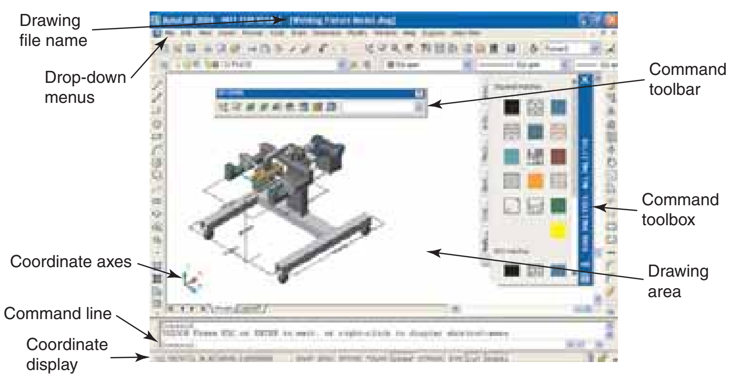

Figure 7-4 The drawing display of a typical CAD program includes drop-down menus, toolbars, and status displays. Commands can be accessed in a variety of ways to suit the user's needs. (Autodesk, Inc.)

Figure 7-5 Plotters produce hard copy from CAD drawing files. (CalComp)

electronic mail to a client, a viewer configured for the software may be needed to display the drawing.

Regardless of the drawing and production methods used, CAD programs offer a variety of ways to manage projects from design to completion. The following sections discuss the basic features, tools, and commands used to generate CAD drawings.

Using Basic CAD Functions

One of the main benefits of CAD drafting is the added productivity and efficiency made possible by tools and commands in the software. Many of these tools are designed to automate the common tasks associated with traditional (manual) drafting. There are a number of basic features and functions common to most types of CAD software. These include coordinate systems, drawing aids, layers, linetypes, and symbols. These features are discussed in the following sections.

Coordinate Systems

As previously discussed, objects in a CAD drawing are defined with coordinates. ***Coordinates*** are points representing units of real measurement from a fixed point. Most CAD programs provide a basic coordinate system and the ability to create user-defined coordinate systems. The most basic coordinate system in a typical program is the ***world coordinate system***. This system is based on the ***Cartesian coordinate system***. In this system, objects are defined by coordinates along the X axis (horizontal axis), Y axis (vertical axis), and Z axis (the axis projecting perpendicular from the XY plane). Coordinates are located in relation to the 0,0,0 origin. See **Figure 7-6**.

The horizontal and vertical axes of the Cartesian coordinate system divide the XY drawing plane into four quadrants. See **Figure 7-7**. Coordinates are entered as positive or negative, depending on the location from the origin. Referring to **Figure 7-7**, the coordinate (2,2) is located in the upper-right quadrant. This quadrant has positive X coordinates and positive Y coordinates. The coordinate (4,-3) is located in the lower-right quadrant. This quadrant has positive X coordinates and negative Y coordinates. The coordinate (-6,8) is located in the upper-left quadrant. This quadrant has negative

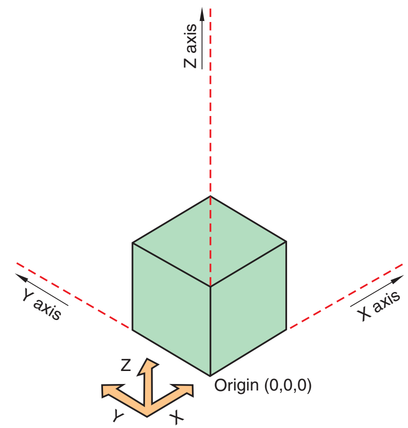

Figure 7-6 In the Cartesian coordinate system, coordinates establish points of measurement along the X, Y, and Z axes in relation to the 0,0,0 origin.

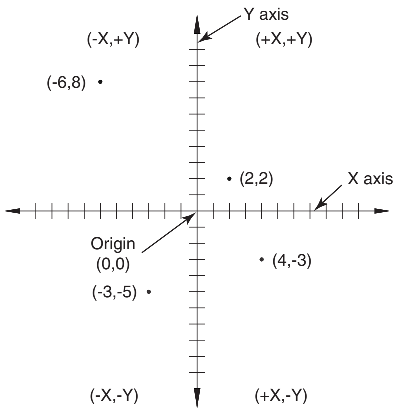

Figure 7-7 The XY axes of the Cartesian coordinate system divide the drawing plane into four quadrants. Coordinates have positive or negative X and Y values.

X coordinates and positive Y coordinates. The coordinate (-3,-5) is located in the lower-left quadrant. This quadrant has negative X coordinates and negative Y coordinates.

Objects drawn with XY coordinates are sufficient for 2D drawings. A third coordinate axis, the Z axis, is required for 3D drawings. This axis is used for coordinate entry above or below the XY plane. A point with a positive Z coordinate, such as (0,0,1), is located "above" the XY drawing plane. When looking at a drawing on screen, this location can be thought of as a point projecting out of the monitor toward you. A point with a negative Z coordinate, such as (0,0,-1), is located "below" the XY drawing plane. When looking at a drawing on screen, this location can be thought of as a point projecting into the monitor away from you. In order to draw objects in 3D space with a CAD system, it is important to be able to visualize them in three dimensions with coordinates along each axis. See **Figure 7-8**.

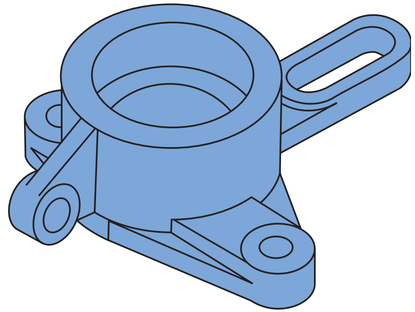

Figure 7-8 A third axis (the Z axis) is needed to generate three-dimensional images like the one shown. The ability to visualize objects in 3D space is fundamental to creating 3D drawings. (ROBO Systems)

There are three common forms of coordinate entry used in the Cartesian coordinate system. Coordinates may be entered as ***absolute coordinates***, ***relative coordinates***, or ***polar coordinates***. See **Figure 7-9**. When using absolute coordinates, objects are drawn using points in relation to the coordinate system origin (0,0). The absolute coordinate (2,2) indicates that the point is located two units from the origin along the positive X axis and two units from the origin along the positive Y axis. When using relative coordinates, objects are drawn using coordinates in relation to the last coordinate specified (or the origin). For example, entering the relative coordinate (@5,4) after entering the absolute coordinate (2,2) places the next point five units along the positive X axis and four units along the positive Y axis at the coordinate (7,6). Refer to **Figure 7-9B**.

When using polar coordinates, coordinates are located at a given distance and angle from the origin or from the last coordinate specified. Polar coordinates are entered using a format such as *(distance<angle)*. This format specifies a linear distance and angle in the

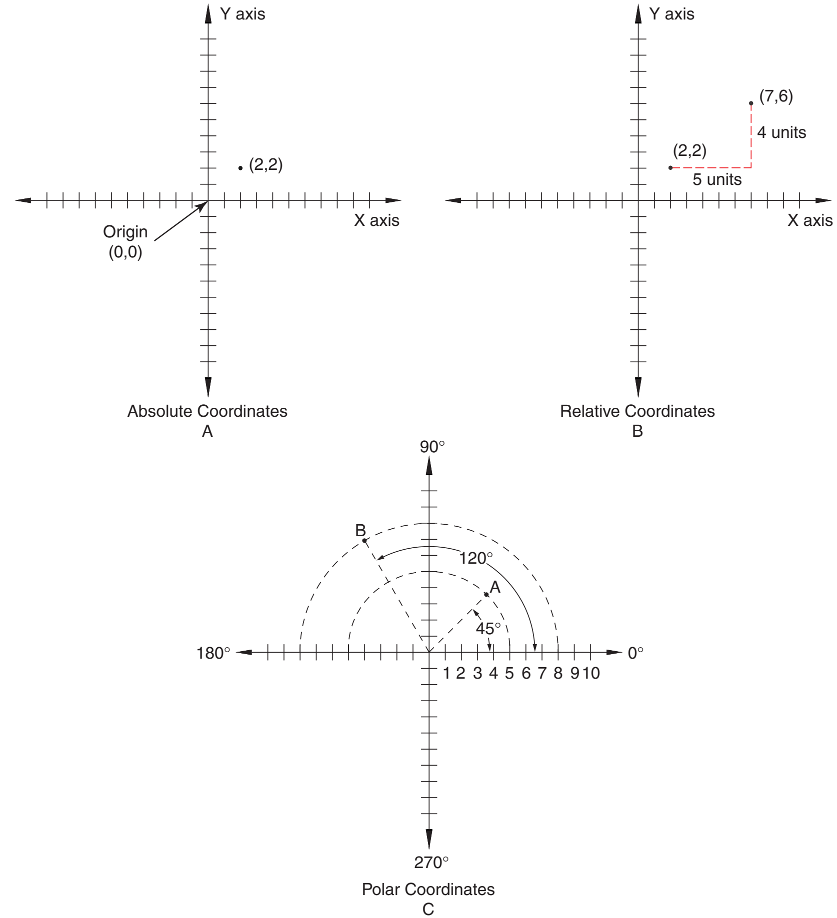

Figure 7-9 The three types of coordinate entry used in the Cartesian coordinate system. A—The absolute coordinate (2,2) is located 2 units along the positive X axis and 2 units along the positive Y axis from the 0,0 origin. B—Entering the relative coordinate (@5,4) locates the next point five units along the positive X axis and 4 units along the positive Y axis at the coordinate (7,6). C—Polar coordinates are located at a specified distance and angle from the origin or a given point. Angular values are measured counterclockwise. Point A represents the polar coordinate entry (@5<45) in relation to the origin. Point B represents the polar coordinate entry (@8<120) in relation to the origin.

XY plane relative to the origin or another point. Angles are most commonly measured counterclockwise, with the positive X axis representing 0°. Referring to **Figure 7-9C**, the polar coordinate entry (5<45) locates the point five units away from the origin at an angle of 45° in the XY plane. The polar coordinate entry (8<120) locates the point eight units away from the origin at an angle of 120° in the XY plane.

Each of the different types of coordinate entry can be used when creating a drawing. The entry used typically depends on the object drawn. For example, it may be useful to use absolute coordinates when a given point is known, or when drawing straight lines. Relative coordinates may be used when locating points from a common feature. Polar coordinates are useful for drawing inclined lines and round objects.

User Coordinate Systems

As previously discussed, the default world coordinate system in a CAD program has the origin located at 0,0,0. This is typically sufficient for most 2D drawings, since coordinates for 2D objects can be drawn on the XY drawing plane without specifying a third coordinate along the Z axis.

When creating drawings in 3D, however, it is often useful to change the world coordinate system to a different coordinate system. This is because features in a 3D drawing are usually drawn in relation to surfaces on an object, rather than exact coordinates in 3D space. A ***user coordinate system*** is a relative drawing configuration that allows you to orient a drawing plane to a specific surface. Coordinates can then be located on the user-defined drawing plane in relation to a fixed origin. The origin used may be a specific point on the object, such as a corner or center point. See **Figure 7-10**.

User coordinate systems greatly simplify the 3D drawing process. There are also viewing tools and drawing commands that are useful for 3D drawing. Viewing tools and 3D-based modeling methods are discussed later in this chapter. Commands used in 3D drawing are discussed in Chapter 13.

Figure 7-10 A user coordinate system is used to establish a drawing plane in 3D space so that objects can be drawn on the surface of the plane. The XYZ coordinate axes identify the orientation of the drawing plane. In this 3D model of a phone, the XY drawing plane is oriented so that objects can be added to the mouthpiece. Note the direction of the axes.

Drawing Aids

In addition to coordinate systems and the numerous commands used to create basic geometric shapes, CAD programs offer a number of drawing aids that simplify the drawing process. These features make it easy to specify distances and locate coordinates when drawing basic objects such as lines and circles. The typical drawing aids in a CAD program include grid and snap, object snap, and orthogonal mode.

In CAD, a ***grid*** is a network of uniformly spaced points used to determine distances. Displaying a grid is similar to using graph paper in manual drafting. The grid spacing may be set to any value that simplifies the process of locating points at specific increments. When used, the grid display is for reference only. It does not print when the

CAREERS IN DRAFTING

Drafting/CAD Teacher

What would I do if I were to become a drafting/CAD teacher? Because I would be a type of career and technical education teacher, I would use many different methods of presenting information and concepts relating to drafting and computer-aided drafting (CAD) in order to help students learn how to solve design problems. I would assist students in learning how to properly create drawings that are used to manufacture or construct objects.

What would I need to know? I would need to be able to properly organize a classroom and know how to present the information, concepts, and skills that I need to teach my students. I would need to know how to use (and instruct how to use) various manual drafting tools as well as computers and CAD software. I would need to be familiar with and competent using a variety of tools, techniques, and procedures as they relate to various specialized fields of drafting—such as mechanical, architectural, electrical, and civil drafting. I would need to know how to work effectively with diverse ethnic and socioeconomic groups of students. I would also need to know how to design classroom presentations; plan, evaluate, and assign lessons; prepare, administer, and grade tests; evaluate oral presentations; maintain classroom order and discipline; effectively work with and communicate with other staff and parents; assist students in setting career goals; and help with a wide variety of extracurricular activities.

Where would I work? I would spend a majority of my time in a classroom environment instructing students. However, my work could take me out of the classroom for field trips and other academic and extracurricular endeavors. Many teachers also have home offices where they spend many hours preparing for their classes.

For whom would I work? I could work for a public school district, usually at a secondary level. I could also work for a public or private technical school, trade school, college, or university. Some drafting/CAD teachers also work for large corporations to keep professional staffs current with the latest technologies, practices, and procedures.

What sort of education would I need? While in high school, I would need to take courses in drafting, mechanical drawing, CAD, and computer science, along with required high school courses. All 50 states require public school teachers to be licensed and have a minimum of a bachelor's degree from an approved teacher education program. Some states require that teachers earn a master's degree within a specified period of time after being hired. Also, many drafting/CAD programs are designated as vocational programs, and most states require that teachers of vocational programs be vocationally credentialed. Job experience as a drafter or CAD drafter is very helpful in acquiring a vocational credential.

What are the special fields relating to this career? There are many areas of study in which I can teach. Math, science, technology education, and computer science are probably the most closely related to drafting/CAD.

What are my chances of finding a job? In general, the overall job outlook for teachers over the next several years is good to excellent, depending on the subject matter, grade level, and locality. However, there are several factors regarding job opportunities for drafting/CAD teachers. First, many teachers now teaching drafting and CAD are nearing retirement age. Hence, new teachers are going to be needed to fill those positions. Second, at present, the job market is sorely lacking in qualified drafting/CAD teachers that are not already employed. And third, there are two realities

(*continued*)

Drafting/CAD Teacher *(continued)*

working against prospective drafting/CAD teachers. On a comparative basis, there are not as many drafting/CAD positions in existence as there are in other areas of study (such as math). Also, most positions are found in more densely populated areas with larger schools because many rural schools do not offer this kind of program. So, it could be concluded that drafting/CAD teachers will be in very high demand over the next several years—when existing positions become available.

How much money could I expect to make? Teacher pay varies greatly because of numerous variables. Generally speaking, I could expect to make more if I taught in a metropolitan area than if I taught in a rural setting. Recent statistics identify the average income of a public school teacher to be $44,367, but pay can range from $24,960 to $68,530. Private school teachers generally earn less than public school teachers. Degree held, locale, and amount of experience are the three largest contributing factors to the level of pay that I could expect. Also, if I taught in a technical school, trade school, college, or university, I could generally expect higher pay. I could also earn extra pay by coaching, teaching summer classes, or sponsoring various extracurricular activities, clubs, or organizations.

Where else could I look for more information about becoming a drafting/CAD teacher? See the US Department of Labor's Bureau of Labor Statistics Occupational Outlook Handbook (at www.bls.gov) or visit the Recruiting New Teachers Web site (at www.rnt.org). A list of accredited teacher education programs can be obtained from the National Council for Accreditation of Teacher Education (at www.ncate.org). Information about vocational education can be acquired through the Association for Career and Technical Education (www.acteonline.org) and also through the International Technology Education Association (www.iteawww.org).

If I decide to pursue a different career, what other fields are related to drafting and CAD? Because teaching drafting and CAD is much like teaching applied geometry, teaching math would be similar. Some of the content in art classes is similar to that in drafting classes. General technology education also encompasses some of the content taught in drafting/CAD courses. Many projects completed in the average drafting program also have close ties to science. Thus, I could become a teacher of art, math, science, or technology education, and still be teaching in a related field.

drawing is plotted.

Snap is a function that allows the user to align ("snap") the cursor to specific increments, or snap points, in an invisible grid. Snap can be used with or without the grid display turned on. However, it is common to set the snap spacing in conjunction with the grid spacing. For example, if the grid spacing is set to .50″, snap may be set to .25″ so that the cursor can be "snapped" to the grid points as well as the midpoints between grid lines.

Object snap is a function that allows the cursor to be aligned, or snapped, to specific locations on an object. Object snap can be set to one or more modes that determine the type of location. This is useful for drawing objects using existing points on another object. For example, the Endpoint object snap mode allows you to attach the cursor to an endpoint of an object. The Midpoint object snap mode is used to attach the cursor to the midpoint of an object, such as a line. The Center object snap mode is used to attach the cursor to the center of a circle or an arc. Object snap can

also be used to draw objects that are parallel, perpendicular, or tangent to other objects.

Orthogonal mode simplifies the task of drawing straight lines. When orthogonal mode is enabled, the movement of the cursor is confined to straight horizontal and vertical movement in relation to the drawing plane. Inclined lines cannot be drawn when using this mode. Orthogonal mode is useful for drawing lines at 90° angles, such as the outlines making up a drawing border.

Layers and Linetypes

In manual drafting, it is common to have several different views or plans on separate sheets for complex drawings, such as mechanical parts with section views or architectural plans for a building. When this is the case, the sheets are overlaid on top of each other so that the different drawings can be viewed separately. In CAD drafting, drawings can be managed in a similar way through the use of layers. ***Layers*** are user-defined object settings that can be displayed or "turned off" to distinguish the different types of content in a drawing. See **Figure 7-11**. Using layers, several different displays can be shown within a single drawing file. It is very common, for example, to create separate layers for object lines, construction lines, section lines, text, and dimensions. The display of each layer can be turned on or off as desired. In this way, certain portions of the drawing can be "hidden" while displaying other features. This helps drawing productivity because objects can be temporarily removed from the drawing without deleting them to free up drawing space. In architectural projects, different plans are commonly placed on different layers within a single drawing file. The floor plan, foundation plan, and plumbing plan, for example, may each be assigned to a separate layer. This provides a way to plot different displays from a single drawing.

Layers are typically named to reflect their content. For example, all of the dimensions on a drawing may be assigned to a layer named Dims. In addition, each layer may be assigned its own color. In many cases, company or school standards specify layer naming conventions and how to group drawing content.

Layers may also be assigned different linetypes to distinguish content. A ***linetype*** is a setting used to describe a line definition in the Alphabet of Lines. Examples of linetypes include the Object, Centerline, and Hidden linetypes. When a line is drawn with a specified linetype, it has the same characteristics as the equivalent line in the Alphabet of Lines. Each linetype may have its own lineweight setting to reflect the plotting thickness desired. When using a plotter with pens, the line thickness is determined by the size of the plotter pen.

Drawing specifications such as layer and linetype settings should be determined before starting a project. Saved settings for layers, linetypes, object snaps, and other CAD functions can be specified in a drawing template and used each time a new drawing is started. Templates and setup commands are discussed later in this chapter.

Symbols

One of the basic principles of CAD is to never draw the same object twice. For example, objects can be copied and reused once they are drawn. Copying objects is discussed later in this chapter. Another way to avoid drawing objects repeatedly is to use symbols. ***Symbols*** are saved or predrawn objects designed for multiple use in drawing projects. Once something is drawn and saved as a symbol, it can be inserted into a drawing as many times as needed. This is a powerful function that greatly increases drawing productivity. Symbols are commonly used in architectural and electrical drawings to represent items such as windows, doors, and outlets.

Many companies store hundreds of

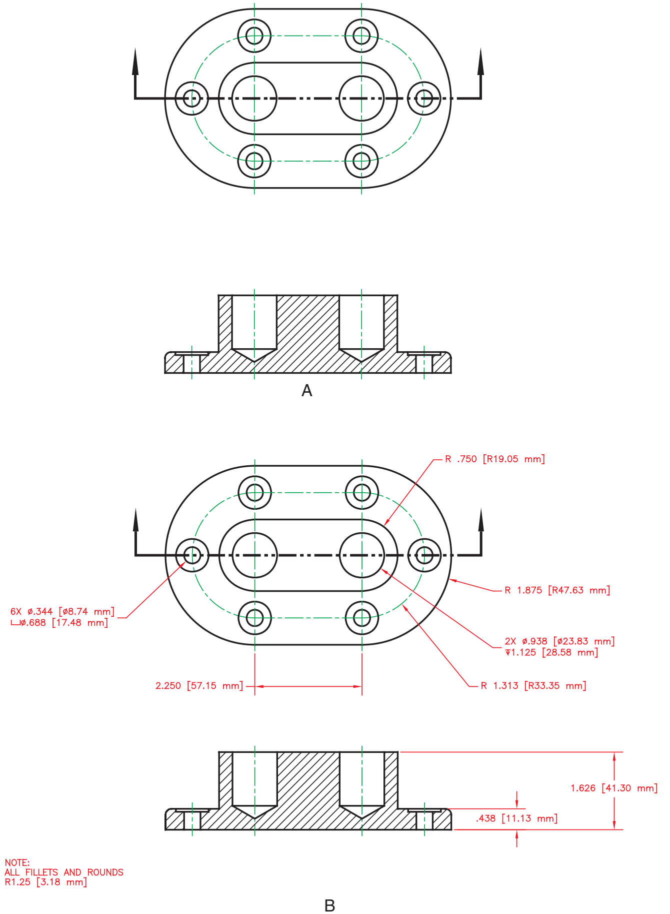

Figure 7-11 Layers are used in CAD drawings to distinguish different content, such as different linetypes and dimensions. A—The object lines, centerlines, section lines, and cutting-plane line in this drawing are on different layers. Each layer has the appropriate linetype. The Centerline layer is assigned the color green. All other layers are assigned the color black. B—The dimension layer is turned on to show dimensions. This layer is assigned the color red.

symbols in symbol libraries. A ***symbol library*** is a collection of related drawing symbols. See **Figure 7-12**. To create a symbol, the shape is drawn and saved with a name. It can then be inserted into the drawing where it is stored or into other drawings. Many manufacturers and drafting firms provide symbols of their products that can be downloaded from Web sites on the Internet.

In some CAD programs, symbols may be saved with attributes. ***Attributes*** are text strings of information about the related symbol. Attributes may be created to identify a product number, price, size, or material. They can be displayed along with the symbol on the drawing, or they may be set invisible. Attributes are commonly used to create drawing schedules, which list manufacturing and purchasing information about parts and products on a drawing.

Drawing Setup Functions

As is the case with manual drafting projects, CAD drawings should be planned carefully prior to beginning work. Making drawing settings ahead of time increases efficiency and is important to being a successful CAD drafter. CAD programs provide a number of commands and features used to set up drawings. Applying these functions should become a normal routine when using a CAD system.

Most CAD programs base linear and angular measurements on the current unit settings. A drawing can be set to use decimal inch, architectural, metric, or engineer's units. Units are typically set with the **Units** command. The unit format selected depends on the drafting discipline.

Regardless of the unit format used, objects are drawn at full size in CAD drafting. This means that an object 2″ × 3″ is drawn at that size. The drawing scale determines the size of the drawing when it is plotted. The drawing scale is based on the size of the drawing media. It affects the size of dimensions and is determined before beginning a drawing along with the sheet size. A number of settings are typically made in a CAD drawing when specifying the scale factor, such as linetype scaling and text height.

As previously discussed, layers are

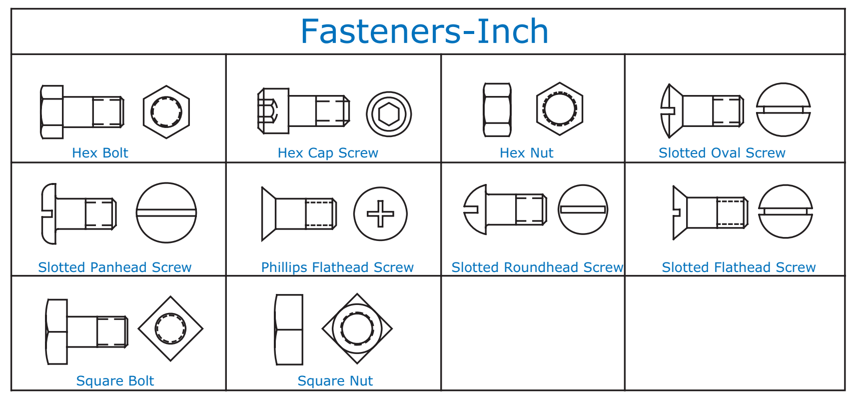

Figure 7-12 A symbol library of fasteners used in mechanical drafting.

normally created during the drawing setup process. Linetypes are defined and assigned to layers as needed. This provides a means to organize a wide variety of content.

Many of the drawing aids previously discussed can be saved in a drawing template. A *template* is a saved set of configurations used to start a drawing file. Different templates can be created for different drafting disciplines or applications requiring predefined entities such as symbols. They may include settings for the unit format, sheet size, and drawing scale. It is also common to have predefined text styles, dimension styles, and layer assignments in a template. The use of templates saves drawing time and allows drafters to focus on the drawing project at hand.

Creating Objects

As previously discussed in this chapter, there are a variety of ways to create objects using CAD. In most cases, the creation of an object begins with a command. Within a command sequence, objects may be created using coordinates, such as absolute coordinates, or parameters, such as radius values and linear measurements. Coordinates and parameters may be entered at the keyboard or specified with the cursor on screen.

Most of the basic geometric shapes discussed in Chapters 3 and 6 can be drawn quickly with drawing commands. The following sections discuss the common methods used to create basic geometric shapes in CAD.

Drawing Lines

Lines are most commonly drawn with the **Line** command. A line may be drawn straight or inclined by specifying coordinates at the keyboard or by using the cursor to pick points on screen. A line requires two coordinates, **Figure 7-13**. Additional coordinates may be entered within a single command sequence to create as many segments as needed. As previously discussed, lines may be displayed

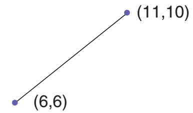

Figure 7-13 A line is created by drawing a segment between two endpoint coordinates.

using different line conventions by applying the proper linetype. Before drawing the line, the layer or linetype must be set current.

Drawing Circles and Arcs

Curves making up CAD-generated circles and arcs are defined mathematically by the program based on the coordinates entered. Circles are typically drawn by specifying the center point and a radius or diameter, **Figure 7-14A**. A circle may also be drawn by specifying points along the perimeter of the circle or by entering a radius and selecting two lines or two circles to which the circle should be tangent. The **Circle** command is most commonly used to draw circles. The center point location and radius value may be entered at the keyboard or picked on screen.

Arcs can be drawn with the **Arc** command. A number of methods are usually available. Arcs typically require a center point, radius, and endpoint. See **Figure 7-14B**. Arcs may also be drawn by specifying three points, or a starting point, a center point, and a third entry, such as a chord length. As with circles, arcs may be drawn tangent to lines, other arcs, or circles.

Drawing Ellipses

Ellipses are drawn with the **Ellipse** command. An ellipse has a center point, a minor axis, and a major axis. See **Figure 7-15**. The axes divide the ellipse into four quadrants. Points for the axis endpoints and center point can be entered at the keyboard or picked on screen.

Elliptical arcs (portions of an ellipse) can

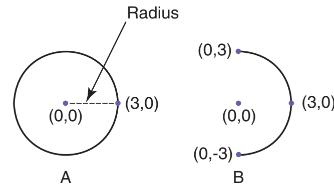

Figure 7-14 Drawing circles and arcs. A—Circles are defined with a center point and radius or diameter. B—Arcs are commonly defined with a center point, starting point, and endpoint, or with points along the arc.

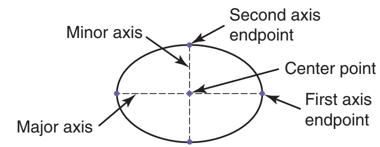

Figure 7-15 An ellipse is drawn by defining a center point and endpoints for the minor and major axes.

also be drawn by specifying start and end angles after locating the center point or axis endpoints. The start and end angles represent points on the curve relative to the angular locations of the axis endpoints. The angles are measured counterclockwise from the first axis endpoint, which is designated as 0°. For example, an arc drawn with a 0° start angle and 180° end angle represents half an ellipse.

Drawing Polygons

The **Polygon** command can be used to draw regular polygons. After specifying a center point, the number of sides is entered. Specifying three sides draws an equilateral triangle. Specifying four sides draws a square. Regular pentagons, hexagons, and octagons can also be drawn.

After entering the number of sides, the command sequence includes prompts for the user to inscribe or circumscribe the polygon.

As you learned in Chapter 6, an inscribed polygon is drawn within a circle. A circumscribed polygon is drawn about a circle. After specifying the orientation of the polygon, the radius of the circle is entered.

Editing Objects

One of the most important advantages of a CAD program is the ability to easily modify objects once they are drawn. Objects can be moved, copied, rotated, and scaled using editing commands. In addition to these basic commands, there are a number of other editing methods that can be used to construct drawings. This provides great flexibility. Some of the most common editing commands in CAD programs are discussed in the following sections.

Moving Objects

It is often necessary to relocate objects after they are drawn. This can be done with the **Move** command. After selecting one or more objects to move, you must specify a base point for the selection set. This may be the corner point of a rectangle or the center point of a circle. You are then asked for a displacement point. The objects making up the selection set are then moved automatically to the new location using the distance specified. Distance values can be entered at the keyboard or picked on screen.

Copying Objects

Copying objects is similar to using the **Move** command, except the original objects are not altered by the operation. Objects can be copied using the **Copy** command. After selecting the objects to copy and the base point, a displacement point is specified. The selected objects are then copied to the new location.

The **Copy** command includes a **Multiple** option. This option allows you to copy the same object to several new locations. This option is entered before selecting the base point.

Rotating Objects

Rotating an object changes the angular position of the object with respect to the current orientation. Objects can be rotated using the **Rotate** command. When using this command, the selected objects are rotated about the base point specified. The objects may be rotated clockwise or counterclockwise. If the objects are already rotated to a given angle, the reference angle is entered, followed by the desired angle of rotation.

Scaling Objects

An object can be reduced or enlarged to a different size by a given scale factor. This is accomplished with the **Scale** command. After selecting the object to be scaled, the base point and scale factor are specified. A scale factor of 0.5, for example, would be used to reduce the size of an object to one-half its original size.

Undoing a Command

CAD programs typically provide a command that allows you to "undo" a previous operation. If you enter an incorrect value for a scale or move operation, you can reverse the action by using the **Undo** command. This command typically allows you to undo several preceding commands, one by one. However, the commands must be undone in sequence.

Erasing Objects

The **Erase** command provides a quick way to remove unwanted objects from a drawing. After you select the objects to erase, the command automatically removes them from the drawing. The **Undo** command can be used to restore an object that has been erased unintentionally.

ACADEMIC LINK

The evolution of computer technology and electronic communication has had a major effect on the way drawings are made and presented. Not long ago, manual drawings were the primary means of communicating manufacturing information to trade workers. Today, drawings are created with computer-aided drafting programs and distributed with electronic media. They are used by workers to program computer-controlled machine tools. Computers then interpret the information and manufacture parts. This is accomplished through various phases of communication—including interaction between the drafter and the computer and the computer and a machine.

There are literally hundreds of CAD software programs that have been used to design products for industrial use. Computer animation programs make it possible to communicate an entire design of a product before it is manufactured or built. Internet technology makes it possible to send, receive, evaluate, and modify drawings in a very short period of time.

When compared to manual drawing techniques, CAD tools have made it much simpler to communicate information. However, it is important to understand that as with other communication tools, CAD is *only* a tool. The same drawing skills, visualization techniques, and concepts practiced in manual drafting must be understood in order to use CAD accurately and successfully.

Arraying Objects

An ***array*** of objects can be created by orienting multiple copies of a selected object in a pattern. This operation is useful when the same object appears in multiple locations in a regular pattern in the drawing (for example, when a pattern of holes is machined in a round part). Arrays may be created in rectangular or polar arrangements with the **Array** command. See **Figure 7-16**. A rectangular array is created by entering the base point, number of rows, number of columns, and the spacing between rows and columns. The number of columns and rows determines the number of objects in the array. A polar array is created by specifying a center point, the number of objects in the array, and an angular value determining the amount of rotation. Entering 360° creates a full rotation of objects about the center point.

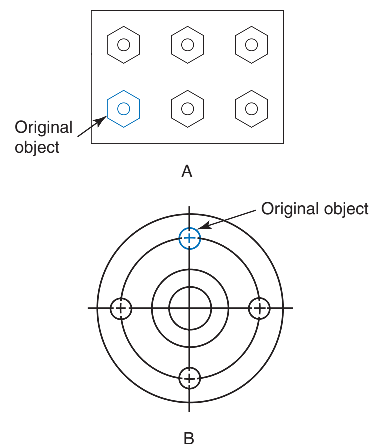

Figure 7-16 Arrays are created by orienting copies of original objects in a regular pattern. A—Rectangular array. B—Polar array.

Mirroring Objects

When drawing symmetrical objects, it is sometimes useful to create a mirror image. This operation allows you to select an object and make a mirror copy. This can save time when you want to draw half of an object and complete it by "mirroring" it. See **Figure 7-17**. The **Mirror** command is used to mirror an object. To use this command, the objects to be mirrored are first selected. Then, a mirror axis is specified. The axis represents a line about which the objects are "reflected." The command sequence typically allows you to keep or delete the original object selected before mirroring.

Creating Rounded and Angled Corners

Rounded and angled corners are often drawn in mechanical drafting. A ***round*** is an arc representing an outside rounded corner. A ***fillet*** is an arc representing an inside rounded corner. A ***chamfer*** is an angled line drawn where two straight lines would normally meet at a corner. Rounds, fillets, and chamfers are used to smoothen sharp edges. See **Figure 7-18**. Rounds and fillets can be drawn with the **Fillet** command. After entering the

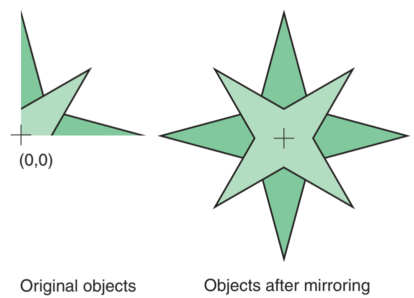

Figure 7-17 Mirroring an object creates a mirror copy about a mirror axis. In this example, the original image is mirrored twice using the X and Y axes.

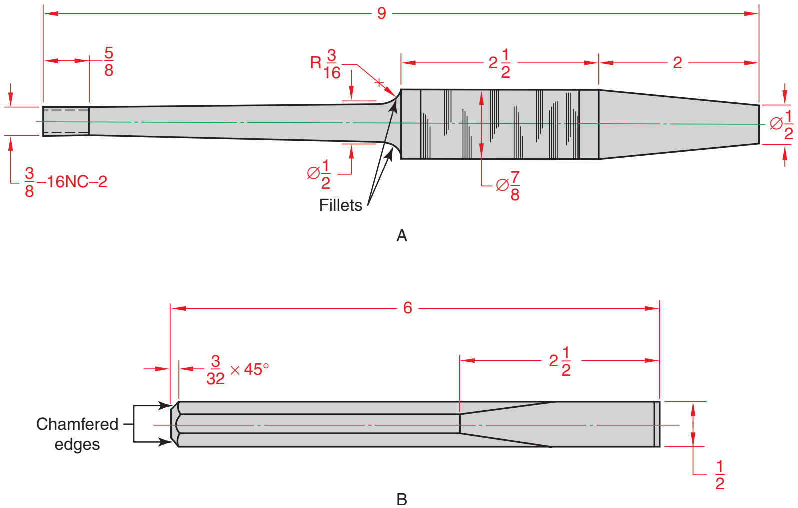

Figure 7-18 Creating rounded and angled features. A—Fillets are created by specifying a fillet radius and selecting the two objects forming the intersection. B—Chamfers are created by selecting two lines and entering the chamfer distances.

command, the fillet radius is set. Then, the two lines, circles, or arcs forming the intersection are selected. The original objects are then trimmed and the arc is automatically drawn.

A chamfer can be drawn with the **Chamfer** command. After entering the command, the chamfer distances from the two lines to the corner are set. A 45° chamfer is created with equal distances. Next, the two lines are selected. As with the **Fillet** command, the lines are trimmed automatically when the chamfer is drawn.

Trimming and Extending Lines

Many objects in a CAD drawing are made up of lines. During the drawing process, it is sometimes necessary to "clean up" areas of the drawing where lines must intersect accurately. Trimming is useful when two lines overrun past a corner. Extending is useful when a line must be lengthened to meet an edge.

The **Trim** command is used to trim lines, arcs, and circles. After entering the command, a cutting edge must be specified. This represents the point to where the object is to be trimmed. Next, the object to be trimmed is selected. The portion of the object extending past the cutting edge is automatically removed.

The **Extend** command is used to extend lines and arcs to meet other objects. After entering the command, a boundary edge must be specified. This represents the point to where the object is to be extended. Next, the object to be extended is selected. A segment connecting the object to the boundary edge is automatically drawn.

Using Display Commands

CAD programs provide a variety of ways to display drawing content on screen. Display commands are used to change the magnification of the drawing, reset the viewpoint, and establish views, such as multiviews in a 2D or 3D drawing. Multiview drawings are discussed in Chapter 9.

In a large drawing, it is often necessary to "zoom" into certain portions to view details. The **Zoom** command provides this capability. After entering the command, you can zoom into a portion of the drawing by windowing around the display. The windowed portion is then shown at a greater magnification scale. You can also enter a magnification scale factor to reduce or enlarge the display relative to the current display. A third option allows you to zoom the view in real time by using the pointing device to move the cursor upward (to enlarge the view) or downward (to reduce the view).

When you wish to move the drawing across the screen to view areas outside of the current display without changing the magnification, you can use the **Pan** command. Panning adjusts the view in real time. The drawing is panned by using the pointing device to move the cursor in the direction desired.

More advanced viewing commands are available with 3D drawing programs. The **Orbit** command is typically used when working with models in 3D space. This is a powerful command that allows you to rotate the model in three dimensions by using the pointing device. The view is changed in real time, allowing you to view different surfaces and features across the model dynamically.

CAD Systems and Software

CAD programs range in capability from simple 2D drawing to advanced 3D modeling and presentation. The type of program used normally depends on the application or drawing discipline for which it is used. While basic CAD programs require relatively inexpensive hardware to drive the system, higher-end programs may require computer equipment costing several thousands of dollars.

As discussed in Chapter 4, a basic CAD system consists of a computer, a monitor (display screen), keyboard, pointing device, and output device. Data is stored on the hard drive of the computer or on portable media, such as CDs. The primary component of a CAD system is CAD software. The software is the set of instructions that tells the computer what to do and when to do it.

CAD software programs can be classified in several different ways. Some CAD programs provide 2D drawing capability only. These programs have many of the functions discussed in this chapter, with the exception of 3D-based tools. Other CAD programs are based on a specific type of 3D modeling, such as solid modeling, surface modeling, or parametric modeling. Some CAD modeling software is specifically designed for mechanical drafting and manufacturing applications. There are also advanced modeling programs used to create photorealistic renderings and animation graphics. The following sections discuss some of the features provided by different types of CAD software.

CAD Modeling Programs

Modeling programs are used to create realistic definitions of objects using XYZ coordinates and a variety of 3D drawing methods. Commands in the software are used to construct a model in 3D space. The resulting model can then be shown in a pictorial view to display the various features and surfaces. Common 3D modeling commands are discussed in Chapter 13.

Three of the most common types of 3D modeling are solid modeling, surface modeling, and parametric modeling. In ***solid modeling***, objects called ***solids*** or ***solid models*** are created to represent the entire mass of an object. See **Figure 7-19**. A solid model is considered to be defined from the actual material making up the object. Solid models are used in mechanical drafting applications because they can be analyzed for properties such as mass and volume.

Models created in ***surface modeling*** are similar to solid models, but the objects are not considered solid. ***Surface models*** have an outer "skin" to represent exterior surfaces. See **Figure 7-20**. While a surface model is not considered as realistic as a solid model, the quality of the representation is very similar. Therefore, surface models are primarily used for presentation purposes.

Parametric modeling is an advanced form of modeling that allows object dimensions, or parameters, to be modified during the construction of a model. This permits changes to be made to different portions of a model during the modeling process. See **Figure 7-21**. Parametric modeling programs are available for both solid modeling and surface modeling.

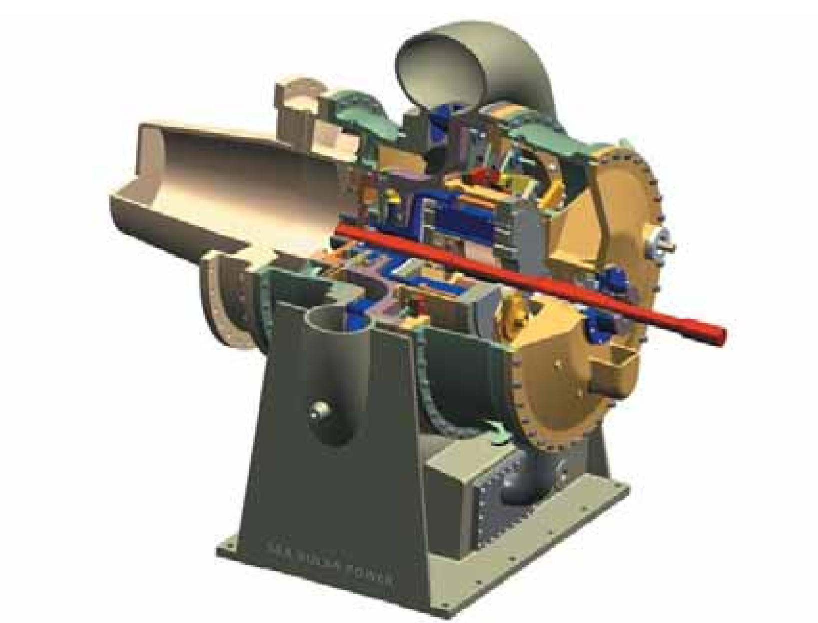

Figure 7-19 A solid model represents the entire mass of an object and the material used in its construction. (Designed with Solid Edge from UGS PLM Solutions)

Figure 7-20 A surface model is a representation of the outer "skin" of the various surfaces simulating the object. (Discreet, a division of Autodesk)

Figure 7-21 Parametric modeling programs provide powerful modeling tools that allow object dimensions to be changed throughout the modeling process. Any changes made affect the entire model. (Designed with Solid Edge from UGS PLM Solutions)

In more advanced programs, changing one parameter affects the entire model. These types of programs can simulate how a part will "work" with other parts in an assembly. This allows the engineer to determine whether possible conflicts exist (for example, if two parts are in the same place at the same time).

Solid modeling, surface modeling, and parametric modeling programs also typically provide rendering capability. In CAD terms, a ***rendering*** is a highly realistic representation of a model with lighting, shadows, and other visual effects applied. Renderings are common in mechanical and architectural drafting, because a mechanical assembly or an interior room can be shown in great detail to a potential client. The models shown in **Figures 7-19**, **7-20**, and **7-21** are rendered models.

CAD/CAM

Computer-aided design/computer-aided manufacturing (CAD/CAM) combines CAD with automated manufacturing operations. In this type of manufacturing, computer numerical control (CNC) machines control the manufacturing processes. Computer data that is input to the machine is used to control the movement of machine tools. After a part is drawn in the CAD program, the mathematical shape and size description of the part, or design data, is calculated by the program for manufacturing. The data is used to cut the material and make the part, **Figure 7-22**.

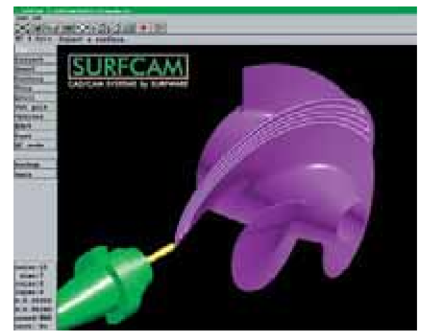

Figure 7-22 CAD/CAM programs use CAD-generated drawings to supply tool data for manufacturing processes. This display shows the generation of the cutter path for machining a personal watercraft impeller. (Courtesy of SURFCAM by Surfware)

Advanced Rendering and Animation Programs

In high-end applications, advanced rendering programs are used to create very realistic displays of complex models. See **Figure 7-23**. These programs provide lighting tools, material surface finishes, and environmental settings that can be used to greatly enhance the appearance of a model. A model set up for rendering in this manner is known as a ***scene***. When the scene is rendered, material finishes and other effects are calculated based on the lighting used. Computer rendering programs require greater amounts of resources in order to perform the calculations needed. The original model may be created within the program, or it may be imported from a different modeling program with less rendering capability.

Some modeling and rendering programs allow you to animate models so that they can be shown in actual operation. Models created in this manner are assigned movement parameters for frame-by-frame animations. Animated models are useful in the architectural field. For example, an architectural project can be presented with an animated tour through a building for a design proposal.

One of the fastest-growing applications of CAD technology is the use of computer-generated animation and imaging for special effects in films. Computer drawing and animation programs are also used for imaging applications in the medical field. While originally conceived for engineering purposes, CAD-based graphics are now used in a variety of industries. Career opportunities in CAD drafting and design will continue to expand as the technology develops.

Figure 7-23 Realistic scenes such as this model of the Apollo spacecraft can be created with the lighting and surface finish controls of an advanced rendering program. (Discreet, a division of Autodesk)

Test Your Knowledge

Please do not write in this book. Place your answers on another sheet of paper.

1. Drawings created in a CAD program are made up of line and arc objects called _____ objects with defined point coordinates in space.
2. In the Cartesian coordinate system, _____ coordinates are located at a given distance and angle from another point.
3. Describe the difference between the world coordinate system and a user-defined coordinate system.
4. A network of uniformly spaced points used as a drawing aid to determine distances is known as what?
5. What are *layers* and what function do they serve in CAD drafting?
6. What is a *template*?
7. Circles are typically drawn by specifying a _____ and a radius or diameter.
8. What editing command is used to orient multiple copies of an object in a regular rectangular or polar pattern?
9. Describe how to create a round or fillet with the **Fillet** command.
10. What display command is used to create a magnified view by windowing a portion of a drawing?
11. What is the difference between a solid model and a surface model?
12. Define *rendering*.

Outside Activities

1. Obtain samples of various types of drawings prepared using a computer. Prepare a bulletin board display with these drawings.
2. Visit an industrial drafting firm that uses a CAD system. Interview a computer workstation operator. How does the CAD system save time? How does it assist with repetitive work? How does it improve productivity? What did the system cost the business? Report to the class what you observed and learned.
3. Visit a computer store that sells CAD equipment. Request literature on the equipment sold. Prepare a bulletin board display with the material.