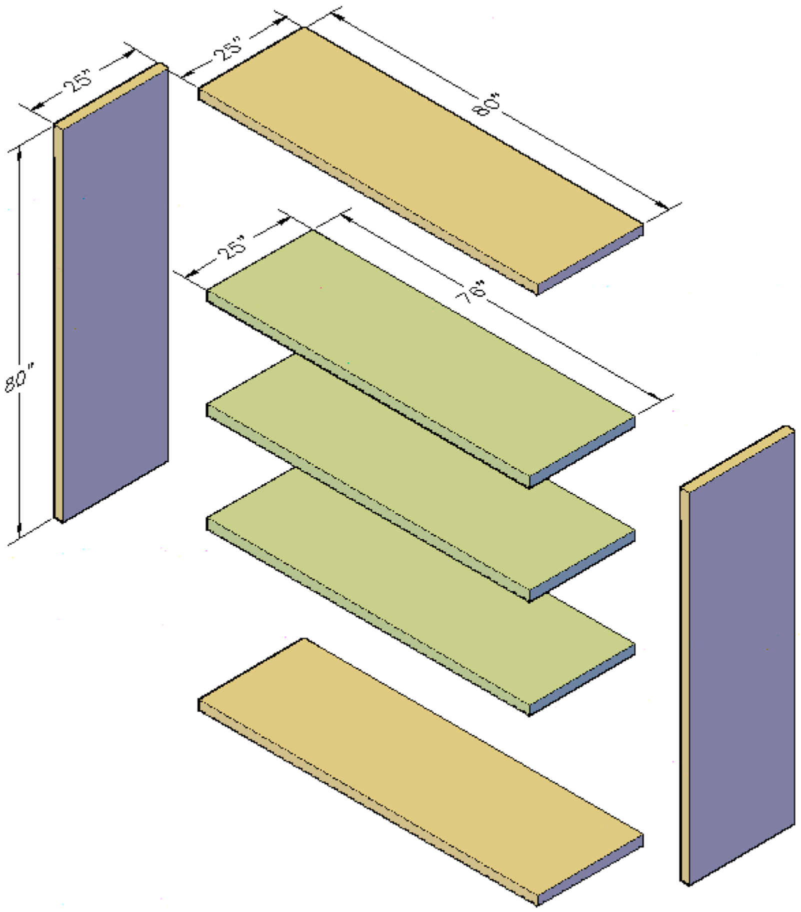
Chapter 22

Object Manipulation



Learning Objectives

In this chapter, we introduce the tools necessary to manipulate objects in 3D space to position them as required by the design. We specifically cover

- Rotate3D
- 3Drotate (gizmo)
- Mirror3D
- 3D array: polar and rectangular
- 3Dscale
- 3Dmove
- Fillets and chamfers in 3D

By the end of this chapter, you will be able to create flat designs of moderate complexity. We introduce multiple small projects throughout this and upcoming chapters to put each new concept to use right away.

Estimated time for completion of this chapter: 2 hours.

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22.1 INTRODUCTION TO OBJECT MANIPULATION

It was already mentioned that extrude is perhaps the single most important command in 3D AutoCAD. Using it, you can create a wide array of objects that are flat in nature, such as building walls, doors, and some furniture, just to name a few items. However, unless you are designing a perfect box of a house, you need to rotate and mirror these objects into position as well as array objects and add fillets or chamfers for more realistic edges. All these tools and more are covered in this chapter. We go through each one and do a few sample exercises. These tools, together with Boolean operations (introduced in the following chapter), are virtually all you need to model a basic architectural design of a building in 3D.

Rotate3D

Although you may not yet have tried it, you can use the regular rotate command in 3D. You can rotate the object on whichever plane you are on. The rotational axis is perpendicular to the plane and the net result is the object "spinning in place." However, you may often want to rotate the object around another axis, for example, make a flat plate "stand up." Recall from the first chapter that you can use the UCS command to simply rotate your active plane and draw new objects that way, but for existing ones you need to use the 3D version of rotate to bring them into position. Rotate3D gives you this ability and is an important design tool.

This command comes in two versions: rotate3D and 3Drotate. The difference is that the former is command driven and the latter uses a graphical "gizmo" to facilitate rotation. We try both, starting with rotate3D. Draw a flat 10″ × 10″ plate and extrude it to 1″ thickness, as seen in Fig. 22.1, with the Conceptual Visual Style shading on and color added.

Notice the colorful UCS icon at the bottom of the figure. It is very prominent on purpose, because it is the focus of our attention while rotating in 3D. What we want to do right now is rotate the plate so it stands up on its side like a vertical wall. What axis do we pick as a "hinge" around which the plate rotates? Fortunately, we have a choice of two: the X and the Y axes. Rotating around the Z does nothing for us in this case. Notice the similarities of this discussion to the one on UCS rotation in Chapter 21, 3D Basics; it is essentially the same idea.

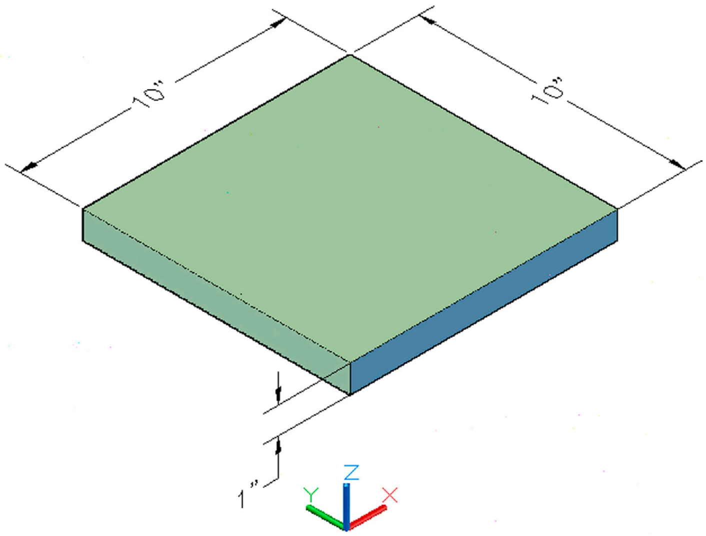


FIGURE 22.1 Flat plate.

So, now that we know what we want to do, let us give the command a try. There is no Ribbon, cascading menu, or toolbar equivalent, so do the following:

Step 1. Type in `rotate3D` and press Enter.

- AutoCAD says: `Current positive angle: ANGDIR = counterclockwise ANGBASE = 0`
  `Select objects:`

Step 2. Select the plate and press Enter.

- AutoCAD says: `Specify first point on axis or define axis by [Object/Last/View/Xaxis/Yaxis/Zaxis/2points]:`

Step 3. Here, you need to choose which axis to rotate around. Let us go with X. Type that in and press Enter.

- AutoCAD says: `Specify a point on the X axis <0,0,0>:`

Step 4. Here, you need to pick the point on the axis of rotation, which should be on the object itself. Using OSNAPs pick the lower left corner point of the plate.

- AutoCAD says: `Specify rotation angle or [Reference]:`

Step 5. Here, you can enter any numerical value, but let us stay with 90° for now. Type in `90` and press Enter. The plate rotates 90° around the X axis and stands on its end, as in Fig. 22.2.

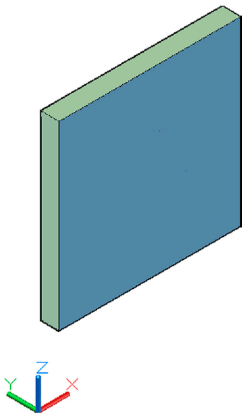


FIGURE 22.2 Plate 3D rotation around the X axis.

In the same exact manner, practice rotating the plate around the other axes. From where it is right now in Fig. 22.2, a rotation around the Z axis makes it face the lower left side of the page. A rotation around the X axis makes it lay down flat again, and a rotation around the Y axis produces no visible results, aside from a shift in position, as the plate is a perfect 10″ × 10″ square.

3Drotate (Gizmo)

An alternative approach to rotating in 3D is a relatively new tool called a *gizmo*. The net result is exactly the same as with the typed command just covered, but the approach is more graphical in nature. Also, toolbar, Ribbon, and cascading menu approaches are available, as seen here in the command matrix.

Keyboard: Type in **3drotate** and press Enter
Cascading menus: **Modify→3D Operations→3D Rotate**
Toolbar icon: **Modeling** toolbar 
Ribbon: **Home** tab→**Modify** 

When you start up the command via any of the preceding methods, you are asked to select the object in question and you see the gizmo shown in Fig. 22.3.

The purpose behind this tool is to be able to easily visualize rotational motion. Following the command line directions, pick a base point, then the circular band that best represents the rotational axis of motion you want. Finally, enter an angle, and the shape is rotated. This all closely matches the previous method and detailed steps are not given, as they are essentially the same. A snapshot of the gizmo in action is shown in Fig. 22.4. Practice both approaches and stick with the one you prefer.

Be sure to understand these procedures thoroughly. Next, we put everything together and draw our first real 3D project, a chair, then move on to mirror3D.

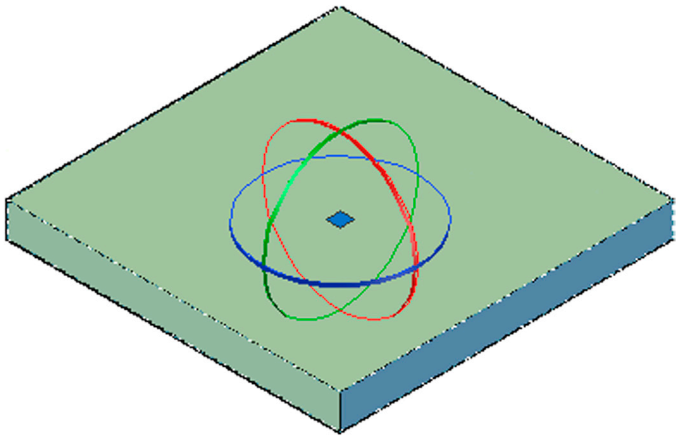


FIGURE 22.3 Gizmo tool.

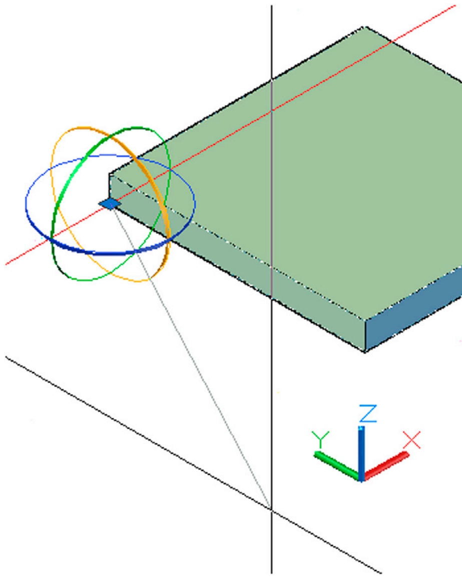


FIGURE 22.4 Gizmo tool rotating an object.

3D Modeling Exercise: Chair

Create the model of a chair based on the dimensions given in Fig. 22.5. The full assembly, at a slightly different angle, is shown in Fig. 22.6. Specifically, you need to

- Create four 2″ × 2″ rectangles extruded 30″ for the legs.
- Create two 24″ × 24″ rectangles extruded 2″ for the seat and backrest.
- Rotate3D one of the rectangles 30° from vertical for the reclining backrest.
- Make sure everything fits together perfectly, adding shading and color of your choice.

Mirror3D

Mirror3D is similar in approach to rotate3D. Much like before, you can use the regular 2D mirror command, but this results in mirroring in the current plane only. What we need is the ability to mirror between any planes. As you may have guessed, the key here is selecting the correct plane (as opposed to axis) to mirror over. Just as a reminder, we have three axes (X, Y, and Z) and three unique planes (XY, ZX, and YZ). Unlike the axes, you do not see the planes; it is something you must envision in your mind. Think of them as a thin sheet of glass that slices through parts. Whatever is on the other side is the mirror image. Erase your chair and let us start with a clean screen. Draw the previous 10″ × 10″ flat plate extruded to 1″ (Fig. 22.7).

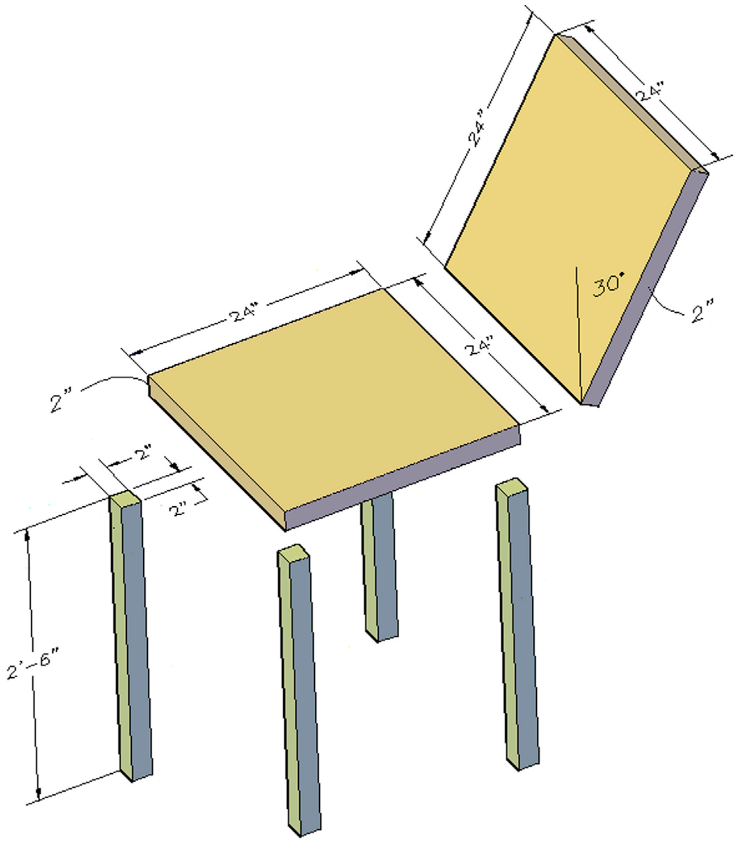


FIGURE 22.5 Drawing project, 3D chair.

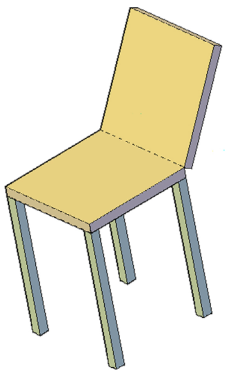


FIGURE 22.6 3D chair, full assembly.

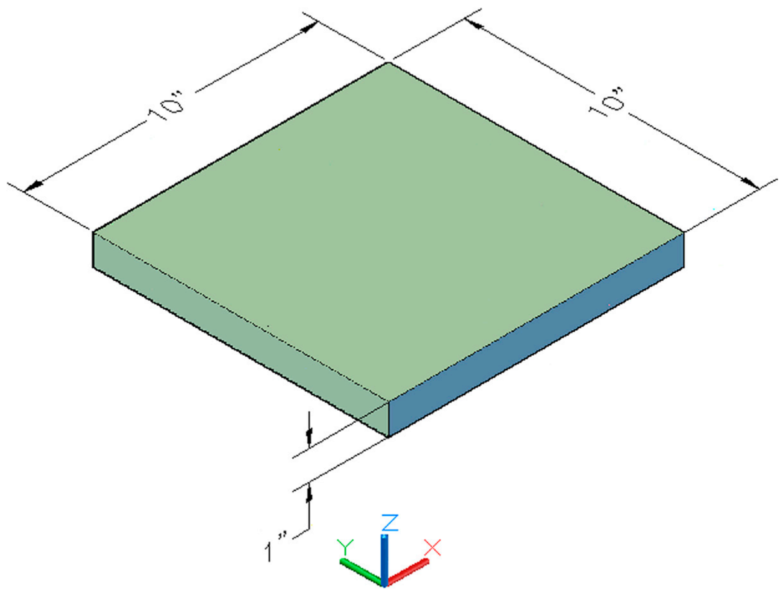


FIGURE 22.7 Flat plate for Mirror3D.

We would like to mirror it so there is another plate next to the darker shaded right side. Before proceeding, identify the correct plane. Remember a plane is not an axis; rather it is formed by two axes put together, so your choices once again are XY, ZX, and YZ. The correct answer is ZX. Do you see why? It is important to be able to quickly recognize these planes. Let us now run through the full mirroring procedure. `Mirror3D` can also be written as `3Dmirror`, with no effect on the command. No gizmo is associated with it, but there is a Ribbon icon, as seen here in the command matrix.

Keyboard: Type in **mirror3d** and press Enter
Cascading menus: **Modify→3D Operations→3D Mirror**
Toolbar icon: none
Ribbon: **Home** tab→**Modify** 

Step 1. Start up the command via any of the preceding methods.

- AutoCAD says: `Select objects:`

Step 2. Select the plate and press Enter.

- AutoCAD says: `Specify first point of mirror plane (3 points) or[Object/Last/Zaxis/View/XY/YZ/ZX/3points] <3points>:`

Step 3. It is here that you need to select the correct plane. As discussed before, type in `ZX` and press Enter.

- AutoCAD says: `Specify point on ZX plane <0,0,0>:`

Step 4. Pick a point somewhere on the mirroring plane using OSNAPs.

- AutoCAD says: `Delete source objects? [Yes/No] <N>:`

Step 5. This is similar to the 2D version of the mirror command. Press Enter for the default. The mirrored image appears as shown in Fig. 22.8.

Go ahead and mirror the two plates over the remaining planes. The procedure is exactly the same, except you type in `YZ` for the first mirror plane and `XY` for the second. The expected results are shown in Figs. 22.9 and 22.10, respectively.

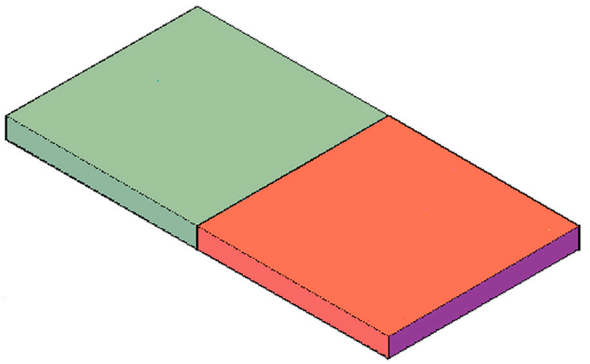


FIGURE 22.8 Flat plate mirrored over the ZX plane.

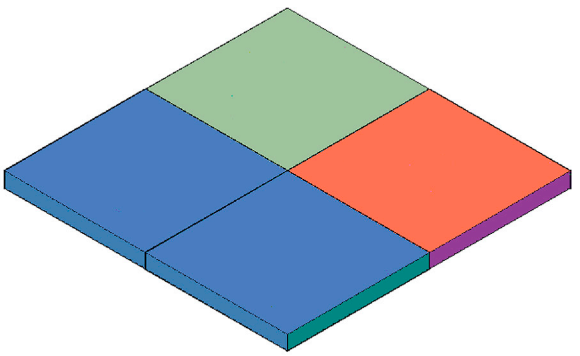


FIGURE 22.9 Flat plates mirrored over the YZ plane.

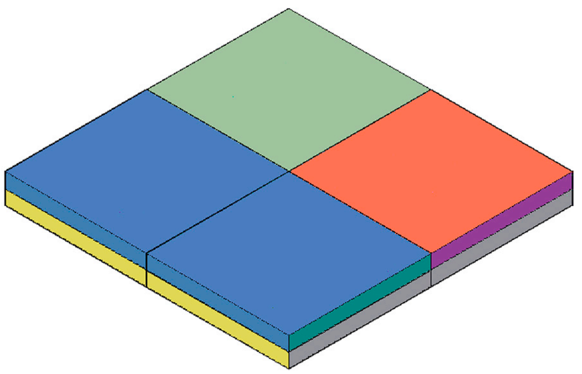


FIGURE 22.10 Flat plates mirrored over the XY plane.

3D Modeling Exercise: Bookshelf

Create the model of a bookshelf based on the dimensions given in Fig. 22.11. The full assembly is shown in Fig. 22.12. Specifically you need to

- Create four 25″ × 80″ rectangles extruded 2″ for the top, bottom, and side shelves.
- Create three 25″ × 76″ rectangles extruded 2″ for the inner shelves.
- Rotate3D any parts that need to be rotated according to design requirements.
- Keep in mind that the distances between inner shelves can be a random value.
- Make sure everything fits together perfectly, adding shading and color of your choice.

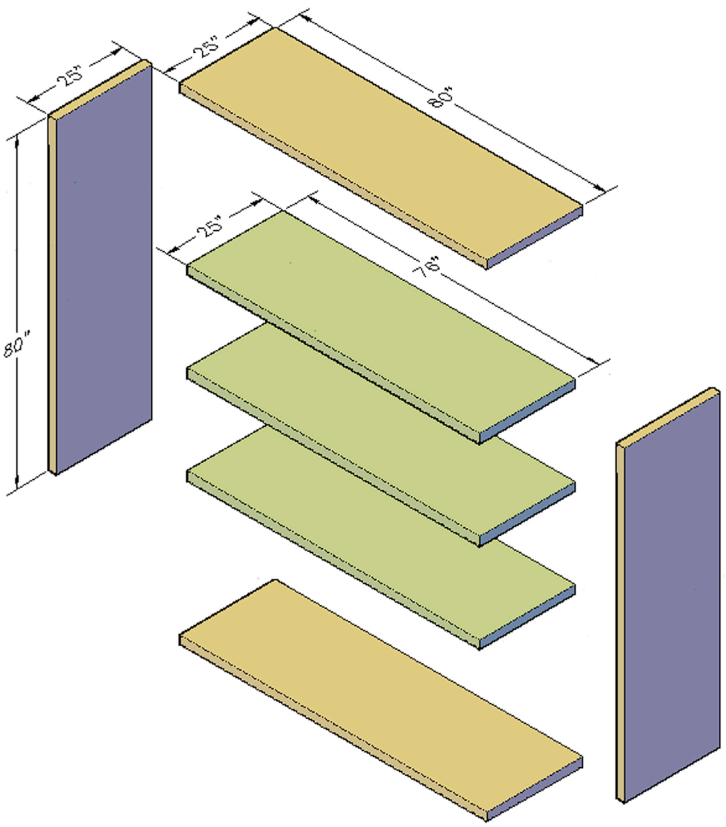


FIGURE 22.11 Drawing project, 3D bookshelf.

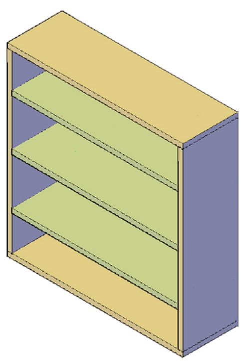


FIGURE 22.12 3D bookshelf, full assembly.

3Darray

The 3Darray is quite similar in principle to the regular 2D one. There is, for starters, both a rectangular and polar form, just as in 2D. With the rectangular array, you just add a 3D component (a level) to the familiar column and row. For the polar array, the one big difference is that two points define the axis of rotation instead of just one point for the center. Another difference is the curious fact that 3Darray is all command-line driven; there is no dialog box.

Let us go ahead and try out the command, starting with the rectangular array. Clear your screen and draw a 2″ × 3″ rectangle extruded to 4″, as seen in Fig. 22.13. Add shading and a color of your choice.

Keyboard: Type in **3darray** and press Enter
Cascading menus: **Modify→3D Operations→3D Array**
Toolbar icon: **Modeling** toolbar
Ribbon: **Home** tab→**Modify**

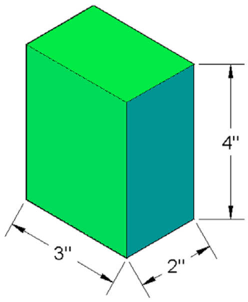


FIGURE 22.13 Extruded block for 3D rectangular array.

Step 1. Start up 3D array via any of the preceding methods.
- AutoCAD says: Select objects:

Step 2. Select the cube and press Enter.
- AutoCAD says: Enter the type of array [Rectangular/Polar]<R>:

Step 3. Press Enter to accept the default Rectangular array.
- AutoCAD says: Enter the number of rows (---) <1>:

Step 4. Enter a small value, such as 5, and press Enter.
- AutoCAD says: Enter the number of columns (|||) <1>:

Step 5. Enter a small value, such as 5, and press Enter.
- AutoCAD says: Enter the number of levels (…) <1>:

Step 6. Enter a small value, such as 5, and press Enter.
- AutoCAD says: Specify the distance between rows (---):

Step 7. Here, be sure to enter a number large enough to allow for space between the rows, 10 in this case.
- AutoCAD says: Specify the distance between columns (|||):

Step 8. Be sure to enter a number large enough to allow for space between the columns, 10 in this case.
- AutoCAD says: Specify the distance between levels (…):

Step 9. Be sure to enter a number large enough to allow for space between the levels, 10 in this case.

The result of the array with the 125 elements is shown in Fig. 22.14. This exact type of array may not be used that often but is still valuable to know. Next, we go over the vastly more useful polar version.

To demonstrate the polar array, we draw an axle with spokes. To create an axle, draw a circle 5″ in diameter and extrude it to 36″. Then, draw a small spoke, say a 1″ circle extruded to 10″, and position it carefully in a perpendicular manner on the tip of the axle. You likely have to rotate3D the spoke into position and attach it using quadrant or center points. After adding shading and color, the result is as shown in Fig. 22.15.

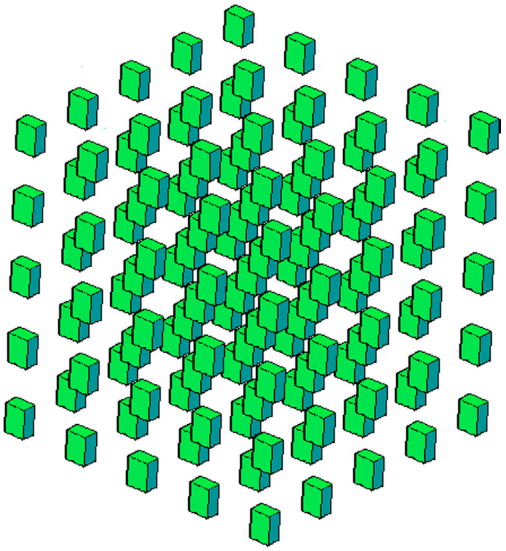


FIGURE 22.14 3D rectangular array.

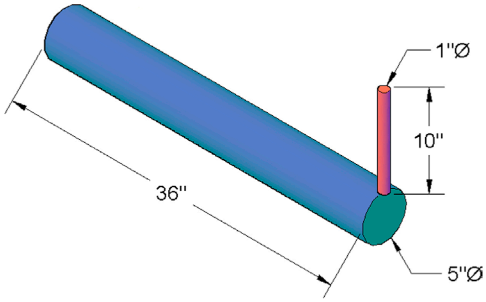


FIGURE 22.15 Axle and spoke for 3D polar array.

Step 1. Start up 3D array via any of the same methods shown earlier in the matrix for the rectangular array.
- AutoCAD says: `Select objects`:

Step 2. Select the spoke and press Enter.
- AutoCAD says: `Enter the type of array [Rectangular/Polar]<R>:`

Step 3. Press `p` to accept the polar array.
- AutoCAD says: `Enter the number of items in the array:`

Step 4. You can enter any value, but let us stick to `10` in this case.
- AutoCAD says: `Specify the angle to fill (+=ccw, −=cw) <360>:`

Step 5. Press Enter to accept the default 360°, as we would like to go all the way around.
- AutoCAD says: `Rotate arrayed objects? [Yes/No] <Y>:`

Step 6. Press Enter for `Yes`, as we want the spokes to rotate.
- AutoCAD says: `Specify center point of array`:

Step 7. Here, you need to specify the center of rotation. Pick the center of the axle using the Center OSNAP.
- AutoCAD says: `Specify second point on axis of rotation:`

Step 8. Here, you need to pick the second center point using OSNAPs on the other side of the axle. These two points together indicate the axis of rotation for the spokes. The result is shown in Fig. 22.16.

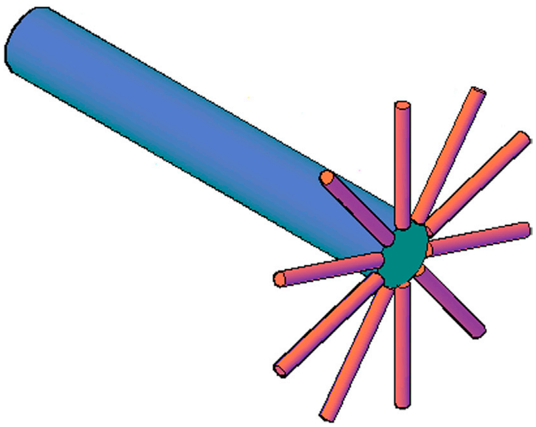


FIGURE 22.16 Completed 3D polar array.

3Dscale

This 3D version of the scale command is not much different from the regular scale (which you can also use in 3D). There is no icon or cascading menu for this command; you have to type it in or use the Ribbon. Draw a basic 3D shaded cube as you did just before for 3Darray. It is reproduced again with a different color (Fig. 22.17).

Keyboard: Type in **3dscale** and press Enter
Cascading menus: none
Toolbar icon: none
Ribbon: **Solid** tab→**Selection** 

Step 1. Start up the 3Dscale command via one of the two preceding methods.

- AutoCAD says: `Select objects:`

Step 2. Select the cube and press Enter.

- AutoCAD says: `Specify base point:`

Step 3. You also see a scaling gizmo appear, which snaps to whatever base point you select (Fig. 22.18).

- AutoCAD then says: `Pick a scale axis or plane:`

Step 4. Pick the XY plane. You can then move the mouse to scale the object or type in a value, as seen in Fig. 22.19.

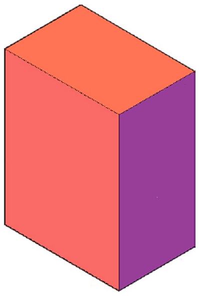


FIGURE 22.17 Extruded block for 3D scale.

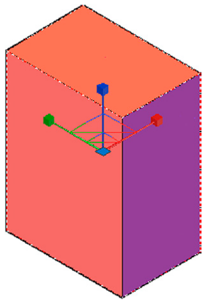


FIGURE 22.18 3Dscale gizmo.

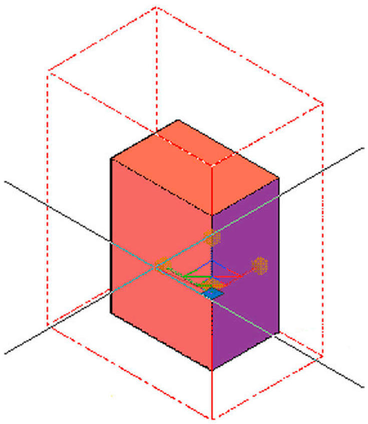
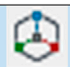


FIGURE 22.19 3Dscale in progress.

3Dmove

Just as 3Dscale was somewhat of a duplication of the regular scale command, so is 3Dmove. However, there is a difference, as this command allows for constrained movement of an object along any selected axis or plane, regardless of your UCS orientation or whether or not Ortho is on. In that regard, it is quite useful, because just randomly moving an object in 3D space (with no constraint, such as Ortho) places the object literally anywhere, and usually nowhere near where you think it is in relation to other objects. The 3D space is quite deceptive. For proof of this, try moving something then using 3D Orbit to glance at the objects from a different perspective. You may be surprised where it really is. Let us try the 3Dmove command on the same random cube you just used.

Keyboard: Type in **3dmove** and press Enter
Cascading menus: **Modify→3D Operations→3D Move**
Toolbar icon: **Modeling** toolbar→ 
Ribbon: **Solid tab→Selection** 

Step 1. Start up the 3Dmove command via any of the preceding methods.

- AutoCAD says: `Select objects:`

Step 2. Select the cube and press Enter.

- AutoCAD says: `Specify base point or [Displacement] <Displacement>:`

Step 3. A 3Dmove gizmo appears, but do *not* pick a base point. Instead, use the mouse to carefully select an axis. As soon as you do, the axis turns gold in color. The cube is constrained (even if Ortho is not on), and you can now slide the cube up and down that axis, as seen in Fig. 22.20.

The procedure is the same for the Y and Z axes. If you select a plane, however, you do need to have Ortho on to be constrained to the chosen plane.

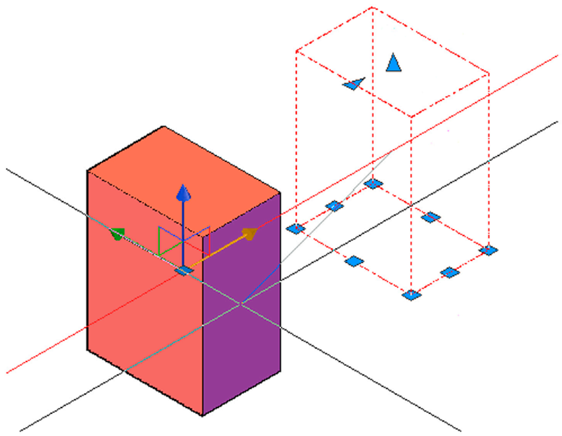


FIGURE 22.20 3Dmove in progress (X axis).

Fillets and Chamfers in 3D

Recall the operation of the fillet command (with a radius of zero) in 2D AutoCAD. You could use the command to trim two intersecting lines or close a gap between those lines. None of that makes any sense when working with 3D models, which are, by definition, already closed shapes. However, recall also that, in 2D, we gave fillets radiuses. We use this feature in 3D by adding radiuses or rounded corners on solid objects. In a way we now use the original and more correct form of the fillet command, which by definition has always been a rounded corner.

There are two ways to work with the fillet command in 3D. One way is by using the 2D approach, that is, typing, toolbar, cascading menu, or Ribbon. The other is via the dedicated Fillet tool available as part of the Solid Editing toolbar. The result is the same but the approach is different. Let us try the 2D version first.

Draw a 12″ × 8″ box and extrude it to 10″, as seen in Fig. 22.21.

Step 1. As first described in Chapter 1, AutoCAD Fundamentals—Part I, start up fillet via any method you choose.

- AutoCAD says: `Current settings: Mode = TRIM, Radius = 0.0000`
  `Select first object or [Undo/Polyline/Radius/Trim/Multiple]:`

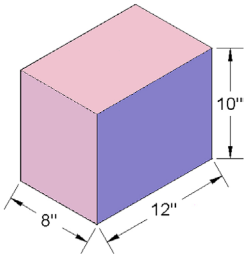


FIGURE 22.21 Extruded block for fillet.

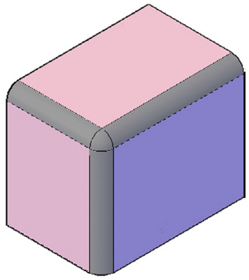


FIGURE 22.22 3D fillet.

Step 2. Press `r` for `Radius`.

- AutoCAD says: `Specify fillet radius <0.0000>:`

Step 3. Enter a reasonable value such as `1″` and press Enter.

- AutoCAD says: `Select first object or [Undo/Polyline/Radius/Trim/Multiple]:`

Step 4. Select one of the cube edges facing you.

- AutoCAD says: `Enter fillet radius <1.0000>:`

Step 5. Confirm this by pressing Enter and continue selecting the remaining two edges. Each time,

- AutoCAD says: `Select an edge or [Chain/Radius]:`

Step 6. After all three edges are selected, you see them dashed. Finally press Enter.

- AutoCAD says: `3 edge(s) selected for fillet.`

The result is shown in Fig. 22.22.

The color of the fillets may be different from the rest of the object, as seen in Fig. 22.22. This depends on what layer is active as you perform the fillet. In this case it was 0, and the color defaults to the standard gray (shown in dark gray, here), although the block itself is colored (shown here in medium and light gray).

The 3D version of fillet is a bit more dynamic in nature. Create another 12″ × 10″ × 8″ box and use the commands seen in the following matrix.

Keyboard: Type in **filletedge** and press Enter
Cascading menus: **Modify→Solid Editing→Fillet edges**
Toolbar icon: **Solid Editing** toolbar→ 
Ribbon: **Solid** tab→**Solid Editing** 

AutoCAD says: `Radius = 1.0000 Select an edge or [Chain/Radius]:`

Select the edge to be filleted and it becomes shaded. You may change the radius or press Enter to accept. You then see a red triangle (a grip). Click on it and drag your mouse back and forth, noting how the fillet changes dynamically, as seen in Fig. 22.23.

Click again and press Enter to confirm the final fillet. While this looks impressive, in most cases, you will likely want to specify an exact fillet size, so the dynamic filleting may not find much use in real design work.

Chamfering is quite similar, so we do not run through the specific steps, but you can also do it through the standard 2D approach or via the 3D dynamic chamfer, as shown next with the command matrix.

Keyboard: Type in **chamferedge** and press Enter
Cascading menus: **Modify→Solid Editing→Chamfer edges**
Toolbar icon: **Solid Editing** toolbar→ 
Ribbon: **Solid** tab→**Solid Editing** 

Once again the edge to be chamfered is shaded and you must enter sizes when prompted or press Enter to accept. You then see two triangular grips this time (Fig. 22.24). Each can be moved to dynamically expand the sides of the chamfer. As with the fillet, you may want to just type in the value.

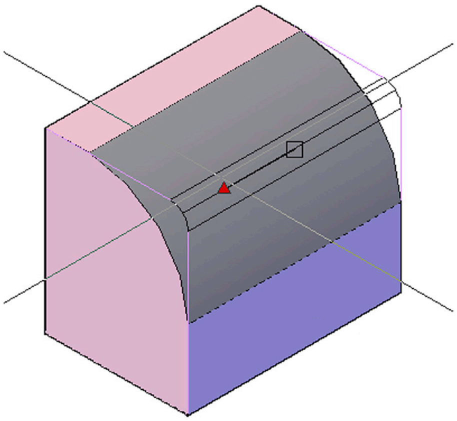


FIGURE 22.23 3D fillet.

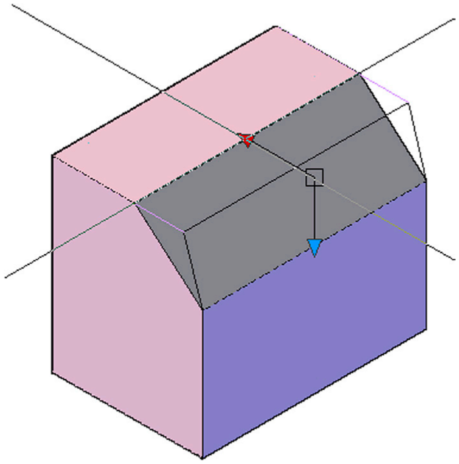


FIGURE 22.24 Dynamic chamfering in 3D.

Review everything covered in this chapter. In the next chapter, we cover Boolean operations, the final key to flat design.

22.2 SUMMARY

You should understand and know how to use the following concepts and commands before moving on to Chapter 23, Boolean Operations and Primitive:

- Rotate3D
- 3Drotate (gizmo)
- Mirror3D
- 3Darray
- Polar
- Rectangular
- 3Dscale
- 3Dmove
- Fillets in 3D
- Chamfers in 3D

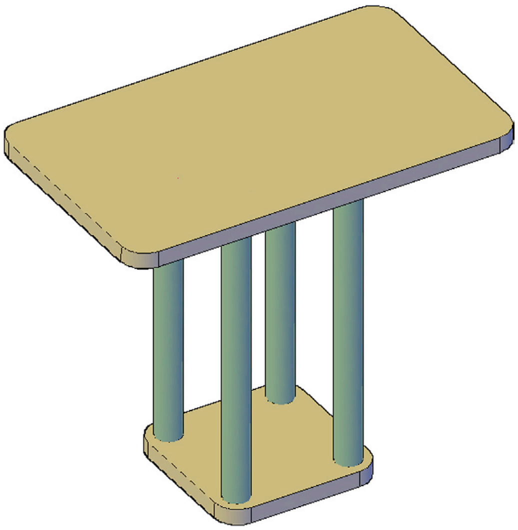
Review Questions

Answer the following based on what you learned in this chapter:

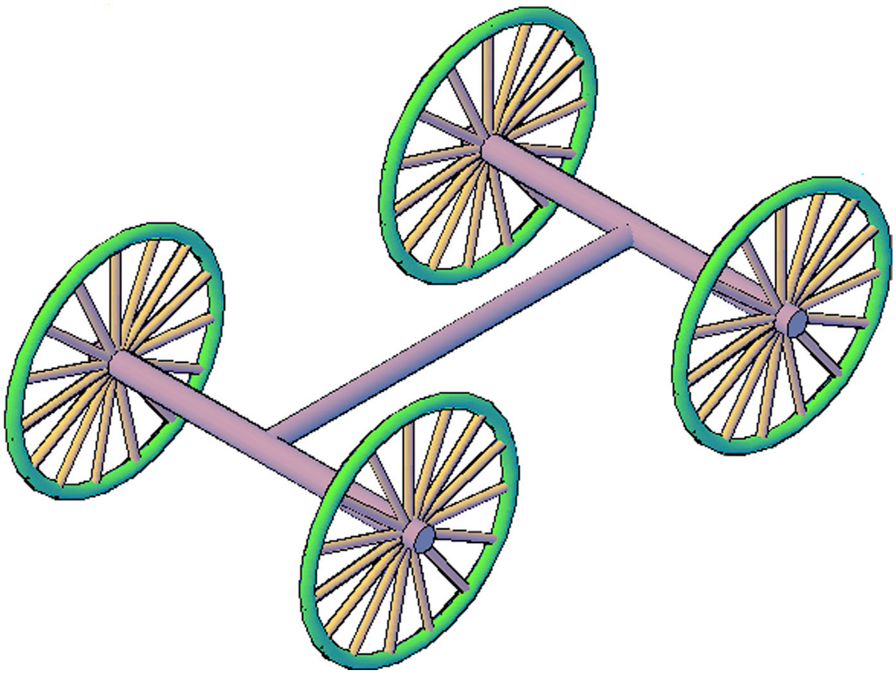
1. Describe the rotate3D procedure. Do you need axes or planes for this command?
2. How is 3Drotate different from rotate3D?
3. Describe the mirror3D procedure. Do you need axes or planes for this command?
4. Describe the 3Darray procedure, both rectangular and polar.
5. Describe 3Dscale and 3Dmove.
6. Describe fillets and chamfers in 3D.

Exercises

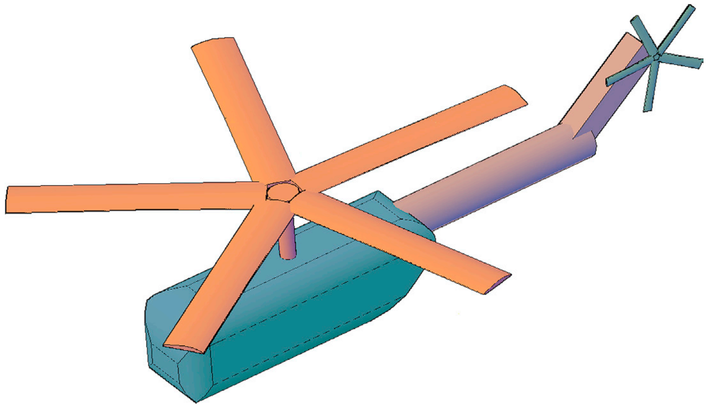
1. Create the following table using the rectangle, circle, extrude, fillet, mirror3D, and a few other commands. The exact size of the table can be anything you want, but if you need some values to get started, the tabletop is 50″ × 30″ and the bottom is 20″ × 20″. All fillets and thicknesses are 2″. (Difficulty level: Easy; Time to completion: 10 minutes.)



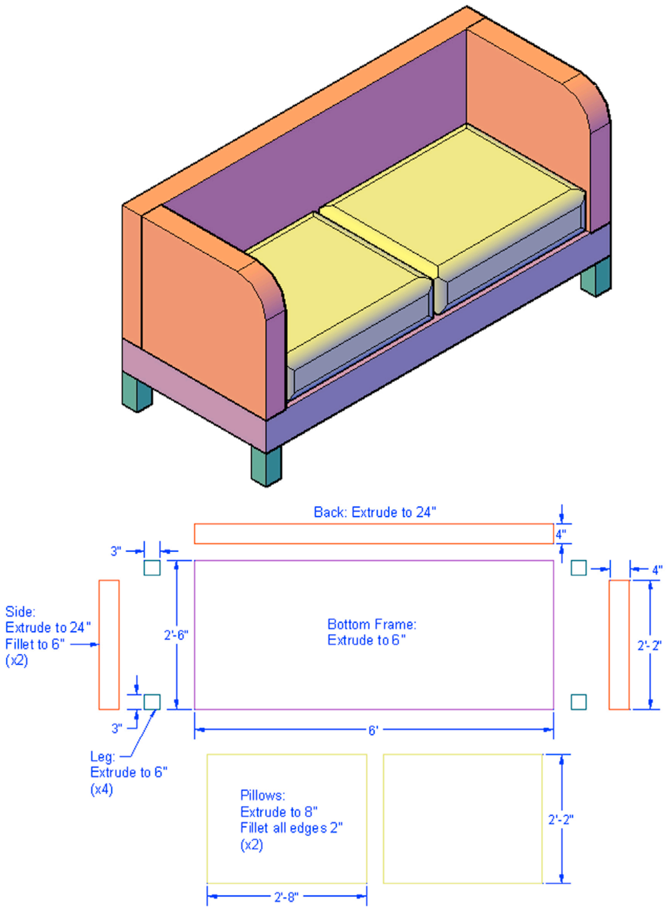
2. Create the following buggy frame. You will need the circle, extrude, 3Darray, donut, copy, and some of the UCS rotation commands. Once again, sizing is not what is important here, but you can make the two main axles 72″ in length and base everything else on that. (Difficulty level: Moderate; Time to completion: 15 minutes.)



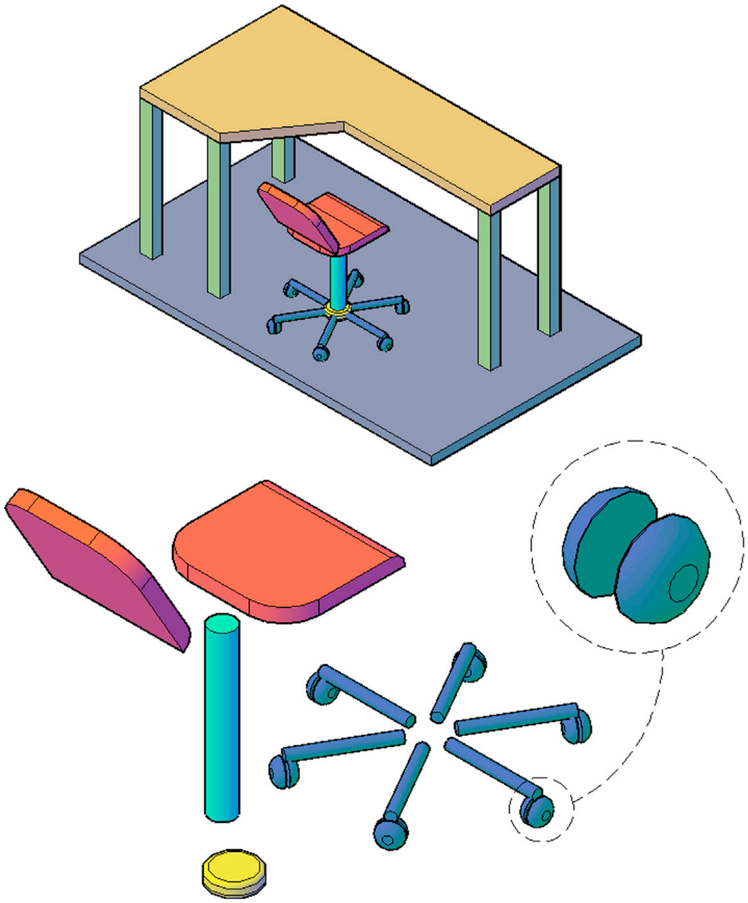
3. Create the following helicopter model using the tools you learned in this chapter. While this design will not win any awards, it will really get you using recently learned commands, such as extrude, fillet, rotate3D, and 3Darray. Start out by creating a basic blade profile (an airfoil) using pline. Then, extrude it and 3Darray the resulting blade around a rotor, similar to the axle and spokes in the previous exercise. Create the body using extrude and fillet. Attach a tail using basic extrude and scale down a copy of the main rotor for the tail rotor, placing everything into position. Finally, shade and color the model. Sizing is up to you. (Difficulty level: Moderate; Time to completion: 30 minutes.)



4. Create the following model of a basic couch. It consists of a lower main frame, backside, and left and right sides (which are filleted). Then add in four legs and two pillows. All the shapes, and their sizing and extrusions, are outlined beneath the model. Set up layers and colors as you see fit. (Difficulty level: Moderate; Time to completion: 15–20 minutes.)



5. Here is one more set of furniture to work on. Create the following table, chair, and floor scene. It is shown from one main angle as well as an additional "exploded" view, and a detail of the wheel. In this exercise, no dimensions are given, so use whatever you think is reasonable—the focus here is on the AutoCAD commands. The floor, legs, and table are all basic extrusions. The chair features extrusions, 3Darray, mirror3D, rotate3D, and some filleting. The "wheels" of the chair are nothing more than an extrusion with a large fillet on one side to form a half-sphere and mirrored. (Difficulty level: Moderate; Time to completion: 30–45 minutes.)



Spotlight On: Chemical Engineering

Chemical engineering is a unique branch of engineering that combines chemistry, physics, and sometimes biology to process raw materials (often chemicals) into useful products (Fig. 1). Chemical engineers are broadly divided into two categories. The category most people associate with the profession is “process engineering.” Here, the focus is on the design and operations of industrial plants (Fig. 2). The second category, less known, but just as important, is “product engineering.” Here, the engineers are tasked with development of chemical substances for products such as cleaners, pharmaceuticals, and other items, including food and beverages.

Often students ask how exactly chemical engineering is different from chemistry. The difference is that chemists generally work with basic compositions of materials, on the atomic and molecular level, using this knowledge to synthesize products. Chemical engineers (and some *applied* chemists), however, are more interested in developing higher level “end user” products and industrial processes. These processes utilize scientific principles but do not develop them. Chemists come up with our fundamental knowledge; chemical engineers apply it in ways useful to society.

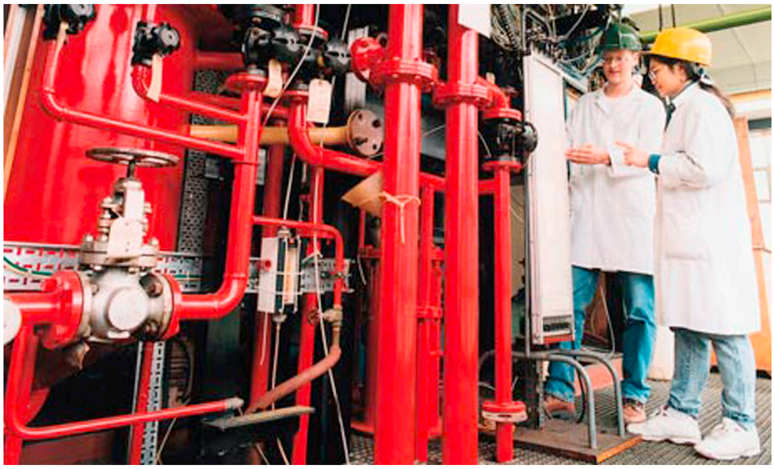


FIGURE 1

Education for chemical engineers starts out similar to education for the other engineering disciplines. In the United States, all engineers typically have to attend a 4-year ABET-accredited school for their entry level degree, a Bachelor of Science. While there, all students go through a somewhat similar program in their first 2 years, regardless of future specialization. Classes for chemical engineers include extensive math, physics, chemistry, and thermodynamics. In their final 2 years, chemical engineers specialize by taking courses in biochemistry, kinetics, transport processes, polymer science, and materials, among others.

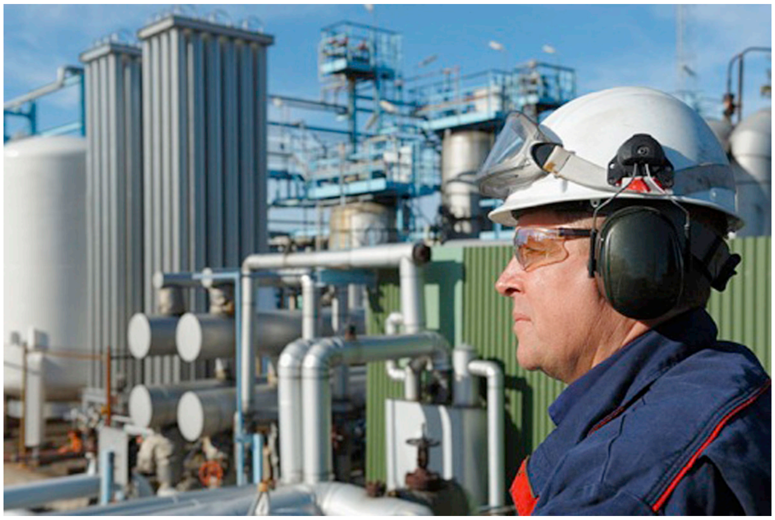


FIGURE 2

Upon graduation, chemical engineers can immediately enter the workforce or go on to graduate school. Although not required, some engineers choose to pursue a Professional Engineer (P.E.) license. The process first involves passing a Fundamentals of Engineering (F.E.) exam, followed by several years of work experience under a registered P.E., finally sitting for the Chemical Engineering P.E. exam itself.

Chemical engineers can generally expect starting salaries in the $65,000/year range with a bachelor's degree and $77,000 with a masters (2011 data), which is one of the highest among engineering specialties, just behind petroleum engineering, which in itself is a field that attracts some chemical engineers. The 2014 median annual pay was $96,940. This, of course, depends highly on market demand and location. A master's degree is highly desirable and required for many management spots.

So, how do chemical engineers use AutoCAD and what can you expect? One major application of AutoCAD in this profession is P&ID. This is a topic that was mentioned in several Level 1 chapters, with a few corresponding exercises. P&ID stands for "piping and instrumentation diagrams," and these are commonly used in chemical and process engineering with respect to plant design. A basic P&ID diagram is shown in Fig. 3.

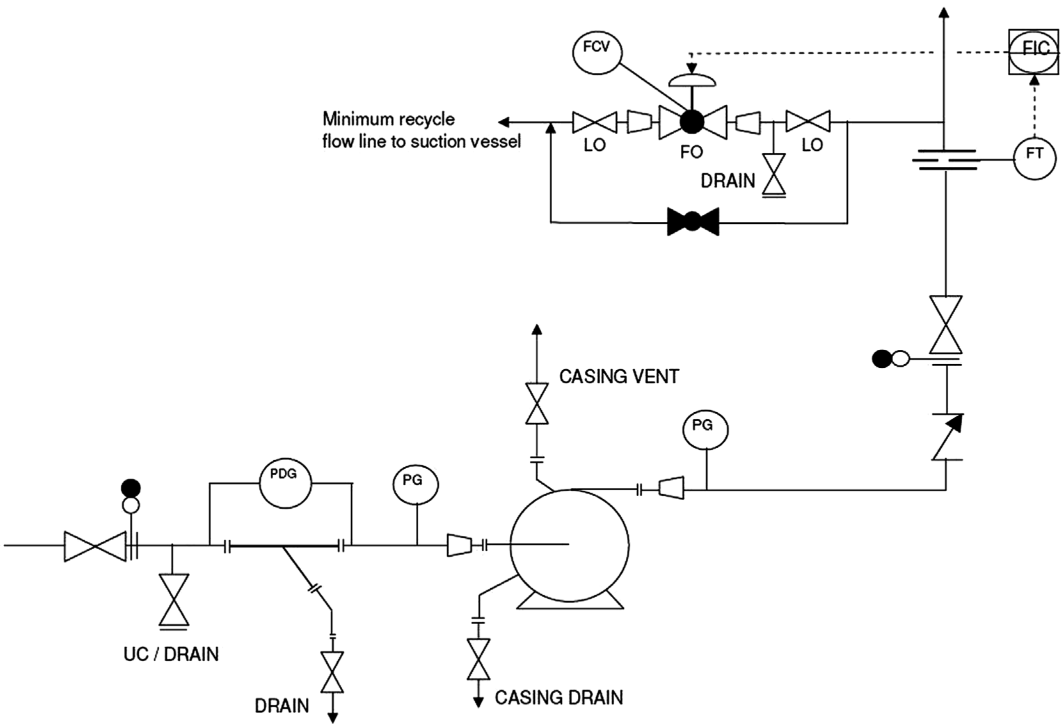


FIGURE 3 Basic P&ID diagram.

Much like electrical schematics, most P&IDs are 2D in nature (though 3D models are used on occasion) and inherently simple from an AutoCAD perspective, though probably far from simple in the engineering sense. The key here is accuracy and precision! The schematics have to be easy to understand and read, and that may be the biggest challenge and responsibility of drafting—to present a complex design in an easy-to-read manner. The layering system is relatively straightforward, with layer names reflecting the functionality of the pieces. Expect to see modular design, symbol libraries, and data-embedded blocks, a.k.a. *attributes*, in this field.

Autodesk has an add-on package to automate and simplify working on P&IDs called, unsurprisingly, *AutoCAD P&ID*. It has tools to assist with error checking, managing data, and symbol libraries. Autodesk also makes Plant 3D, for design and visualization of plant design. There are of course other companies in the market, such as PROCAD, Bentley and its OpenPlant software, Siemens with Cosmos P&ID, and Intergraph's SmartPlant. If your career takes you into this field, you will likely encounter these design and testing packages.