6. Three Dimensional Design and Solid Modelling

6.1. INTRODUCTION

Modern CAD systems such as AutoCAD, Mechanical Desktop, 1-DEAS, and Pro/Engineer are capable of creating models of objects in several different forms. They may be wireframe, surface, or solid. These models can be further processed to provide the geometry necessary for analysis by other programs. Thus, for example, stress or thermal analysis can be done prior to the production of actual hardware.

There are two-dimensional and three-dimensional CAD systems. In two-dimensional system the graphics screen is used as a substitute for drawing paper. All drawings are produced only in one plane without any depth. Most of the larger CAD systems have an ability to model in three dimensions. The spatial image of the object is drawn in a pictorial projection using x-y-z co-ordinate geometry and is stored in the memory. It can be recalled and redrawn in 3-D pictorial projection or in orthographic projection representing the image of the object in a number of 2-D views, i.e. the front, end, plan and auxiliary views.

6.1. GEOMETRICAL MODELLING

Geometrical modelling is a general term applied to three-dimensional computer-aided design techniques. There are three main types of geometrical modelling used, namely: *line* or *wireframe* modelling, *surface* modelling and *solid* modelling. Each have their own particular applications in the design of engineering components which is dependent on the ability of the method to model certain geometric structures effectively and generate the correct data for analysis. The usefulness of the model in the design process depends on whether it is a line, surface or solid model or in fact any combination of the three. Each method has its own capabilities in allowing the designer to visualize and analyse the model but all should interface to 2D draughting so that a working engineering drawing of a 3D model can be generated.

A *wire frame* representation is a 3-D line drawing of an object showing only the edges without any side surface in between. The image of the object, as the name applies has the appearance of a frame constructed from thin wires representing the edges and projected lines and curves if required, as shown in Figure 6.1(a). The main disadvantage of this wire frame representation is that the hidden detail lines are shown and the resulting drawing is a maze of lines, which can be very confusing and disorientating.

3-D solid modelling Some CAD systems are capable of producing the complete solid models of the objects in colour, displaying full surfaces with the light, highlights and shadows, thus accomplishing very realistic images (Figure 6.1(b)).

2.5-D type of figures are wire frame representations, where the original 2-D shape can be translated or rotated into a 3-D shape as shown in Figure 6.1(c).
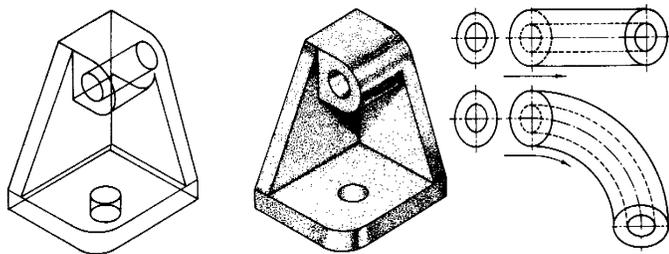

Figure 6.1. (a) Wire frame, (b) Solid model and (c) 2.5-type model

Surface modelling is more sophisticated than wire frame representation, but is cheaper to run than solid modelling. Initially the wire frame is created and the gaps between all individual frames are then filled in by flat or rounded surfaces. This model can be easily modified and colour shaded, if required.

6.2. THREE DIMENSIONAL (3-D) MODELLING

One application of a three-dimensional model is in the generation of an engineering drawing by arranging multiple views of the model on a used on the drawing drawing sheet and then annotating these views with dimensions, labels and notes. If the underlying 3D model is of the solid or surface type, then automatic hidden-line removal scale may be views. Figure 6.2 shows an example of a wire-frame model and the arrangement of views of this model on a drawing sheet. The approach ensures consistency in the geometry between the views of a drawing, but it may be seen that interpretation is not entirely straightforward.
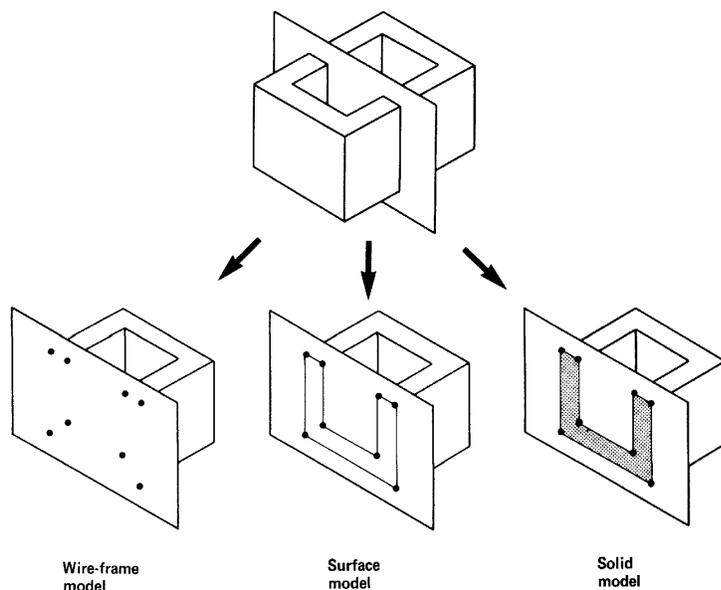

Figure 6.2. Wire-frame, surface and solid representations of a box

The methods that have been developed for three-dimensional modelling involve the representation of geometry as a collection of lines and other curves, or of surfaces, or of solids in space. These methods will be considered in turn below, but first it is appropriate to explain some terminologies. It has been seen that drawings are constructed in a two-dimensional coordinate system. Three-dimensional (3D) models are constructed in 3D space - typically in a right-handed cartesian coordinate system. There will normally be a fixed coordinate system which is used for the overall definition of the model — we will call this the global coordinate system (OCS) - and, in addition, a movable world coordinate system (WCS) may be used to assist in the construction of the model.

6.2.1. Using X,Y,Z Point Coordinates

The coordinate systems presented up to this point in the text have been 2D coordinates, specifying point ordinate locations on the X,Y plane of the World Coordinate System. The World Coordinate System, WCS, as a fixed coordinate system used by default in CADD software such as AutoCAD. In the WCS, the X axis is horizontal, the Y axis is vertical, and the Z axis is perpendicular to the plane. Specifying a 2D absolute point coordinate is done by supplying an X,Y value. A 2D coordinate specification defaults to a 0 value for the Z axis. This means that the coordinate specification 6,4 is interpreted 6,4,0. To specify a 3D

point coordinate that does not lie on the X,Y plane, a nonzero Z axis value is supplied Figure 6.3(a) shows a representation of the point coordinate 6,4,2. Notice that the point is found 6 units after the positive X axis, 4 units along the positive Y axis, and 2 units on the positive Z axis.
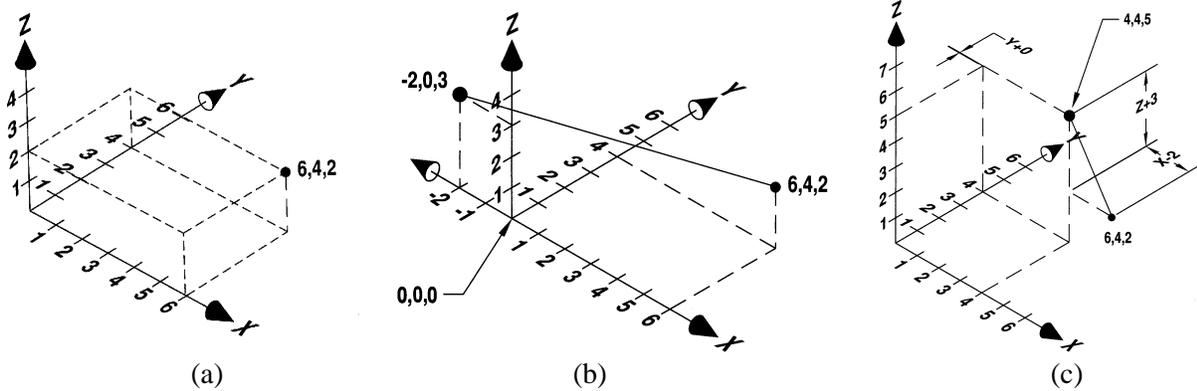

| (a) | (b) | (c) |

Figure 6.3. Point coordinates

The X,Y,Z coordinate specifications work the same as standard X,Y coordinates with regard to absolute and relative specifications. This means that a coordinate point entered as X,Y,Z indicates an absolute location in 3D space. When the coordinate point is preceded by the"@" symbol, the coordinate entry is terpreted as being relative to the last point entered. The first example in the following sequence uses absol coordinate entry. The results are shown in Figure 6.3(b). The second example uses relative coordinate en and its results are shown in Figure 6.3(c):

Command: L or LINE   Command: L or LINE
Specify first point: 6,4,2   Specify first point: 6,4,2
Specify next point or [Undo]: -2,0,3   Specify next point or [Undo]: @-2,0,3
Specify next point or [Undo]:   Specify next point or [Undo]:

6.2.2. The Right-Hand Rule

The *right-hand rule* provides an easy-to-understand reference to determine the positive and negative directions of the X, Y, and Z axes. Knowing how to use this simple reference makes it easier to visualize the relationships of the X,Y, and Z axes in 3D space. Figure 6.4(a) shows the first point of the right-hand rule. Hold your right hand so your thumb points in the positive direction of the X axis and your index finger points in the positive direction of the Y axis. When you are using the default WCS, the back of your hand is toward the screen, your thumb points right, and your index finger points up. Now, extending your middle finger as shown in Figure 6.4(b) shows you the positive direction of the Z axis. In the WCS, the positive direction of the Z axis is toward you. This method still works when you are using a UCS; rotate your hand appropriately to match the setting of the UCS.
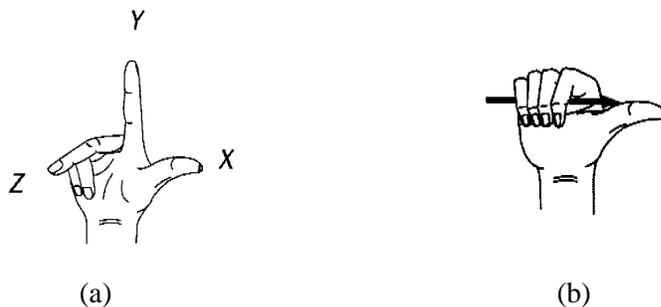

(a)   (b)

Figure 6.4. The right hand rule and positive direction of axis

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6.2.3. Three Dimensional Polar Coordinate Entry

CADD software also provides similar options for working in a 3D drawing environment. There are two variations of the polar coordinate entry system that provide much greater flexibility when en tering 3D point coordinates. These variations are called *cylindrical* coordinates and *spherical* coordinates. Cylindrical coordinates are a simple variation of polar coordinate entry that use a standard polar coor - dinate entry followed by a Z axis value.

In this example, the line object is started at 2,2 in the current X,Y plane. Because no Z coordinate is specified, the point is interpreted as 2,2,0. The first part of the *To point:* coordinate entry, @2<90, works in the X,Y plane, just like its 2-D equivalent. The 6 value that follows indicates a Z axis value. Because this is preceded by the ''@'' symbol, all of the values are calculated from the last point entered: 2,2,0. The resulting point location is 2 units at 90° in the X,Y plane, or 2,4,0, and 6 units in the positive Z direction for a result of 2,4,6. Figure 6.5(a) demonstrates the results of this example.

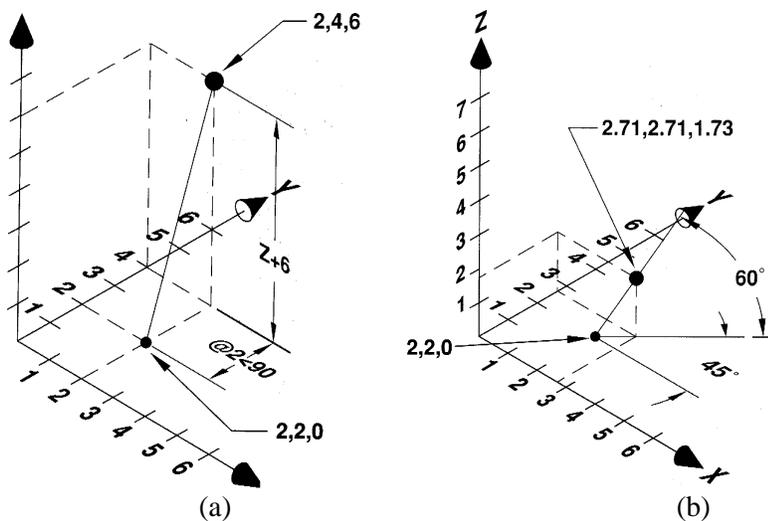(a)   (b)

Figure 6.5 The cylindrical and the spherical coordinate entries

The spherical coordinate system provides a true 3D polar coordinate entry option. This coordinate en try method allows you to specify the distance from the point of origin followed by the angle *in* the X,Y plane and the anglefrom the X,Y plane. A spherical coordinate specification looks like this: @2<45<60 (Figure 6.5(b)).

6.3. LINE OR WIREFRAME MODELLING

Line modelling or, as it is often called, wireframe modelling is the simplest form of geometrical representation of an object. Two-dimensional draughting is in fact a form of line modelling, the major difference being that point information is stored as three coordinate values and the definition of circles and arcs may specify a plane of orientation. As with 2D draughting, a component is stored in the computer as a series of geometric entities which simply represent the boundaries, edges or vertices of the component model. Figure 6.6(a) is a wireframe model of a simple component and at first glance it is not easy to determine the shape of the object as no hidden lines have been removed.
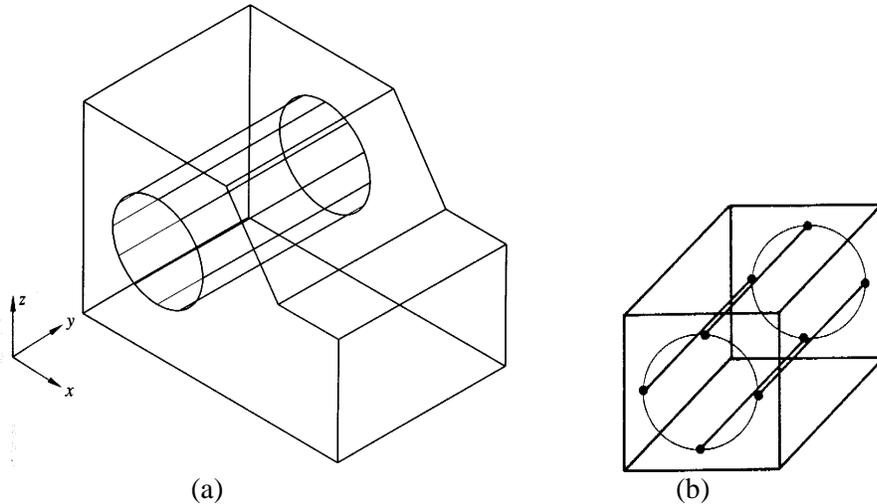
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(a)   (b)

Figure 6.6. A line or wireframe model

A wire frame is effectively a line drawing of a 3-D object and is a method of representing the 3-D geometry of the edges and nodes of an object without a full surface representation. The object has the appearance of a frame constructed from wire. It can be quickly displayed and manipulated. The block in Figure 6.6(b) is shown as a wire frame with only 16 lines and 2 circles.

The difficulty with a wire frame model is that hidden lines are not removed and, for complex items, the result can be a jumble of lines that is impossible to determine. Similarly, because surface features are not displayed there are no *contour* lines and so the surface can be ambiguous and the resulting interpretation of the object open to question.

6.4. 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 6.8) The control points are an intuitive tool with which the user can work. In contrast, B-spline patches allow local control; moving one control point does not affect the whole surface.
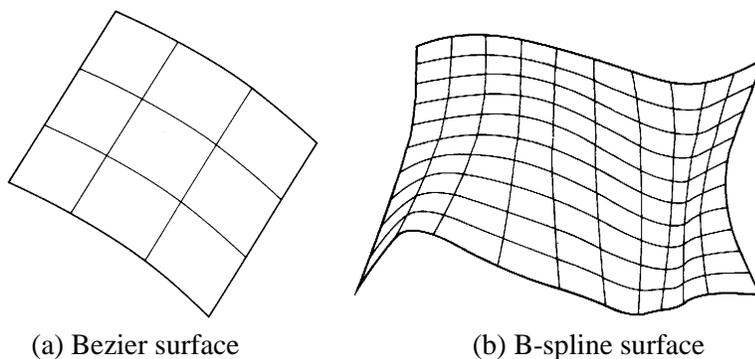

(a) Bezier surface   (b) B-spline surface

Figure 6.7. Bezier and B-spline surfaces

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

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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.

6.5. SOLID MODELLING

The representation of objects as solid models has been the subject of much research over the last twenty years or so, and continues to be a major theme for study, as the objectives have by no means been achieved. It may be seen, however, that it is a natural extension from the use of essentially 'one-dimensional' entities (curves) or 'two-dimensional' entities (surfaces), to try to model shape using three-dimensional solids.

Such programs are known as solid modellers or volume modellers and can hold complete unambiguous representations of the geometry of a wide range of solid objects. The completeness of the information contained in a solid model allows the automatic production of realistic images of a shape and automation of the process of interference checking. Finally, new applications programs may be written which exploit the completeness of the solid model to decrease or eliminate the necessity for user intervention in design, analysis (such as finite element analysis) or manufacturing tasks (such as the generation of instructions for numerically-controlled machining).

Solid modelling takes the designer into areas of still greater realism than that of surface or line modelling. As well as the object's surfaces being mathematically represented the solid mass between the surfaces is also defined. There are two types of solid modelling methods used in modern CAD systems: *boundary representation* (B-Rep) and *construction solids geometry* (CSG). With the B-Rep method a shape or profile is defined and then either a solid of revolution is produced about a given axis or the shape is extruded in a given direction. Construction solids geometry modellers provide a range of solid primitives such as spheres, cylinders, cuboids, wedges, etc., which can be defined at any size, position and orientation (Figure 6.8).
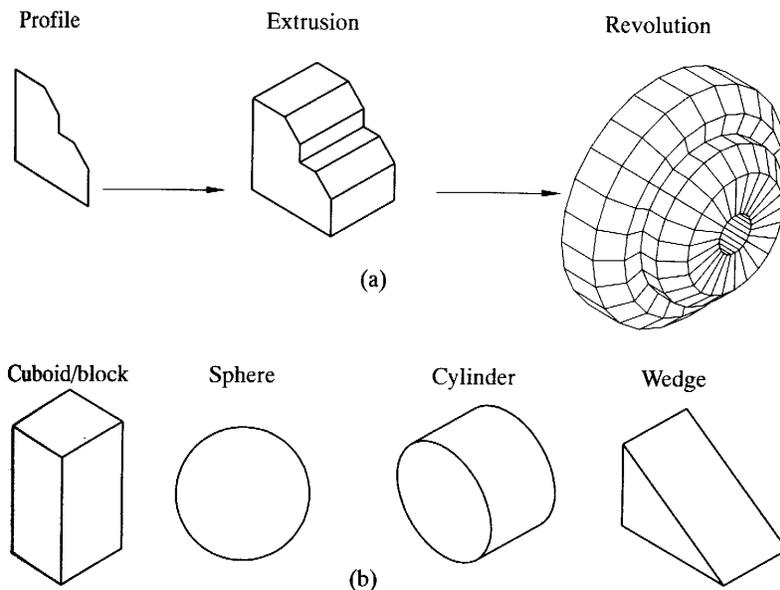
Figure 6.8. Solid modelling function (a) B-Rep operations , and (b) common CSG primitives

Many solid modelling systems such as I-DEAS and CATIA, is not in fact a pure CSG modeller but has CSG functions for the creation of and operations on solid primitives. There are also geometry construction facilities for creating profiles and generating models by extrusion and revolution of those profiles The solids thus generated can then be treated as primitives so that other generated solids or primitives can be used to modify them by Boolean operations.

The process of union completely adds and fuses two construction solids as shown in Figure 6.9(b). The process of difference completely subtracts one solid from another as shown in Figure 6.9(c), where a cylinder representing a drilled hole is subtracted from another solid. The process of intersection is the most complicated out of three. The required solid is formed only by two construction solids combining together or intersecting, and any extraneous volumes are completely ignored, as shown in Figure 6.9(d). The entire object required is built methodically from different construction solids in many progressive stages.
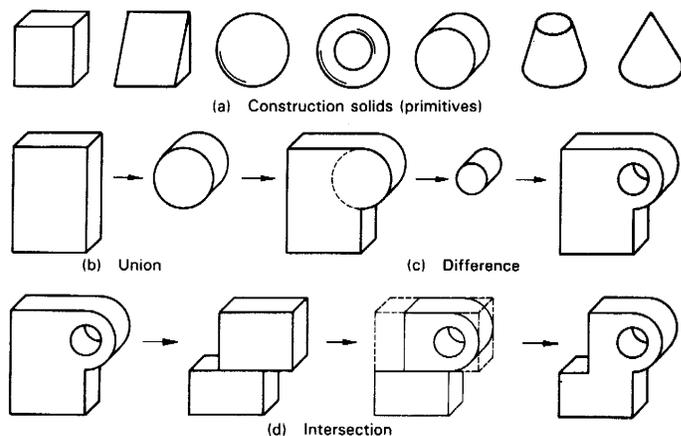

Figure 6.9. 3-D modelling

6.6. REPRESENTATION SCHEMES FOR SOLID MODELS

It is possible to produce a complete solid model, with all the information, e.g. full surfaces and hidden detail being displayed. Alternatively an abbreviated form can be displayed, which shows cylinders as multifaceted surfaces and no hidden lines removed. In practice, most commercial solid modellers employ a combination of the approaches, the most appropriate being chosen for a particular task. The quality of image produced by a full solid modeller, with highlights and shadows, is often so good that it can be confused with photographs taken of the real object.

All solid modelling systems provide facilities for creating, modifying and inspecting models of three-dimensional solid objects, but there are a large number of different possible methods for representing such models in a computer. However, representation schemes may be divided into six general classes as follows:
- Pure primitive instancing
- Generalised sweeps
- Spatial occupancy enumeration
- Cellular decomposition
- Constructive solid geometry (CSG)
- Boundary representation (B-rep).

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Representation schemes where the elements of a shape are explicitly held in the model are termed evaluated representations. Conversely, those where the elements must be calculated from implicit instructions for construction of the shape are known as unevaluated representations. We now describe the six types of representation scheme. Each representation is illustrated by a figure depicting a plan view of a simple three-dimensional prismatic part. The representation schemes most widely used in commercial modellers are cellular decomposition, CSG and B-rep.

Pure primitive instancing. Modellers using this technique can handle a number of families of objects, each defined parametrically (Figure 6.10). A particular solid is specified completely by giving the family to which it belongs together with a limited set of parameter values. Clearly, a disadvantage of such systems is that the range of objects that can be handled is restricted to those in the families pre-defined in the system.
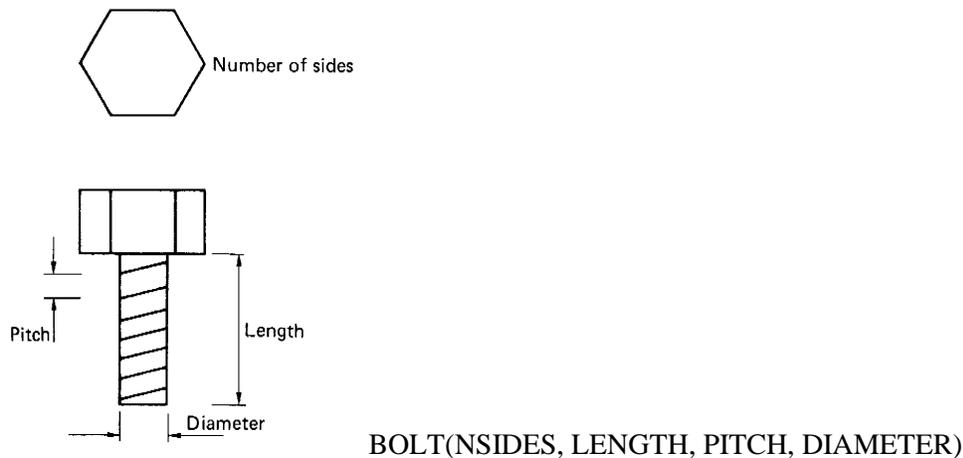
BOLT(NSIDES, LENGTH, PITCH, DIAMETER)

Figure 6.10. Pure primitive instancing

Generalised sweeps. A solid is defined in this scheme in terms of volumes swept out by two-dimensional or three-dimensional as they move along a curve (Figure 6.11).
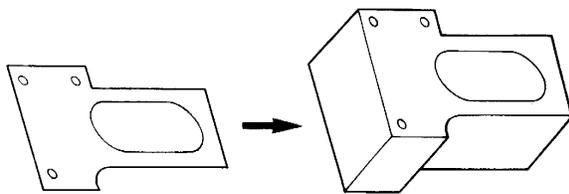
Figure 6.11 Generalised sweep

Spatial occupancy enumeration. For this technique three-dimensional space is divided up into cubical cells at a particular resolution and objects are modelled by listing the cells that they occupy (Figure 6.12). This representation scheme needs large amounts of store for reasonable resolution and thus has not been generally favoured for practical systems. However, this problem has been alleviated in a recent development of this scheme known as *decomposition*. The spatial sub-division is divided into a hierarch) of levels. In each succeeding level the resolution doubles in each coordinate (x, y and z) so that a cube at one level will be divided into eight sub-cubes at fit next. The space occupied by the model for a given resolution is significan reduced since only those cells that are occupied at each level are stored sub-division is onjy necessary for partially occupied cells.

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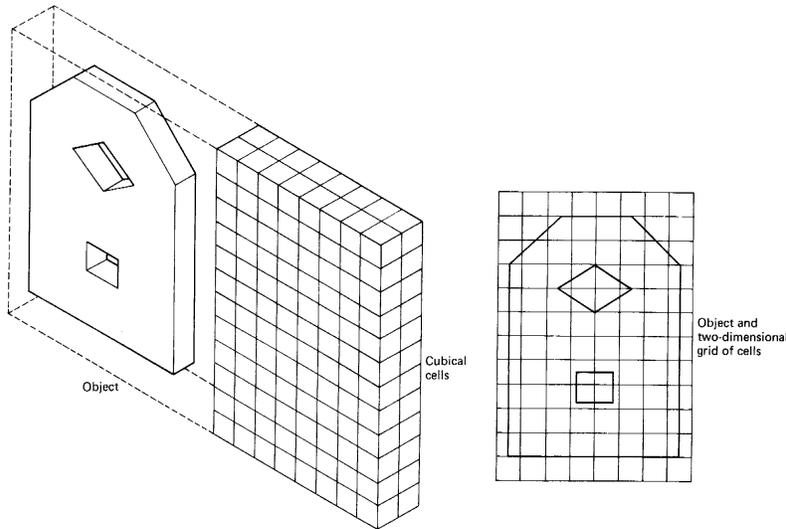Figure 6.12. Spatial occupacy enumeration

Cellular decomposition. An object is represented in this scheme by a list of the cells it occupies, but the cells are not necessarily cubes, nor are they necessarily identical (Figure 6.13).
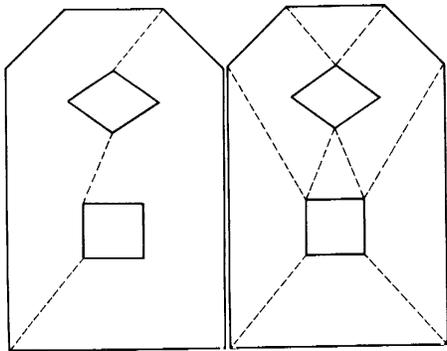

Figure 6.13 Cellular decomposition

Constructive solid geometry(CSG). An object is represented in terms of a combination of so-called primitive volumes such as cuboids, cylinders, cones or spheres (Figure 6.8). In the constructive solid geometry (CSG) approach, a solid object is represented in a computer as a combination of simpler solid objects. The types of combination available are the (Boolean) set operations of *union, intersection* and *difference,* and the complete solid object is *constructed* from the solid primitives using these operations.

The data base for models using CSG is a combination of data and of logical procedures for merging the various blocks. It is compact to store, but lengthy to build. If only the CSG *tree* is kept comprising of which blocks are used, how they are connected and their sizes, then the storage is very compact (Figure 6.14).
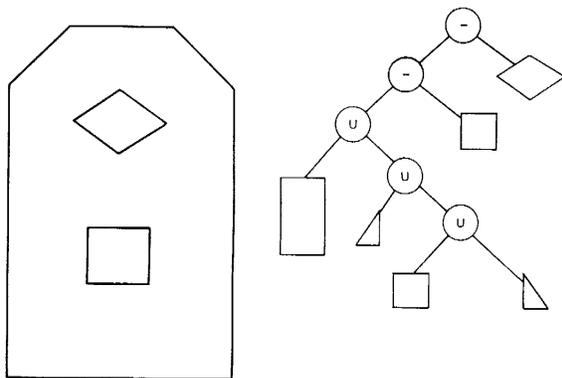
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Figure 6.14. Constructive solid geometry

The alternative name for the CSG method, set-theoretic modelling, arises from the way in which primitives are combined using the union, intersection and difference operators of set theory. Figure 6.15 shows the effect of these operators on a block and a cylinder.
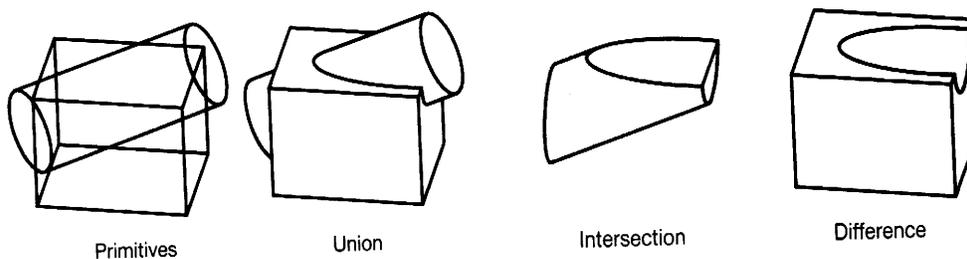

Figure 6.15. Boolean operations on a block and cylinder

The method of constructing CSG models is such that quite complex shapes may be developed relatively quickly, but only within the limitations of the set of primitives available within the system. Many features found on engineering components (particularly those produced using such manufacturing processes as forging or casting) such as fillet blends, or draft to allow the component to be withdrawn from the mould or die, may be difficult or time-consuming to produce using CSG techniques.

Boundary representation (B-rep) Objects are represented in this scheme by their enclosing surfaces or boundaries (Figure 6.16). In a boundary representation (B-rep) modeller, a solid is represented by an evaluated data structure containing the elements which describe its boundary. These elements are divided into two categories: topological and geometric. The topological elements are linked together in a network or *graph* which represents their interconnections or *connectivity* in terms of vertices, edges and faces. This face-edge-vertex graph contains no geometric information about an object — the geometric elements (points, curves and surfaces) which give form and fix it in space are separate.
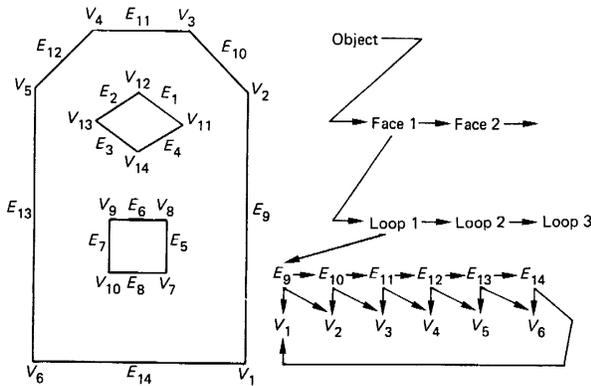
Figure 6.16. Boundary representation

In a B-Rep system, a solid is defined by five views —plan, front, two ends and the reverse plan. Rubber banding lines are used to inter-relate corresponding features in the various views. B-Rep stores a description of the object in terms of its surfaces, edges and vertices as shown in Fig. 15.35. Since the boundary information is kept at all times as an explicit definition, it is quicker to build the model than using CSG, but the data base that must be stored is larger. B-Rep is very compatible with wire frame models, but modifications are more difficult to make than when using CSG. B-Rep is a useful technique for non-standard shapes, e.g. aircraft, fuselage and wing shapes and for car body styling.

6.7. ISOMETRIC DRAWING

Another effective way of communicating 3D information is by creating an *isometric* view of drawing. *Isometric drawings* create a 3D pictorial in which the tree axes are true measurements of the object and form equal angles. Isometric drawings are commonly used when the creation of an actual 3D model is not practical. Sometimes an isometric drawing is combined with a standard orthographic drawing to as in the visualization process. An isometric drawing can be used to simulate a 3D view of an object. In some cases, this may be much quicker than actually creating a full 3D drawing. CADD softwares such as AutoCAD provide some basic isometric drawing tools to assist you when creating isometric views.

The isometric snap and grid properties are set in Drawing Aids dialog box as shown in Figure 6.17. Enabling the isometric snap/grid mode changes the the cursor into an isometric cursor. An isometric cube is shown in Figure 6.17 with the three isometric planes labeled. While isometric mode is on, the cursor can be set to the correct configuration for each of these isometric plans as needed.
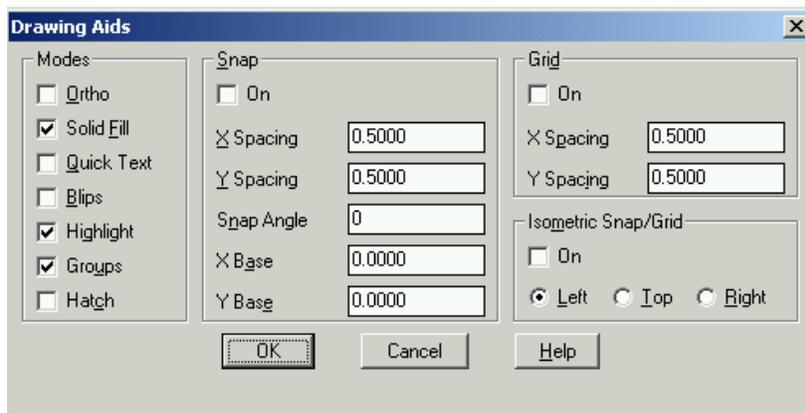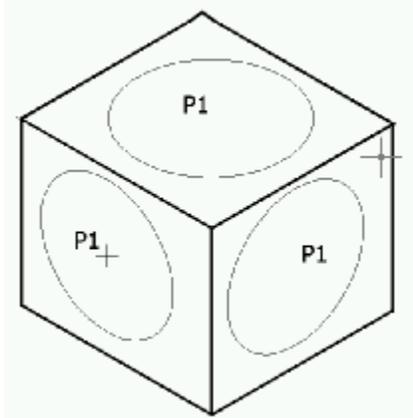

Figure 6.17. Isometric snap/grid settings on drawing aids dialog box

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Because an isometric plane is rotated and not viewed flat, an isometric circle appears as an ellipse. When in isometric mode, the ellipse command offers the isocircle option to assist in drawing isometric circles and arc (Figure 6.18):

Command : EL or ELLIPSE ¿
Specify axis endpoint of ellipse or [Arc/Circle/Isocircle]:**i** ¿
Center of circle: **P1**
<Circle radius>/Diameter: *specify a radius* ¿

Figure 6.18. Isometric circles

It is not a common practice to fully dimension isometric drawings. However, it is sometimes necessary try to dimension specific features or use a leader for pointing in an isometric drawing. When drawing the dimensions, the DIMALINED option ⬚ can be used because most isometric lines are drawn true lenght. To adjust the dimensions to appear to be in an isometric plane, the OBLIQUE option ⬚ is used (Figure 6.19).

Command: _dimaligned
First extension line origin or press ENTER to select: ¿
Select object to dimension: **P1**¿
Dimension line location (Mtext/Text/Angle): **P2** ¿
Dimension text = 30

Command: _dimedit Dimension Edit (Home/New/Rotate/Oblique) <Home>: **o** ¿
Select objects: <*pick any point on dimension*> 1 found
Select objects: ¿
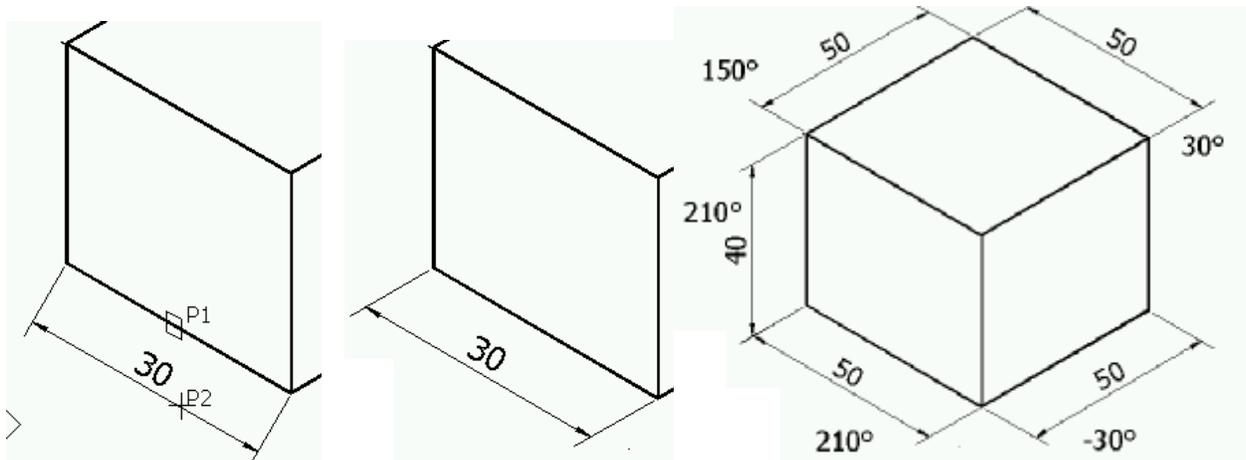Enter obliquing angle (press ENTER for none): **210** ¿

Figure 6.19. Dimensioning in isometric drawing

Questions

1. Describe three criteria used to evaluate the usefulness of a solid modeling system for a particular application.
2. What is the minimum information needed to define a true wireframe model? Is there enough information in a wireframe model to determine which edges are hidden?
3. What are the advantages and disadvantages of the three types of curves used to make surface patches?
4. Can you depict a hole in an object using a primitive-based solid modeler? What other types of solid modelers could be used?
5. Define the three types of Boolean operations, and sketch examples of each one. Can you derive the same final object using different Boolean operations and/or primitives?
6. Describe the differences and similarities of B-rep models and CSG models; do the same for wireframe models and B-rep models.
7. What modeling methods are appropriate for use in a hybrid modeler?
8. What is the difference between local and global coordinate systems? Which type would be associated with a workplane?
9. Will a translation operation always change the global coordinate location of all vertices on the object? What about a rotation operation?
10. Describe three different real-world applications of 3-D modeling in industry. What types of modeling systems might be used? What types of analyses might be performed on the model?
11. What is UCS ?
12. Why do 3D drawings present an idea more effecively than 2D drawing?
13. Where is the Z axis found in the Cartesian coordinate system ?
14. How can a 3D coordinate be specified as relative to the last point entered ?
15. Describe how cylindrical and spherical coordinates are used ?

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