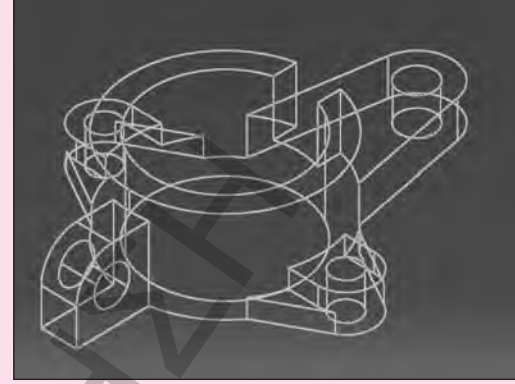


Design and 3-D Modeling



OBJECTIVES

After completing this chapter, you will be able to:

1. Describe the engineering design process and the role graphics plays.
2. Describe concurrent engineering and design for manufacturability (DFM).
3. Describe the types of modeling systems used in 3-D modeling.
4. Explain the role 3-D modeling plays in the engineering design process.
5. List and describe the modeling techniques used in design.
6. Describe the rapid prototyping process.
7. List and describe the analysis techniques used in design.
8. Explain how graphing and visualization can be used in the design process.
9. Describe the total quality management (TQM) process.

6.1 ENGINEERING DESIGN

Design is the process of conceiving or inventing ideas mentally and communicating those ideas to others in a form that is easily understood. Most often the communications tool is graphics.

Engineering design is one of the processes normally associated with the entire business or enterprise, from receipt of the order or product idea, to maintenance of the product, and all stages in between (Figure 6.1). The design process requires input from such areas as customer needs, materials, capital, energy, time requirements, and human knowledge and skills.

6.1.1 Traditional Engineering Design

Traditional engineering design is a linear approach divided into a number of steps. For example, a six-step process

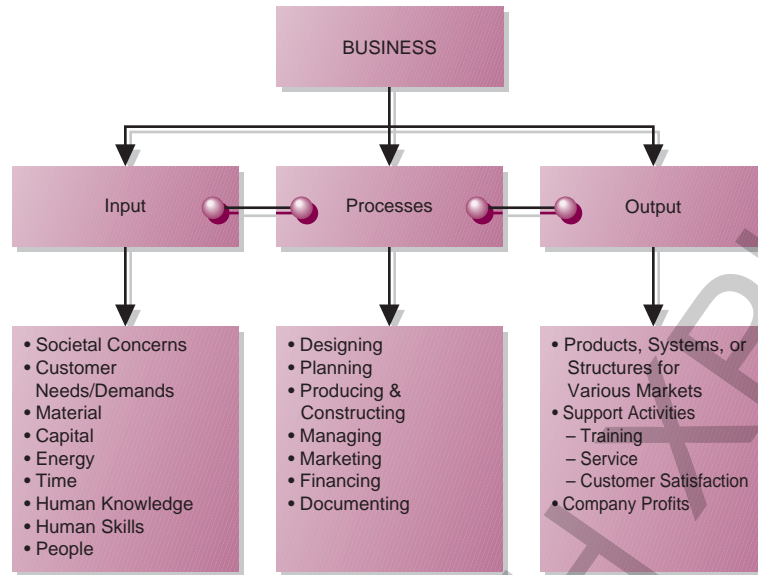


Figure 6.1 The Business Process

A manufacturing business or enterprise includes all the inputs, processes, and outputs necessary to produce a product or construct a structure. Designing is one of the major processes in such a business.

might be divided into problem identification, preliminary ideas, refinement, analysis, documentation, and implementation. The design process moves through each step in a sequential manner; however, if problems are encountered, the process may return to a previous step. This repetitive action is called **iteration** or looping. Many industries use the traditional engineering design process; however, a new process is developing that combines some features of the traditional process with a team approach that involves all segments of a business.

6.1.2 Concurrent Engineering Design

The **production process** executes the final results of the design process to produce a product or system. In the past, the creative design process was separated from the production process. With the advent of computer modeling, this separation is no longer necessary, and the modern engineering design approach brings both processes together.

Concurrent engineering is a nonlinear team approach to design that brings together the input, processes, and output elements necessary to produce a product. The people and processes are brought together at the very beginning, which is not normally done in the linear approach. The team consists of design and production engineers, technicians, marketing and finance personnel, planners, and managers,

who work together to solve a problem and produce a product. Many companies are finding that concurrent engineering practices result in a better, higher-quality product, more satisfied customers, fewer manufacturing problems, and a shorter cycle time between design initiation and final production.

Figures 6.2 and 6.3 represent the concurrent approach to engineering design, based on 3-D modeling. The three intersecting circles represent the concurrent nature of this design approach. For example, in the ideation phase, design engineers interact with service technicians to ensure that the product will be easily serviceable by the consumer or technician. This type of interaction results in a better product for the consumer. The three intersecting circles also represent the three activities that are a major part of the concurrent engineering design process: ideation, refinement, and implementation. These three activities are further divided into smaller segments, as shown by the items surrounding the three circles.

The center area in Figure 6.3 represents the 3-D computer model and reflects the central importance of 3-D modeling and graphics knowledge in engineering design and production. With the use of a modeling approach, everyone on the team can have access to the current design through a computer terminal. This data sharing is critically important to the success of the design process.

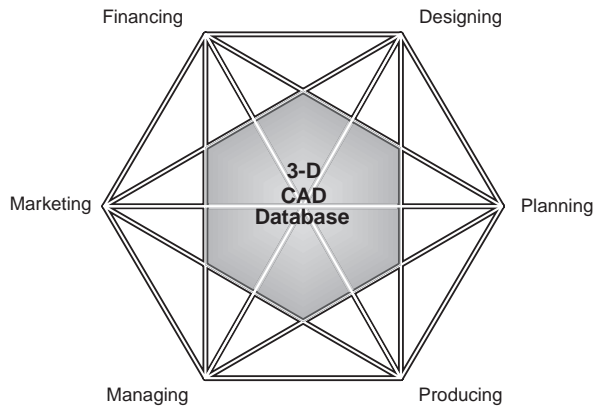


Figure 6.2 Sharing the 3-D CAD Database

The concurrent engineering model shows how every area in an enterprise is related, and the 3-D CAD database is the common thread of information connecting the areas.

Through the sharing of information, often in the form of a database, it is possible for all areas of the enterprise to work simultaneously on their particular needs as the product is being developed. For example, a preliminary 3-D model could be created by the design engineers early in the ideation phase. A mechanical engineer could use the same 3-D model to analyze its thermal properties. The information gained from this preliminary analysis could then be given to the design engineers, who could then make any necessary changes early in the ideation phase, minimizing costly changes later in the design process.

6.2 | 3-D MODELING

Traditionally, the means of communication in the engineering design process was through paper drawings done by hand. With the increasing availability of CAD tools, these 2-D technical drawings are being produced on computer. More recently, 3-D modeling software has become available on increasingly powerful PCs and increasingly inexpensive engineering workstations (Figure 6.4). Because 3-D modeling systems create models of the product being designed, such a system offers considerably more possibilities as to how it can be integrated into the design process than a 2-D CAD drawing does.

The following section offers an overview of the most common approaches for generating 3-D computer models. Because working with a 3-D model is so much different than creating a 2-D drawing, the ways in which these models are

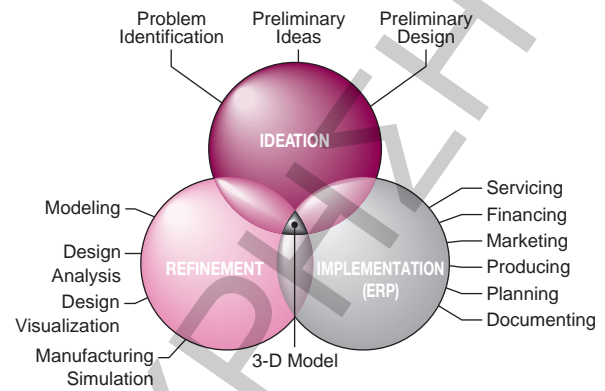


Figure 6.3 Concurrent Engineering Design

The engineering design process consists of three overlapping areas: ideation, refinement, and implementation, which all share the same 3-D CAD database.

constructed and viewed are also discussed. As the various stages of the design process are presented, the ways in which 3-D modeling can play an integral role will be outlined.

6.2.1 Wireframe Modeling

The simplest 3-D modeler is a **wireframe modeler**. In this type of modeler, which is a natural outgrowth of 2-D CAD, two types of elements must be defined in the database: *edges* and *vertices* (Figure 6.5). For the tetrahedron in the figure, the vertex list contains the geometric information on the model. Each vertex is defined by an (X, Y, Z) coordinate, which anchors the model in space. The topology of the model is represented by the edge list. The edge list does not contain coordinate information. The location, orientation, and length of an edge must be derived indirectly, through calculations of the vertices at either end of the edge. For example, edge E1 consists of vertices V1 and V2. The coordinate locations of V1 (0,0,0) and V2 (1,0,0) indicate that E1 has a length of 1 and is oriented along the X axis.

6.2.2 Surface Modeling

Surface models define the surface features, as well as the edges, of objects.

Different types of spline curves are used to create surface patches with different modeling characteristics. For example, the advantage of Bezier surface patches is that they are easy-to-sculpt natural surfaces (Figure 6.6). The control points are an intuitive tool with which the user can work.

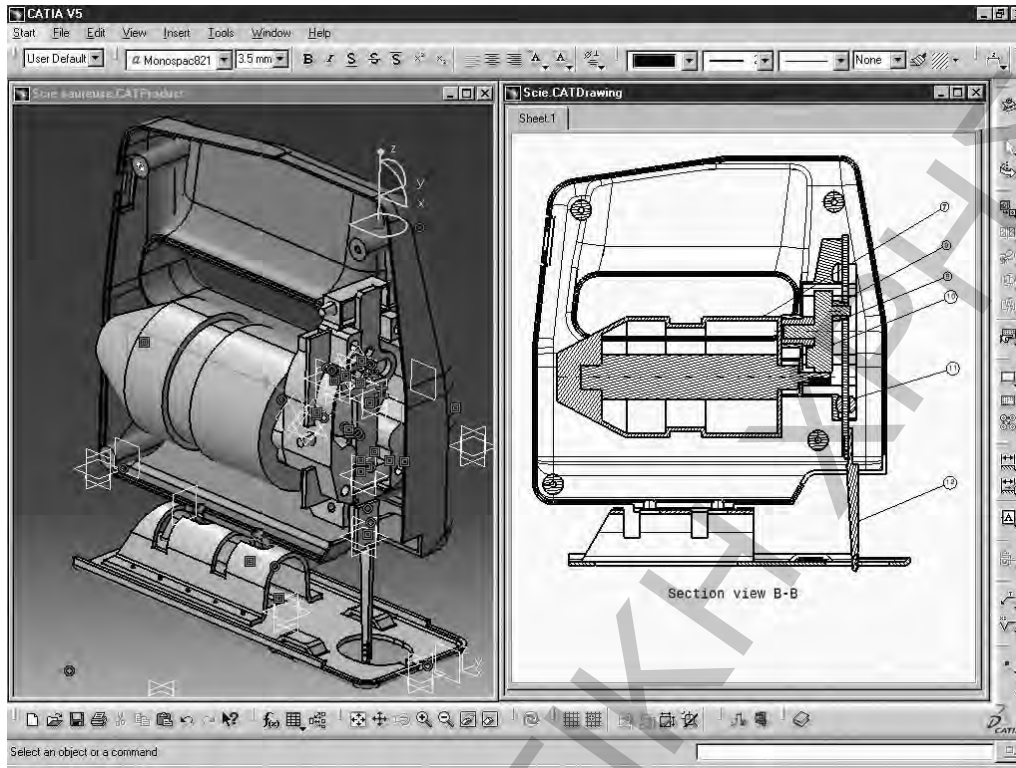


Figure 6.4 Production Drawing

PC workstations are popular for particularly demanding 3-D modeling work. (Copyright of Dassault Systèmes Group.)

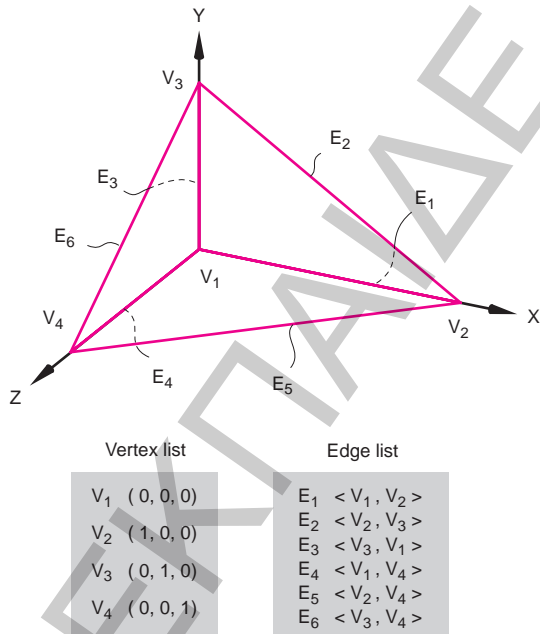


Figure 6.5 The Vertex and Edge List of a Wireframe Model

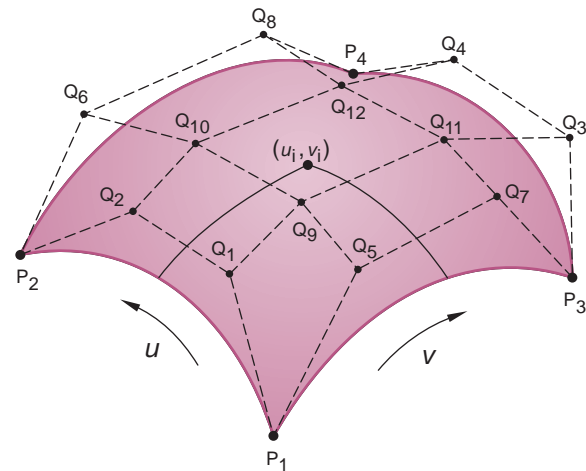


Figure 6.6 A Bezier Bicubic Surface Patch

The patch consists of four connected Bezier curves and 16 control points.

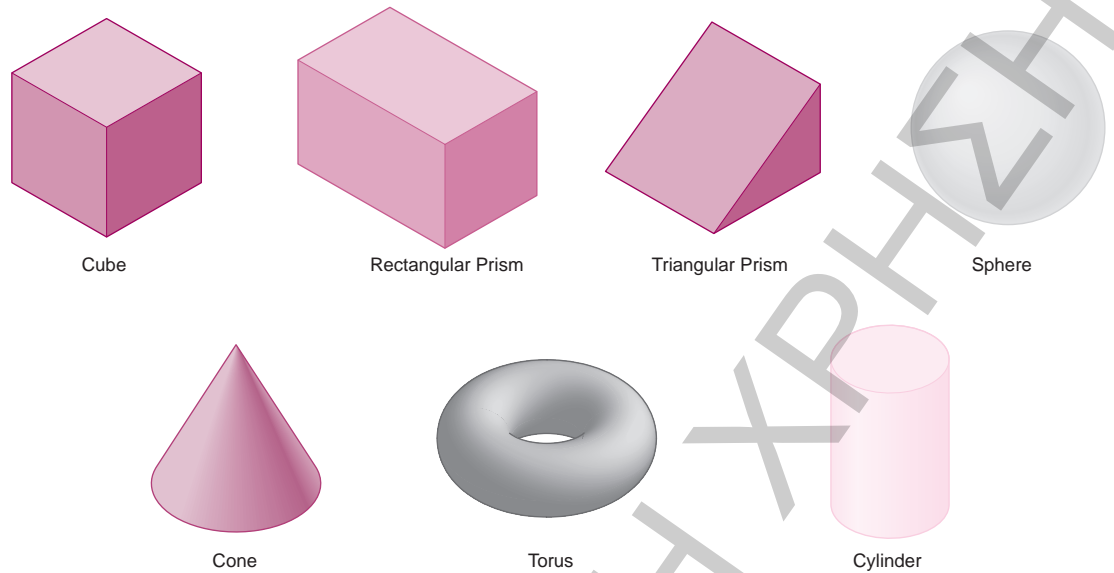


Figure 6.7 Common Geometric Primitives

In contrast, B-spline patches allow local control; moving one control point does not affect the whole surface. With B-splines, it is much easier to create surfaces through predefined points or curves. NURBS surfaces use *rational* B-splines, which include a *weighting* value at each point on the surface. The weighting value allows some points to have more influence over the shape of the curve than other points. This means that a wider variety of curved surfaces are possible than with regular B-splines. Because NURBS surfaces can also precisely describe conic surfaces, they are gaining popularity in many tasks previously handled by other types of 3-D modelers.

6.2.3 Solid Modeling

Through the use of parametric description, surface modelers can accurately describe the surface of an object. Often, however, information about the inside of an object, that is, its solidity, is also required. **Solid models** include volumetric information, that is, what is on the inside of the 3-D model, as well as information about the surface of an object. In this case, the surface of the model represents the boundary between the inside and outside of the object.

Primitive Modeling Many objects, including most mechanical parts, can be described mathematically using basic geometric forms. Modelers are designed to support a set of *geometric primitives*, such as cubes, right rectilinear prisms (i.e., blocks), right triangular

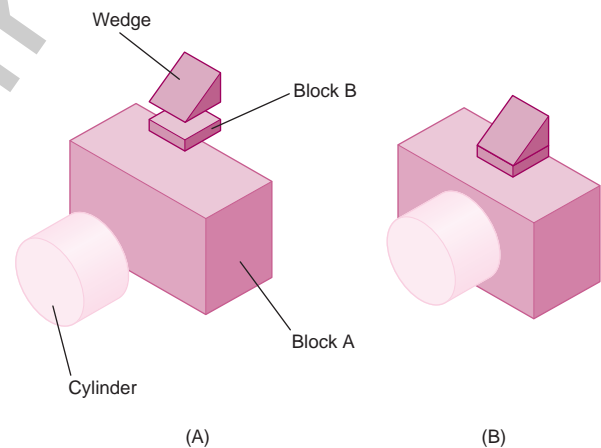


Figure 6.8 A Camera Described with Geometric Primitives
Additive modeling with geometric primitives allows a variety of objects to be represented.

prisms (i.e., wedges), spheres, cones, tori, and cylinders (Figure 6.7). Although most geometric primitives have unique topologies, some differ only in their geometry, like the cube and the right rectilinear prism.

Many modelers also allow primitives to be joined together to create more complex objects. The user mentally decomposes the object into a collection of geometric primitives and then constructs the model from these elements (Figure 6.8).

Design in Industry

Microlights Limited

Illuminating the Future with Autodesk Inventor™

Time was when unimaginative and unsuitable lighting drove customers to take items outside shops so that they could be sure of the color before purchasing. Microlights Limited, the British designer and manufacturer of lighting solutions for the international retail, hotel, and leisure market changed all that. In business since 1984, the United Kingdom-based company has built an impressive reputation for technical and performance leadership. Microlights creates innovative lighting designed to reveal true colors; cost-effective, energy-efficient, and low-maintenance lighting to encourage shoppers to explore the whole store. Customers include Harrods, Jaeger, and Thomas Cook Global and Financial Services.

3D Design Comes of Age

Lighting design involves much more than a base, a bulb, and a shade. The lighting market is very subjective and highly competitive. Companies succeed only with the right balance of creativity, engineering, and value. To stay competitive, Microlights has been a long-term user of computer-aided design. They used Autodesk's AutoCAD® software for 2D design and recently decided to move to 3D. Microlights evaluated PTC and Autodesk products in a real design scenario. Each supplier was asked to produce complete 3D design and documentation for an 18-part luminaire from 2D drawings already created by the company. The lamp-head comprised the complete assembly of reflector, various standard parts and fastenings, castings

There are a number of positive aspects to using a limited set of primitives. First, limiting the allowed topologies reduces the risk of an *invalid* model. Typically, the only safeguards needed are limits or rules on parameter input. For example, the diameter of a cylinder could not be specified as zero. Second, the limited number of allowable shapes means a very concise and efficient database. Third, the limited range of primitives means a model that is unique and is easy to validate.

Constructive Solid Geometry (CSG) Modeling Constructive solid geometry (CSG) modeling is a powerful technique that allows flexibility in both the way primitives are defined and the way they are combined. The relationships between the primitives are defined with **Boolean operations**. There are three types of Boolean



Microlights are used in a Thomas Cook outlet

(Courtesy of Microlights)

and moldings, and glass. Full documentation included general arrangements, visualizations, parts drawings, standard part drawings, and assembly drawings. Suppliers were given just two days to complete the task. Autodesk Inventor™ software was selected hands down.

operations: **union** (\cup), **difference** ($-$), and **intersection** (\cap). Figure 6.9 shows how each of these operations can be used to create different forms. The critical area is the place where two objects overlap. This is where the differences between the Boolean operations are evident. The union operation is essentially additive, with the two primitives being combined. However, in the final form, the volume where the two primitives overlap is only represented once. Otherwise there would be twice as much material in the area of overlap, which is not possible in a real object. With a difference operation, the area of overlap is not represented at all. The final form resembles one of the original primitives with the area of overlap removed. With the intersection operation, *only* the area of overlap remains; the rest of the primitive volume is removed.

“It is just so easy to use,” says Colin Davies, Engineering Manager at Microlights. “It’s like designing on a canvas and it works in the same way that designers think.”

Inventor’s ease-of-use has been reflected in the minimal training requirements at Microlights. Training will never be eliminated completely since there is always a need to lay down a proper foundation for effective use of any system. But for Microlights this was achieved with a 2-day foundation course for each member of the design team, supplied by one of Autodesk’s specially accredited MCAD Plus resellers.

“Inventor helps you develop good design disciplines, especially in part numbering and bill-of-material,” adds Davies. The Autodesk Inventor part numbering system is highly flexible. A wide range of data can be attributed to an individual part, selectively displayed, and used to create a bill-of-materials.

One Model Is Worth 1,000 Words

With 3D visualizations, customers can better relate to the designs the company produces and can grant design approval without seeing physical prototypes. In fact, Autodesk Inventor’s visualization capabilities are so effective that the company intends to cease production of printed product brochures. Instead, Inventor-produced images will be published either to the Web or on CD.

Products will be presented more quickly to customers, and hard-copy publication costs and timescales are reduced.

Teamwork and Communication for Competitive Advantage

Autodesk Inventor enables true collaborative engineering, allowing the design group to work as team, accessing the same model at the same time. But the value of the product extends beyond the design department. Communication with other parts of the organization has improved significantly, too. Now new departments have access to the virtual prototypes before committing to material purchase or production setup and packaging. New designs are brought to market faster than ever before, at lower cost and with higher quality, further strengthening Microlights’ competitive position. According to Davies, “We have halved development times, with similar savings in other parts of the process, too.” As well as creating new designs, the company’s standard parts catalogue is being added to the system. Out of over 200 parts, 2 new designers have added 50 in less than 2 months. Autodesk Inventor has truly made light work for Microlights.

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Boundary Representation (B-Rep) Modeling **Boundary representation (B-rep) modeling** and CSG modeling are the two most popular forms of solid modeling. With CSG modeling, surfaces are represented indirectly through half-spaces; with B-rep modeling, the surfaces, or *faces*, are themselves the basis for defining the solid. The face of a B-rep model is fundamentally different from a face in a wireframe modeler. Although both include a set of edges connected at vertices, a B-rep face explicitly represents an oriented surface. There are two sides to this surface: one is on the *inside* of the object (the solid side), and the other is on the *outside* of the object (the void side).

6.3 | CONSTRAINT-BASED MODELING

In a traditional 3-D modeling system, defining the size or shape of a geometric feature is typically done inde-

pendently of any other feature. It is completely up to the user of the CAD system to make sure the resulting model reflects the real-world design constraints the final product will have to face. With a simple part consisting of three overall dimensions and one or two features (e.g., holes or slots), making sure these features are properly placed as the part is constructed is not a major task. On the other hand, with complex parts or large assemblies, the total number of features to track can be a major task. Traditionally with CAD systems, it has been up to the operator to ensure that when one part is modified, related features on other parts are also updated. **Constraint-based modeling** is a technique that can help the CAD operator manage the model modification process.

Although the use of solid modeling grew steadily during the 1980s, many of the productivity gains promised by CAD vendors were not being realized by companies. One of the reasons was that the process of creating a solid

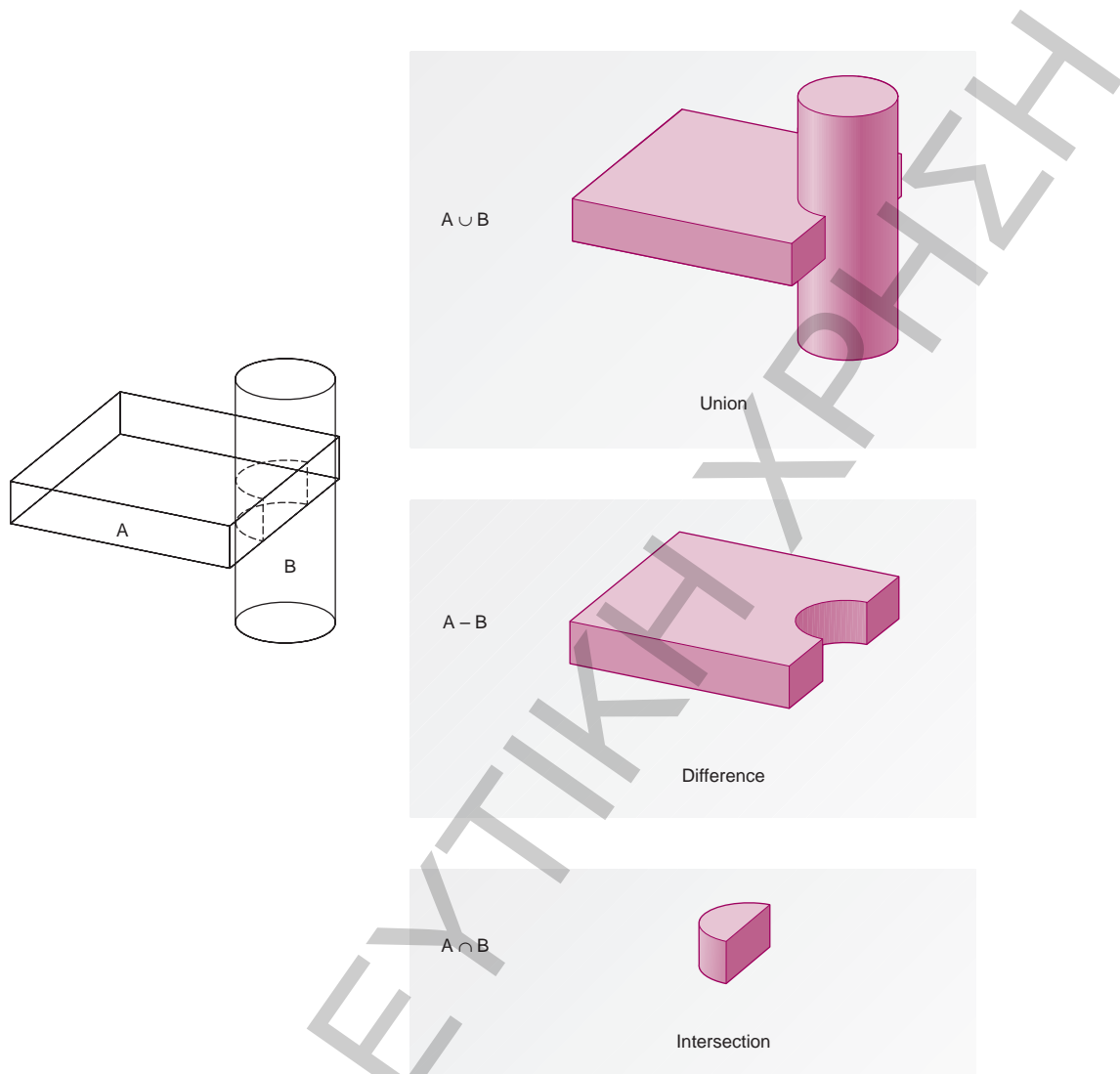


Figure 6.9 The Three Boolean Operations: Union, Difference, and Intersection

The three operations, using the same primitives in the same locations, create very different objects.

model was much more abstract than the process of designing real-world products.

In a constraint-based modeler, a part is created by describing the relationship of geometric elements with equations and logical relationships. For example, in a traditional CAD modeler, if a plate is to have a length equal to 32 mm and a width of half the length, a rectangle 32 mm long and 16 mm wide is created (Figure 6.10A). In a constraint-based modeler, the geometric relationships are coded directly into the model with *parameters*: the length would be defined as $P_1 = 32$ mm

and the width defined as $P_2 = P_1/2$ (Figure 6.10B). With the geometry defined with parameters, the equations are solved to derive dimensional values for each of the features. The power of this approach is seen when the model is modified. Instead of having to individually update all related dimensions, one dimension can be altered, and all dimensions linked through parameters automatically reflect the change. For example, if the length of the plate is reduced ($P_1 = 20$), the width automatically reduces by the appropriate amount to reflect the change in length (Figure 6.10C).

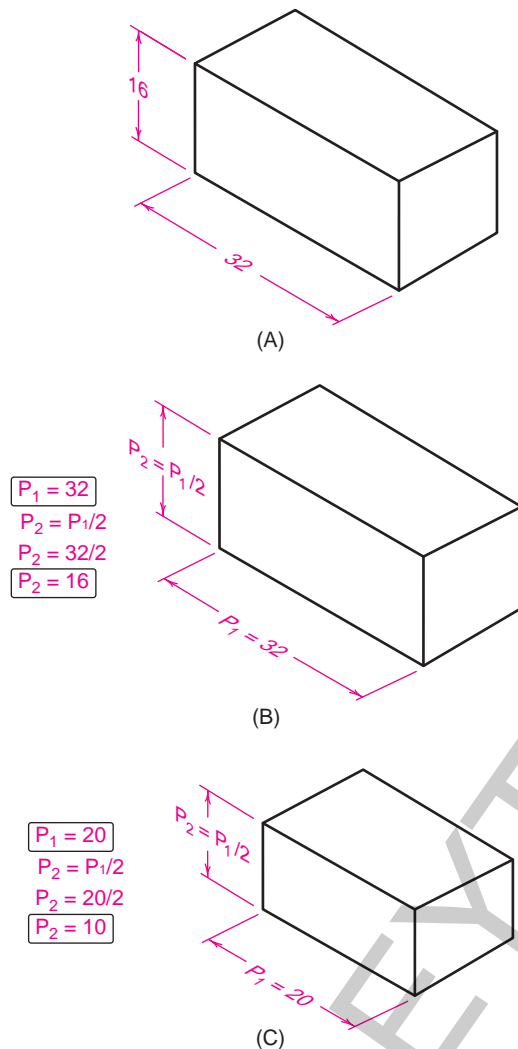


Figure 6.10 Traditional and Parametric Part Definition

(A) A traditional CAD modeler creates geometry of a specified size. (B) With a constraint-based modeler, geometry is defined through parameters represented as an equation. (C) Parameters can easily be altered to represent new values.

Like dimensions, parameters can be associated with geometric features such as lines, curves, and planes. Unlike dimensions, parameters do not have to represent a single static value. Parameters can be

- Assigned numeric values (e.g., $P_1 = 32$ mm).
- Related to other parameters through equations (e.g., $P_2 = P_1 + 20$).
- Related to other parameters through geometric relationships (e.g., P_3 is parallel to P_4).
- Varied based on logical relationships (e.g., IF $P_5 > 24$ mm, THEN $P_6 = 6$ mm, ELSE $P_6 = 4$ mm).

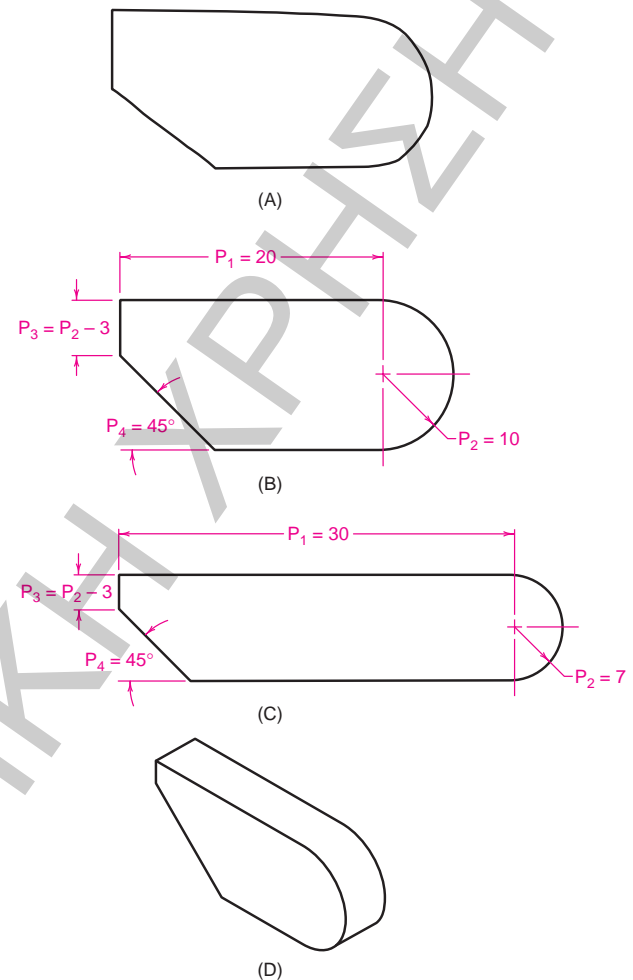


Figure 6.11 Creating a Constrained Model from a Sketch Profile

(A) A rough sketch defines the basic geometry of the 2-D profile. (B) Constraints are added to define the size and shape of the profile. (C) The size and shape of the profile can be altered at any time. (D) Once constrained, the profile can be extruded or swept into a 3-D part.

It is important to remember that parameters are always related back to geometric features. A parameter that represents a numeric value measures a distance or angle between two features (i.e., points or lines). Likewise, geometric relationships such as parallelism are made between features such as lines or planes.

In many constraint-based modelers, the modeling process begins by creating a 2-D *sketch profile* (Figure 6.11A). Unlike in a traditional 2-D or 3-D CAD package, the geometry does not have to be created with a high degree of accuracy; it only needs to represent the basic geometric features. The next step is to *constrain*

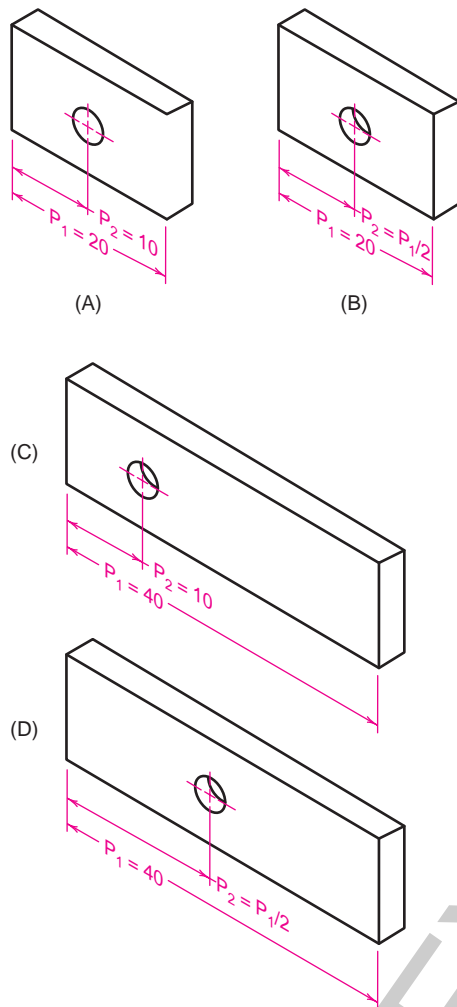


Figure 6.12 The Effect of Design Intent on Model Changes

(A) Though these two parts are initially the same, the parametric constraints represent two different design intents. The part on the left intends to have the hole fixed at an offset of 10 from the left edge whereas the part on the right intends to have the hole centered. (B) The differences in the design intent can be seen when the overall width of the part is altered. Only the hole on the part on the right shifted to the center.

the model by assigning enough parameters to fully define the size and shape of the 2-D profile (Figure 6.11B). Depending on the modeler, some of these parameters may be automatically assigned. For example, if the two horizontal elements are within a preset tolerance range (say, 5 degrees) of parallel, the two edges are constrained to be parallel. You might think of this as being like a snapping or grid system, but, in fact, it is much more powerful. As the part is resized, the sides will stay paral-

lel no matter how far apart they are. Because all of the features are parametrically defined, one or more of the parametric values can be altered, and all related parameters will automatically update (Figure 6.11C). Once the sketch profile has been constrained and the parameters assigned appropriate values, a 3-D part can be created by an extrusion or sweep operation (Figure 6.11D).

In Figure 6.12A, two plates are created with holes and two different design intents. In the plate on the left, the hole was intended to be placed 10 mm from the left edge, while the plate on the right had the hole placed in the center. When the overall width is set to 20 mm, no difference is seen in the two models, but when the overall width is set to a different value, the difference in design intent is immediately seen (Figure 6.12B). With a traditional modeler, an engineer viewing the model in Figure 6.12A would not be able to tell what the design intent was and, therefore, how the hole should shift if the model was altered.

6.4 FEATURE-BASED MODELING

Another important advancement in 3-D solids modeling is the introduction of **feature-based modeling**. Like constraint-based modeling, feature-based modeling is an attempt to make modeling a more efficient process more in tune with how designers and engineers actually work. Feature-based modeling bundles commands together to automate the process of creating and modifying features that represent common manufacturing operations. Usually implemented in modelers that also have constraint capabilities, feature-based modeling systems use special dialog boxes or other interface elements that allow users to input all of the variables needed to create a common manufactured feature (Figure 6.13).

Examples of manufactured features created through special feature-based dialog boxes include the following:

- Blind holes
- Counterbores and countersinks
- Slots
- Bosses

The hole dialog box shown in Figure 6.13 is a good example of automating the process of creating features in a model. The feature is broken down into its essential variables, with each variable represented by an input in the dialog box. Variables such as the hole's diameter have a value typed in, while the depth can be set to "through" by clicking a button or set to a finite value.

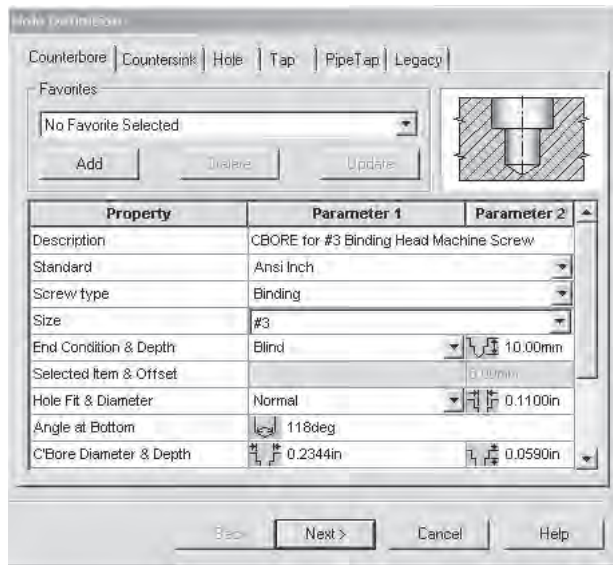


Figure 6.13 Example of a Dialog Box in a Feature-Based Modeler

Notice that all of the essential variables defining the feature are represented as inputs in the dialog box. Typically, many of these variables can also be defined as parameters linked to other features on the model.

The variables entered through the dialog box largely define the *shape* and *size*. Once these variables of the feature are defined, the *location* is defined. By convention, features usually don't constitute an entire part. For that reason, the feature is typically located somewhere on a *base part*. A feature such as a blind hole is located by indicating its orientation to a face and distance from two edges (Figure 6.14). In a constraint-based modeler, all of the variables of the feature—its shape, size, and location—are parametrically controlled and can be updated at any time. In addition, the parameters defining the feature can also be linked to other parameters defining the part. So, for example, the depth of a hole might be related to the overall thickness of the base part.

Earlier in the chapter, Boolean operations were introduced as the primary means of modifying a solids model. With feature-based modeling, one or more Boolean operations are manipulated using intelligent dialog boxes to create common features such as holes, slots, and bosses. Feature- and constraint-based techniques together give the

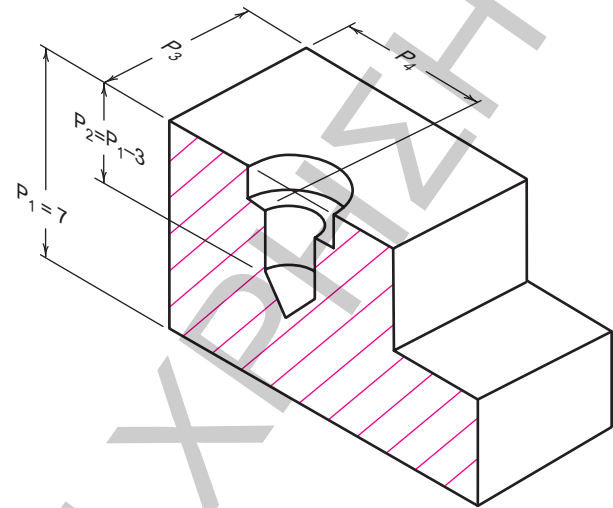


Figure 6.14 Locating a Feature on the Base Part

The blind counterbore is located on the base part relative to a face on the part. The overall depth of the counterbore is linked to the overall height of the part through a parametric equation.

user the ability to easily create and modify common manufactured features. When combined with parts libraries of common fasteners and other parts, assemblies using standard components and manufacturing techniques can be quickly modeled.

6.5 | 3-D MODELING AND THE DESIGN PROCESS

CAD was introduced into most businesses as an automated drafting tool and was then defined as computer-aided drafting. The introduction of 3-D modeling systems has transformed CAD into computer-aided *design*.

CAD 3-D modeling plays an important role in many newly emerging manufacturing techniques, including computer-aided manufacturing (CAM), computer-integrated manufacturing (CIM), concurrent engineering, and design for manufacturability (DFM). All of these manufacturing techniques are aimed at shortening the design cycle, minimizing material and labor expenditures, raising product quality, and lowering the cost of the final product. Central to these goals is better communications within a company. By sharing the 3-D database of the proposed product, more people can be working simultaneously on various aspects of the design problem. The graphics nature of the database has convinced many that 3-D modeling is a superior method of communicating many of the design intents.

3-D Solid Models for Assembly, Working Drawings and Design Verification*

Objective—The multiview and pictorial assembly sketches and models in this section are intended to be used to construct fully constrained 3-D solid part models and product assemblies. Rendered models, photos, and parts lists are included with sketches to help in visualizing and planning product modeling and assembly.

Nominal Dimensions—Assembly and part sketches typically are dimensioned by nominal size only. To achieve manufacturing realism, calculation of appropriate tolerances, fits, and clearances will be required.

Your Solid Modeling Software—Any available parametric solid modeling software may be used for these problems. For assembly of existing parts, determine the key base part and use appropriate assembly constraints when creating 3-D assemblies. For bottom-up part modeling of individual parts, apply construction or datum plane set up as assigned to create part bodies using standard extrusion, revolution, or lofting methods. For top-down modeling, plan your datum

plane layout in assembly mode for part building. Apply 3-D features, such as holes, fillets, chamfers, ribs, thin wall operations as required to create a logical, easy to edit history tree. Use the finished part and assembly model to generate associated multiview documentation containing appropriate drawing views (i.e., front, top, right side, isometric). If assigned, make parametric changes to part model files and use these changes to update the associated multiview documentation.

On-Line Manufacturer's Parts—For standard parts, such as threaded screws, bolts, washers, spacers, bushings, and O-rings, many manufacturers furnish 3-D CAD models of their products online. Where possible, identify and download standard parts in order to save modeling time. Use online searches to investigate the availability of manufacturer's 3-D part models. Determine whether they are available in a format that is compatible with your solid modeling software.

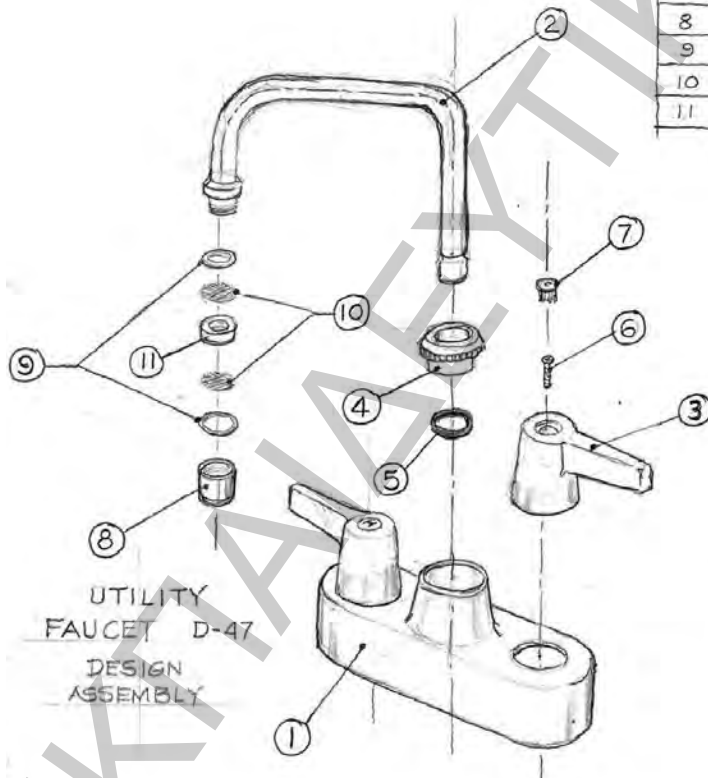


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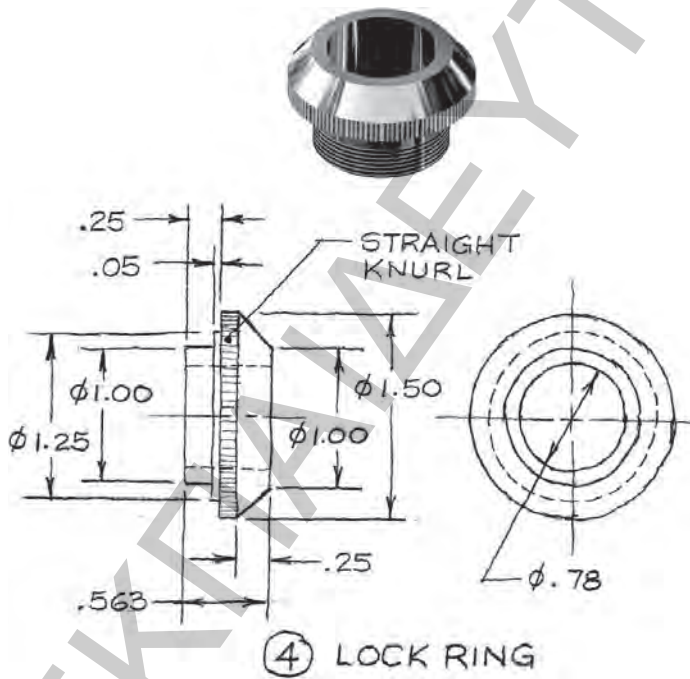
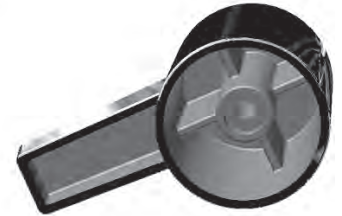
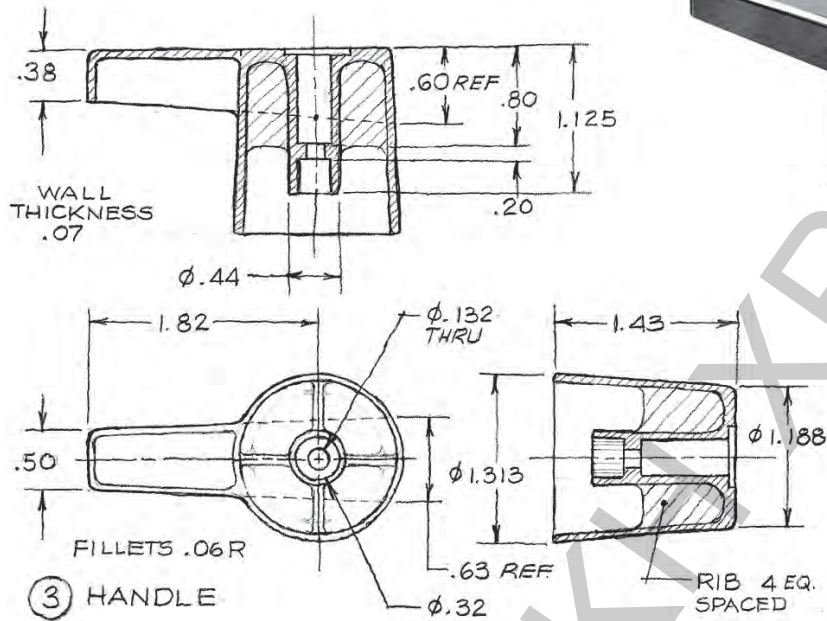
*Special thanks to Bill Ross for use of this exercise



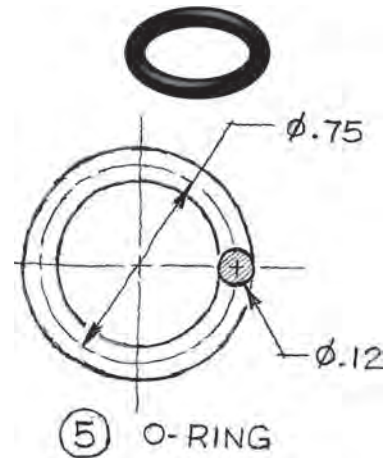
UTILITY FAUCET D-47 PARTS LIST				
No.	PART NAME	MTRL.	QUAN.	FINISH
1	BASE	BRASS	1	CHROME
2	SPOUT	BRASS	1	CHROME
3	HANDLE	BRASS	2	CHROME
4	LOCK RING	BRASS	1	CHROME
5	O-RING	RUBBER	1	
6	SCREW-HANDLE	BRONZE	2	
7	BUTTON H&C	STEEL	2	CHROME
8	NOZZLE	BRASS	1	CHROME
9	RING-FILTER	TEFLON		
10	FILTER-SCREEN	S. STEEL		MESH
11	SPACER	PLASTIC		



Utility faucet—reverse engineer from product

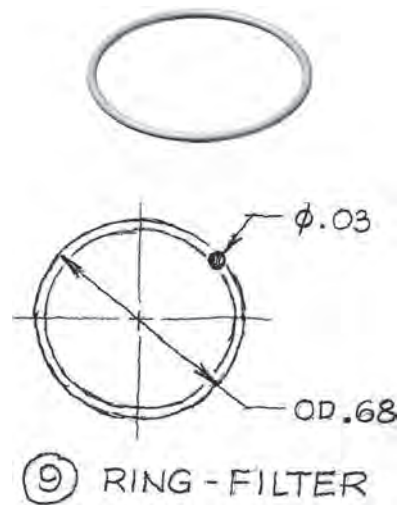
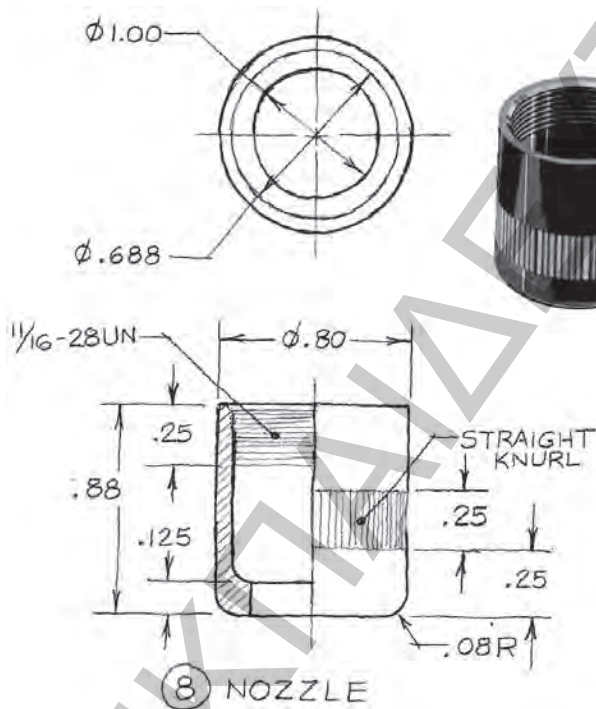
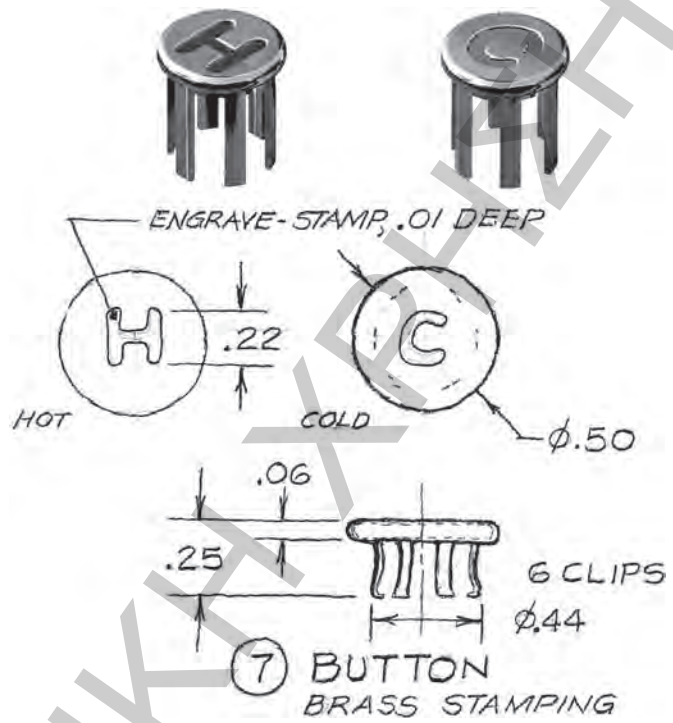
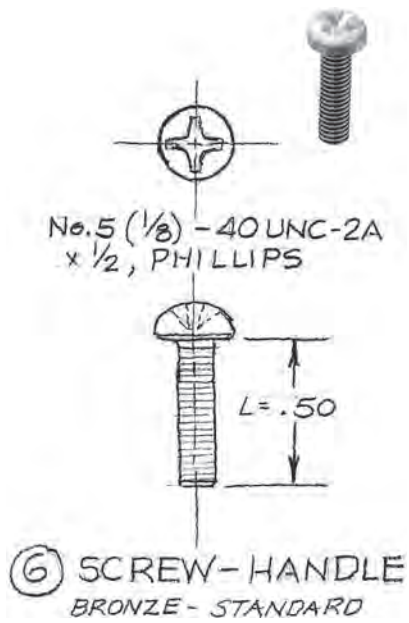


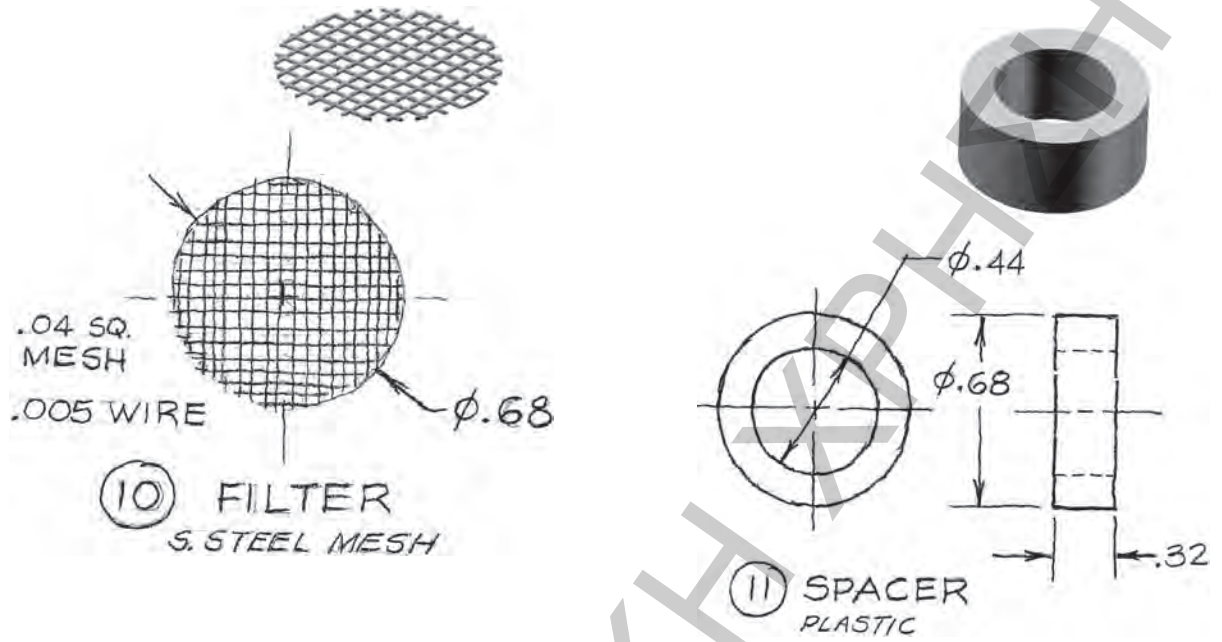
④ LOCK RING



⑤ O-RING

Utility faucet—reverse engineer from product (Continued)





Utility faucet—reverse engineer from product (Continued)