Government College of Engineering and Research Avasari, Pune

SOLID MODELING AND DRAFTING

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CONTENTS

Introduction, Geometry and Topology, Solid entities, Solid representation, Fundamentals of Solid modeling, Half spaces, Boundary representation (BRep), Constructive Solid Geometry (CSG), Sweep representation, Analytical solid modeling, Parametric solid modeling, feature based modeling, etc., Euler Equation (Validity of 3D solids), Mass Property Calculations.

Introduction to Assembly Modeling, Assemblies (Top down and Bottom up approach), Design for Manufacturing [DFM], Design for Easy Assembly & Disassembly [DFA], Design for Safety.

Why solid modeling?
- Recall weakness of wireframe and surface modeling
– Ambiguous geometric description
– incomplete geometric description
– lack topological information
– Tedious modeling process
– Awkward user interface
- 2D standard drawings, assembly drawing and exploded views are generated form the 3D model.
- Can easily be exported to different Finite Element Methods programs for analysis.

Introduction: Product development activity starts with the design of the product. This is a very critical activity which will *influence the cost, performance, service life, quality, manufacturability, maintainability etc.* The challenges before the product designers today are listed below:

✓ Higher customer quality expectations

✓ Need to have innovation and originality in design

✓ Need for global collaboration across and beyond the enterprise among designers, customers and vendors to reduce development lead times

✓ Need to evaluate feasibility throughout the design process

✓ Ability to react quickly to design changes as and when change requests are made

✓ Ability to express the design intent in terms of shape and function using the tools available as well as the ability of the tools to transfer data back and forth seamlessly.

Geometric modeling: Product development activity starts with the design of the product. This is a very critical activity which Manufacturing of machine parts and components is carried out with the help of drawings. Drawings are also required for *process planning, tool design, production planning, and CNC programming, inspection, assembly, costing and vendor development*. Thus, drawings are essential documents for product development as well as for regular production.

GEOMETRIC MODELING: Computer representation of the **geometry of a component using software is called a geometric model**. Geometric modeling is done in three principal ways mentioned below

1. **Wire frame modeling**

2. **Surface modeling**

3. **Solid modeling**

These modeling methods have distinct features and applications.

1. Wire frame modeling: In wire frame modeling the object is **represented by its edges.** In the initial stages of CAD, wire frame models were in 2-D. Subsequently 3-D wire frame modeling software was introduced.

Though this type of modeling may not provide unambiguous understanding of the object, this has been the method **traditionally used in the 2-D representation** of the **object, where orthographic views like plan, elevation, end view** etc are used to describe the object graphically.

(a)

(b)
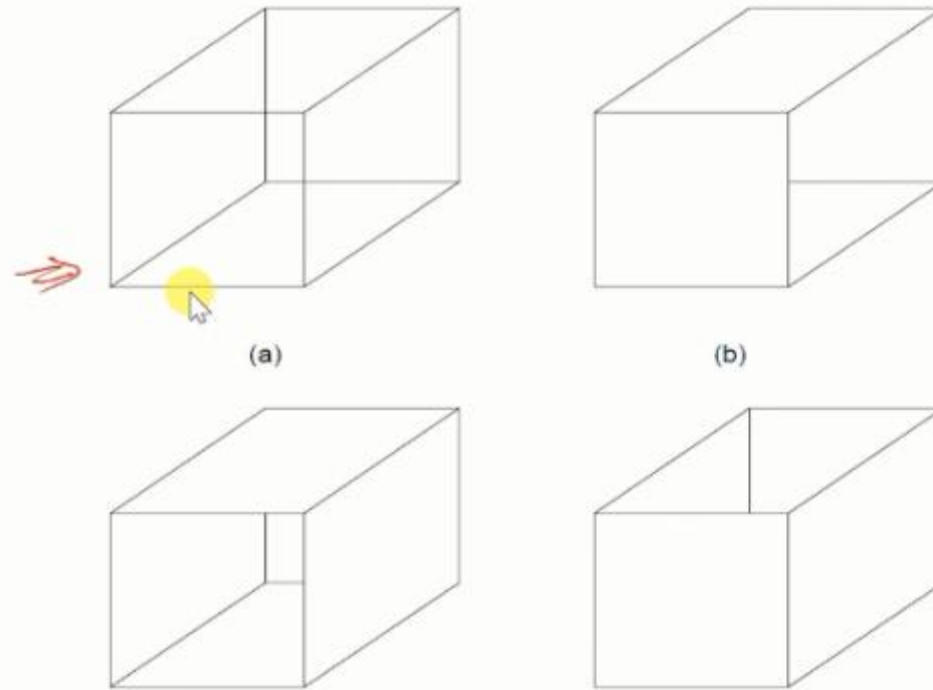
1. Wire frame modeling: A comparison between 2-D and 3-D models is given below:

2 - D Models	3-D Wire Frame Models
Ends (vertices) of lines are represented by their X and Y coordinates	Ends of lines are represented by their X, Y and Z coordinates.
Curved edges are represented by circles, ellipses, splines etc. Additional views and sectional views are necessary to represent a complex object with clarity.	Curved surfaces are represented by suitably spaced generators. Hidden line or hidden surface elimination is a must to interpret complex components correctly.
3-D image reconstruction is tedious.	2-D views as well as various pictorial views can be generated easily.
Uses only one global coordinate system	May require the use of several user coordinate systems to create features on different faces of the component.

2. SURFACE MODELING: In this approach, a component is represented by its surfaces which in turn are represented by their **vertices and edges.** For example, eight surfaces are put together to create a box, as shown in Fig. _Surface modeling has been very popular in aerospace product design and automotive design._ Surface modeling has been particularly _useful in the development of manufacturing codes for automobile panels and the complex doubly curved shapes of aerospace structures and dies and moulds._ **_It can also be created by surface modeling techniques like B-splines or NURBS (Non-Uniform Rational B-splines)._**
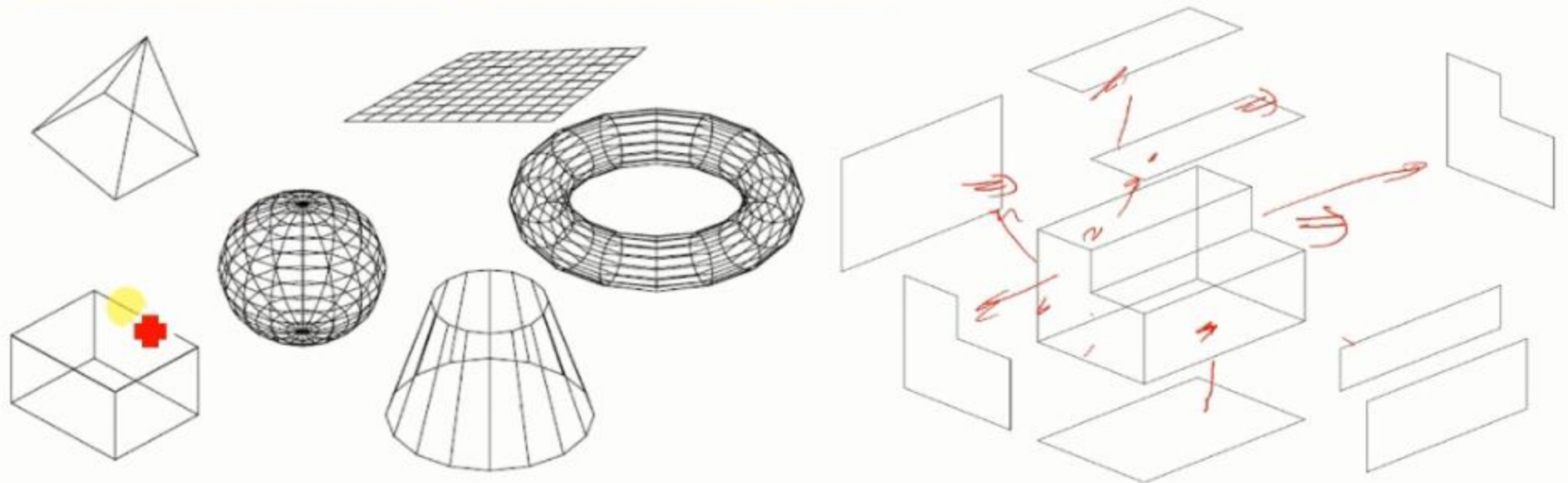
Surface Representation

3. SOLID MODELING: The representation of solid models uses the fundamental idea that a physical object divides the 3-D Euclidean space into *two regions, one exterior and one interior, separated by the boundary of the solid*. Solid models are:

✓ **Bounded**

✓ **Homogeneously three dimensional**

✓ **Finite**

**There are six common representations in solid modeling**

Wireframe Modeling

Wireframe model of an object is created by entirely of points, lines, arcs , circles, conics, and curves.

In 3D wireframe model, an object is not recorded as a solid.

In this form the object is displayed by interconnecting lines.

Instead the vertices that define the boundary of the object, or the intersections of the edges of the object boundary are recorded as a collection of points and their connectivity.
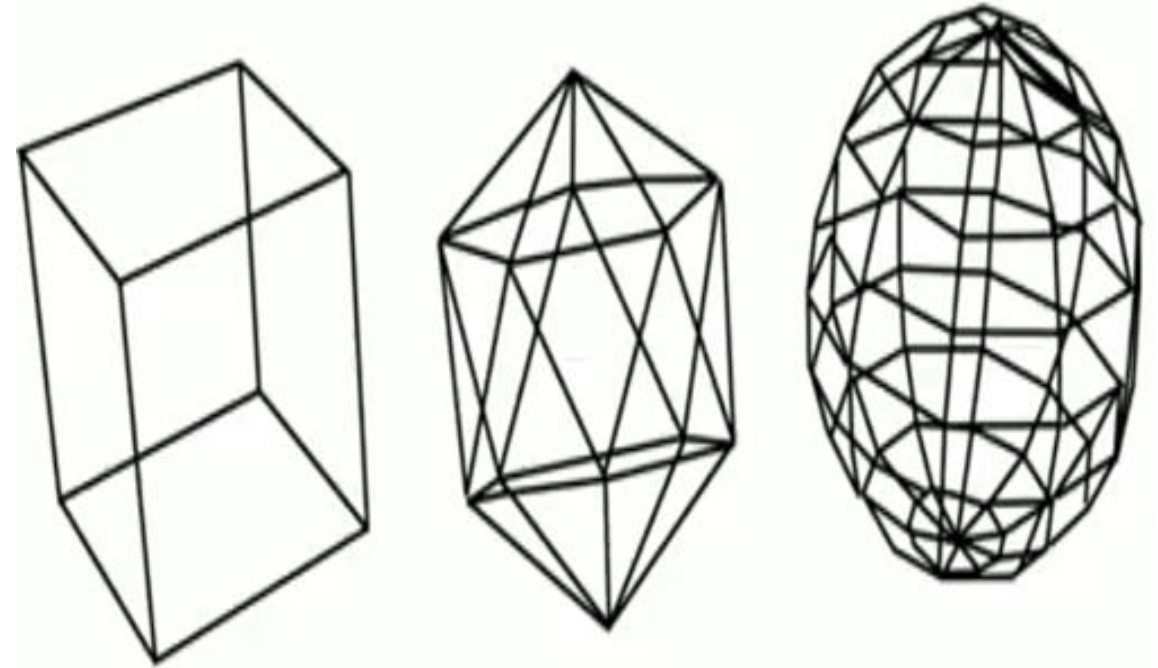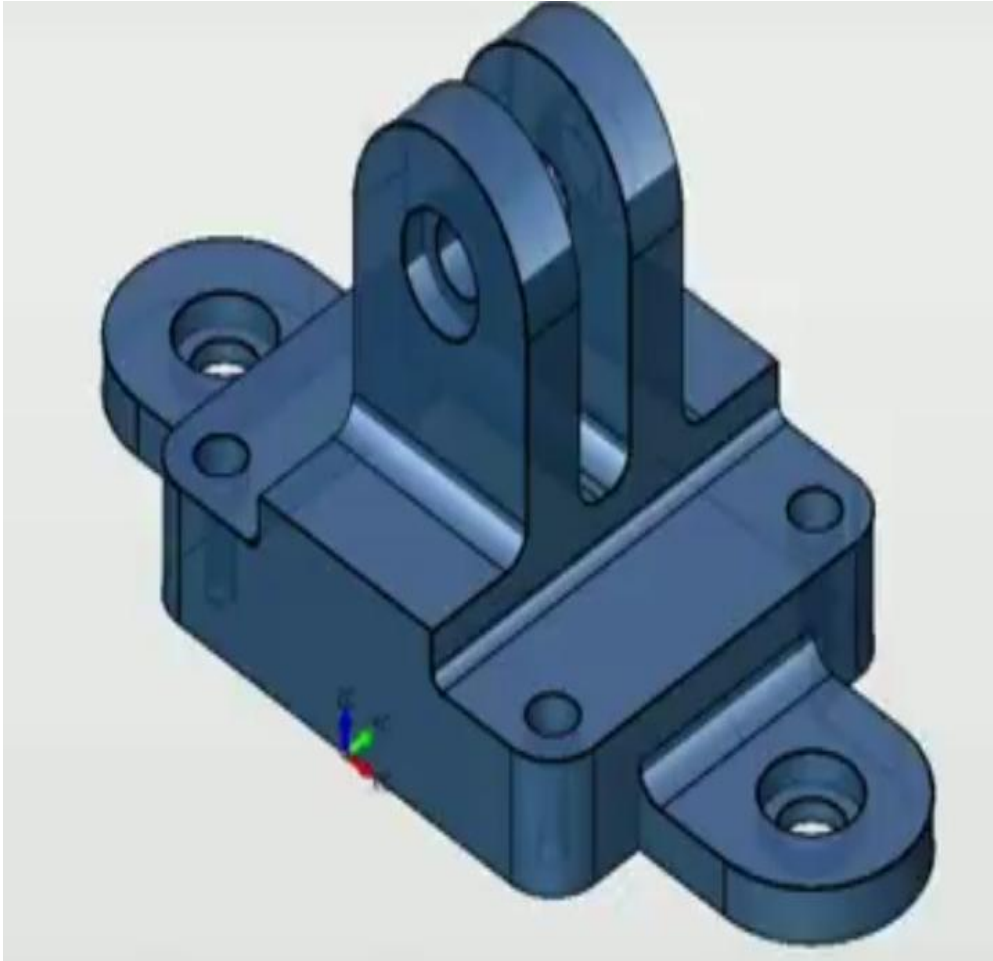
Solid Modeling

Solid models are known to be complete, valid, and unambiguous representations of objects. Simply stated, a complete solid is one which enables a point in space to be classified relative to the object, if it is inside, outside, or on the object. This classification is sometimes called spatial addressability.

A valid solid is one that does not have dangling edges or faces. An unambiguous solid has one and only one interpretation.

Solid modeling achieves completeness, validity, and un-ambiguity of geometric models, Therefore, the automation of tasks such as interference analysis, mass property calculations. Finite element modeling and analysis, Computer Aided Process Planning (CAPP), machine vision, and NC machining is possible.

Solid Modeling

- Solid modeling is a consistent set of principles for mathematical and computer modeling of three-dimensional solids.
- Solid modeling is distinguished from related areas of geometric modeling and computer graphics by its emphasis on physical fidelity.
- Modeling is the process of developing a mathematical representation of the geometry of an object.
- The model resembles the object.
- A model is an artificially constructed object that makes observation of another object easier.

Solid Modeling

- Wireframe and Surface representations contain only Geometric Data.
- Solid Modeling uses topological information in addition to Geometric information.
- Solid Model results in accurate Design which helps to further goal of CAD/CAM like CIM, Flexible Manufacturing leading to better automation of manufacturing process.
- Solid Modeling Support
- Using volume information
  - weight or volume calculation, centroids, moments of inertia calculation,
  - stress analysis (finite elements analysis), heat conduction calculations, dynamic   analysis,
  - system dynamics analysis
- Using volume and boundary information
  - generation of CNC codes, and robotic and assembly simulation

- Analysis automation and integration is possible only with solid models has properties such as weight, moment of inertia, mass.
- Solid model consist of geometric and topological data
  – Geometry shape, size, location of geometric elements
  – Topology connectivity and associativity of geometric elements non graphical, relational information

CAD systems offer two approaches to creating solid models: primitives and features.

The former approach allows designers to use predefined shapes (primitives) as building blocks (like Lego pieces) to create complex solids. Designers must use Boolean operations to combine the primitives. This approach is limited by the restricted shapes of the primitives.

The features are more flexible as they allow the construction of more complexes and elaborate solids than what the primitives offer. Some CAD systems (such as Unigraphics, CATIA, and IDEAS) offer both approaches. While others (such as SolidWorks and Pro/E) offer only the features approach.

- Consider the object shown in Figure, to illustrate the two approaches.
- We can create a block and subtract six cylinders from it using the primitives approach. Or, we can create a rectangle with six circles inside it in the Top sketch plane and extrude it using the features approach.
- The resulting solid is the feature in this case. The features approach is considered by some to be a generalization of the primitives approach.
- Systems that offer the features hideaway the Boolean operations from their users. These operations must be used to create the final solid model.
- A boss command is a form of Boolean union operation, and a cut command is a form of a Boolean subtracts operation.
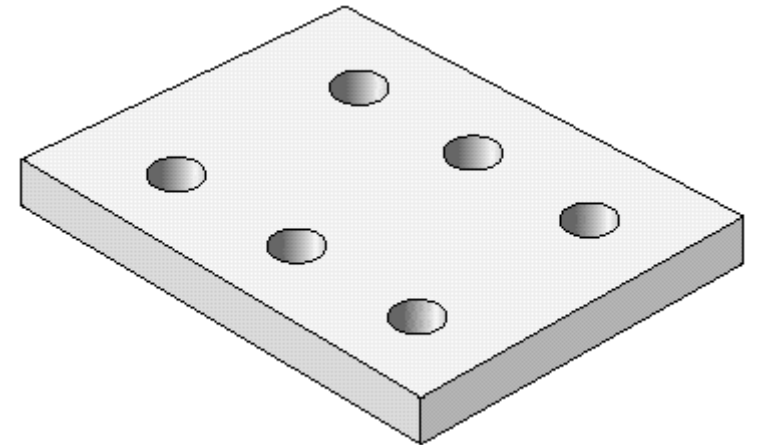
Solid model representation schemes
1. Constructive solid geometry (CSG)
2. Boundary representation (B-rep)
3. Spatial enumeration
4. Instantiation.

A solid model of an object Consists of both the topological and geometrical data of the object. The completeness and unambiguity of a solid model are attributed to the fact that its database stores both its geometry and its topology.

The difference between geometry and topology is illustrated in Figure; Geometry (sometimes called metric information) is the actual dimensions that define the entities of the object. The geometry that defines the object shown in Figure is the lengths of lines L1, L2, and L3. The angles between the lines, and the radius R and the center P1 of the half circle.

GEOMETRY & TOPOLOGY

The data required for the construction of solid models can be divided into two categories.

1) Geometry

2) Topology

GEOMETRY

- Geometry is the actual dimensions that defines the entities of the object.
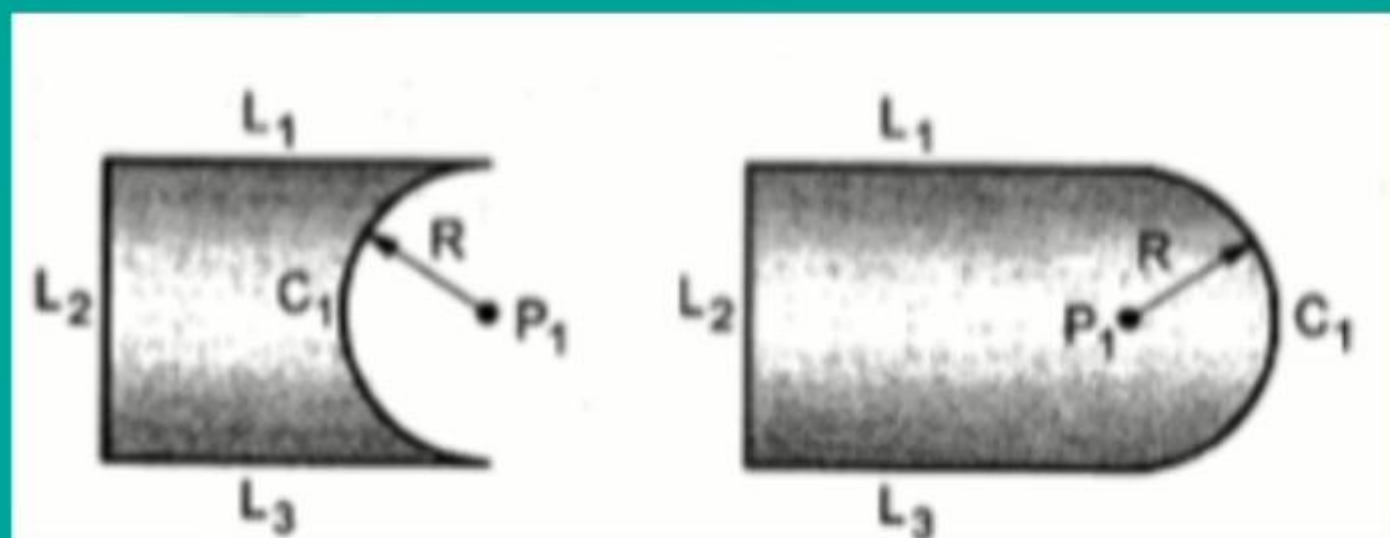
(Same geometry but different topology)

- The geometry that defines the object are

    * the length of lines L1, L2, L3

    * the angle between the lines

   * the radius R of half circle

    * the centre P1 of half circle

TOPOLOGY

- Topology is the connectivity & associativity of the different entities of the object. It describes the way in which the different entities of the object are connected together.
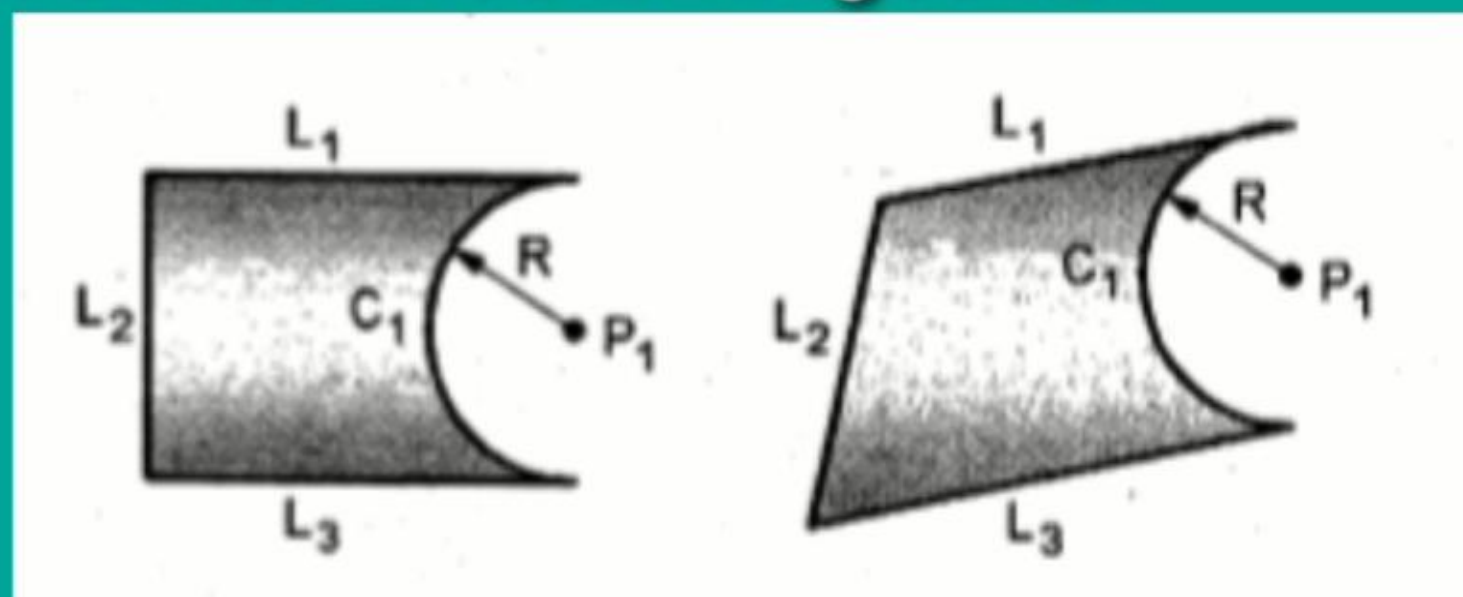
(Same topology but different geometry)

- The topology that defines the object are.

    * the line L1 shares a vertex (point) with line L2 and circle C1.

    * the line L2 shares a vertex with lines L1 & L3
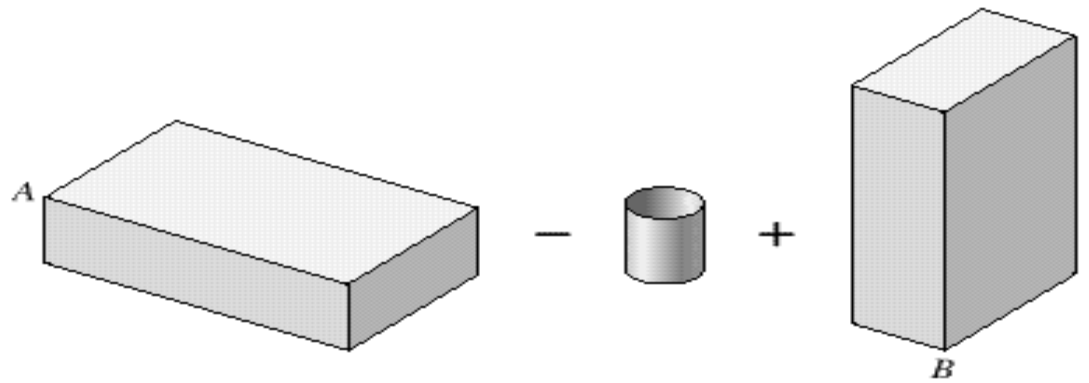
    * the line L3 shares a vertex with line L2 and circle C1.
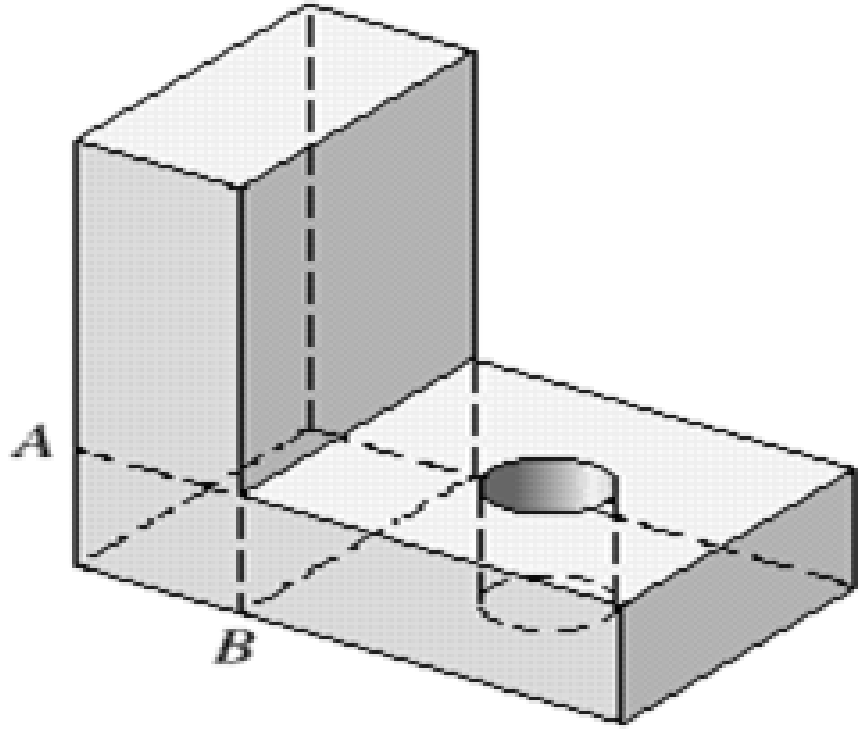
(a) Object

Primitives Approach
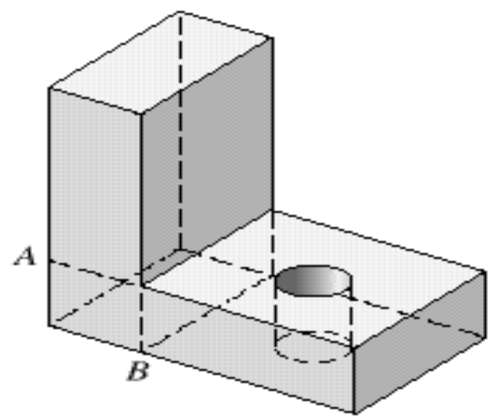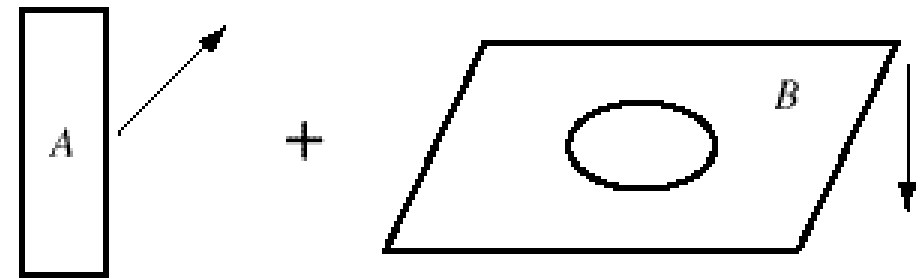

(a) Object
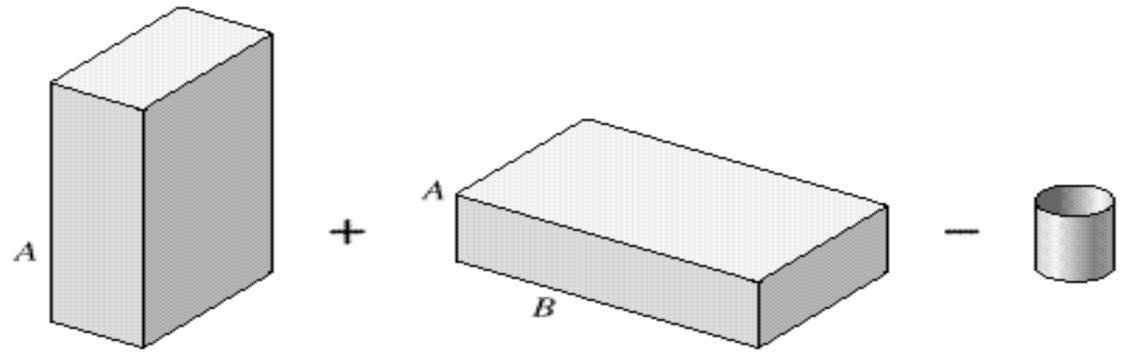
(b) Possible solid model of the object

(c) Alternative solid model of the object

Feature Approach
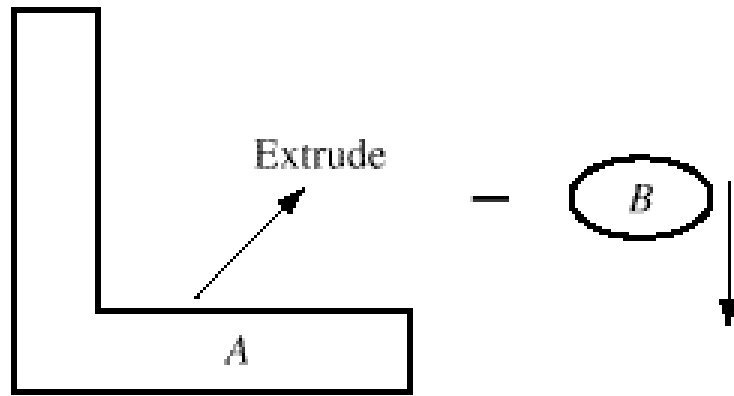
Extrude profile *A* as shown and cut extrude profile *B*

(*a*) Possible sketches of the solid

Extrude profile *A* as shown and add extrude profile *B*

(*b*) Alternative sketches of the solid

WIRE FRAME ENTITIES

- The wire frame entities are Polygons
- The basic wire frame model geometric entities are analytic entities and synthetic entities.
- The analytic entities are points, lines, arcs, circles, fillets, chamfers, and conics.
- The synthetic entities are various types of splines and Bezier curve.

SURFACE MODEL ENTITIES

- The surface model is created by using Analytic and Synthetic entities Explanation: A surface model is generated by using wire frame entities i.e. analytic and synthetic. A system may require one wire frame entity to create a surface of revolution or it may require two wire frame entities to create a ruled surface.

Axis A

1.00

0.50

3.00

0.50
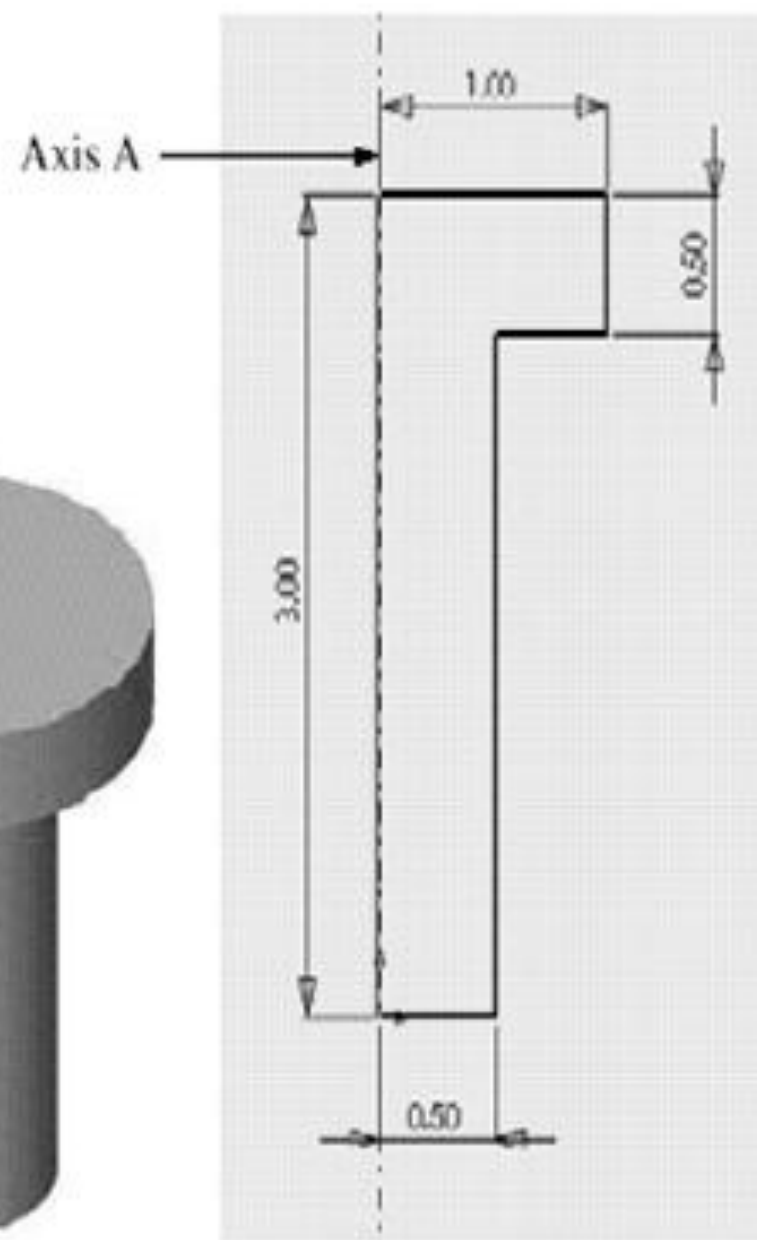
SOLID ENTITIES

- The entities we use to create solid models depend on the approach we use.

- The primitives approach uses primitives and the features approach uses sketches.

- Many CAD systems provide both approaches to increase their modeling domain, the entities required for sketches are curves and surfaces. Primitives are considered building blocks.

- Primitives are simple, basic shapes which can be combined by a mathematical set of Boolean operations to create the solid. The user usually positions primitives as required before applying Boolean operations to construct the final solid.

- There is a wide variety of primitives available commercially to users. However, the four most commonly used ones are the block, cylinder, cone, and sphere. These are based on the four natural quadrics: planes, cylinders, cones, and spheres.

Following are descriptions of the most commonly used primitives:

1. *Block:* This is a box or cube whose geometrical data is its width, height, and depth. Its local coordinate system XLYLZL is shown in Figure. Point P defines the origin of the XLYLZL system. The signs of W, H, and D determine the position of the block relative to its coordinate system. For example, a block with a negative value of W is displayed as if the block shown in Figure is mirrored about the YLZL plane.

2. *Cylinder:* This primitive is a right circular cylinder whose geometry is defined by its radius R (or diameter D) and length H. The length H is usually taken along the direction of the ZL axis. H can be positive or negative.

3. *Cone:* This is a right circular cone or a frustum of a right circular cone whose base diameter R, top diameter (for truncated cone), and height H are user-defined.

4. *Sphere:* This is defined by its radius R or diameter D and is centered about the origin of its local coordinate system.

5. *Wedge:* This is a right angled wedge whose height H, width W, and base depth D form its geometric data.
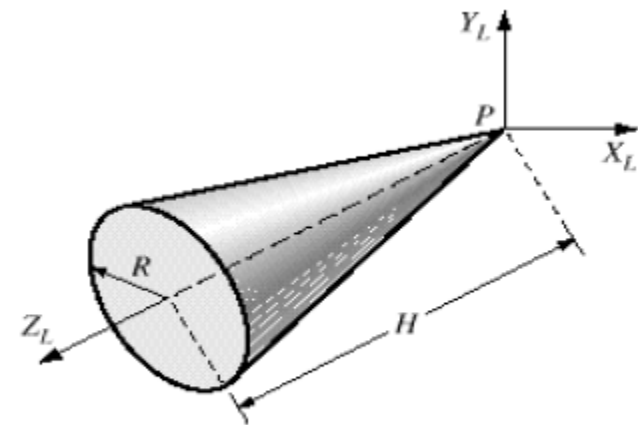
6. *Torus:* This primitive is generated by the revolution of a circle about an axis lying in its plane ZL axis in Figure. The torus geometry can be defined by the radius (or diameter) of its body R1 and the radius (or diameter) of the centerline of the torus body R2, or the geometry can be defined by the inner radius (or diameter) R1 and outer radius R0.
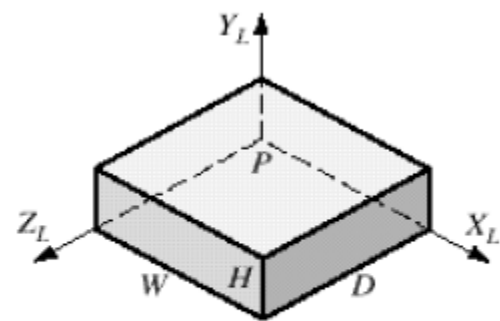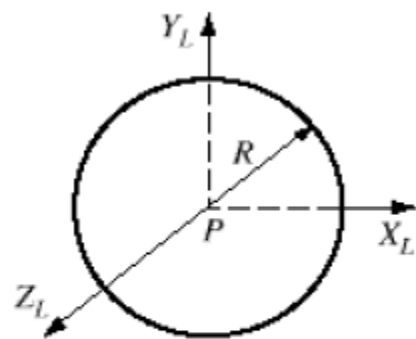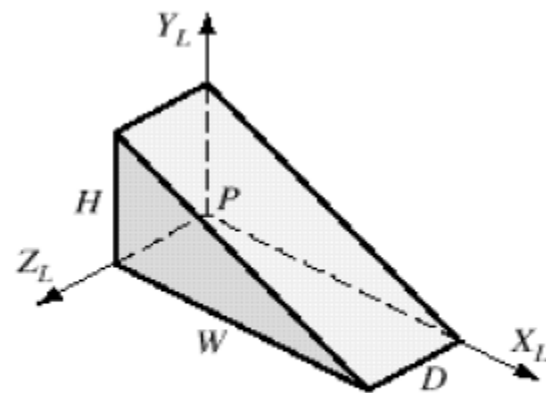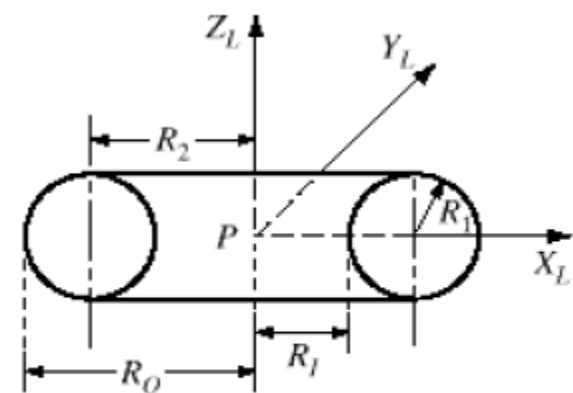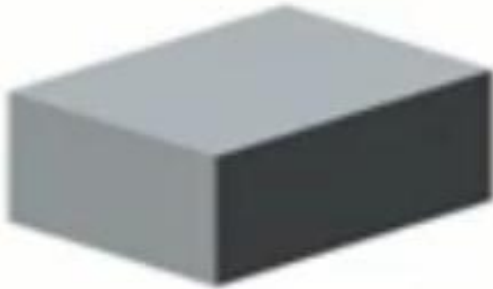
Block
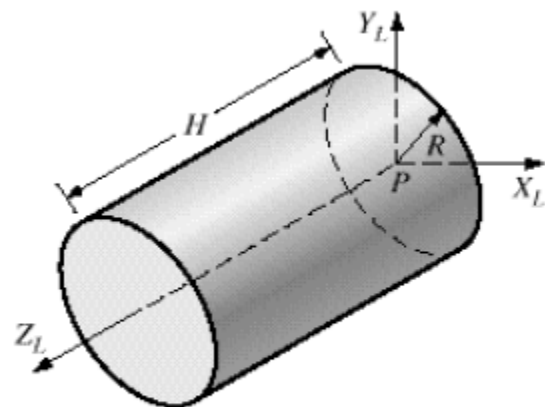
Cylinder

Cone

Sphere

Wedge

Torus

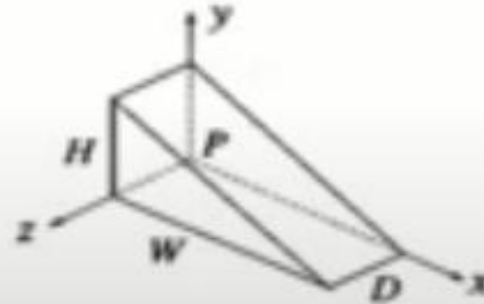# SOLID ENTITIES OR SOLID MODEL PRIMITIVES

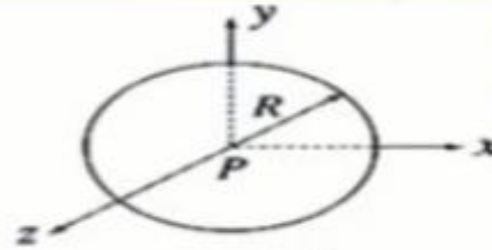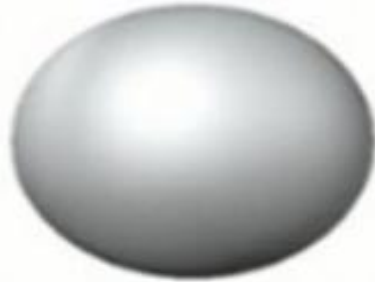| Primitives	Mathematical representation of solid Primitives
Block	Height(H), width(W), and depth (D) $\{(x,y,z): 0 \leq x \leq w, 0 \leq y \leq H$ and $0 \leq z \leq D\}$
Wedge	Right angle wedge Height(H) width(W) and depth (D) $\{(x,y,z): yW+ xH \leq HW,$ and $0 \leq x \leq w, 0 \leq y \leq H$ and $0 \leq z \leq D\}$
Cylinder	Radius (R) and Height(H) $\{(x,y,z): x^2+y^2 \leq R^2$ and $0 \leq z \leq H\}$

SOLID ENTITIES OR SOLID MODEL PRIMITIVES

Primitives	Mathematical representation of solid Primitives
Sphere	Radius (R) $\{(x,y,z): x^2 + y^2 + z^2 \leq R^2 \}$
Cone	Base Radius (R) and Height(H) x^2+y^2 ≤ [(R/H)]^2 and $0 \leq z \leq H$
Torus	Inner radius (R1), Outer radius (R0), radius of center line of torus body (R2), radius of body(Ri). {(x,y,z): (x^2 + y^2 + z^2 − [R1] ^2 − [R2] ^2)^2 ≤4 R2^2(R1^2 − Z)}
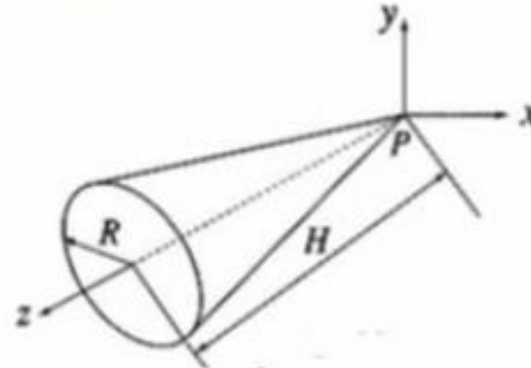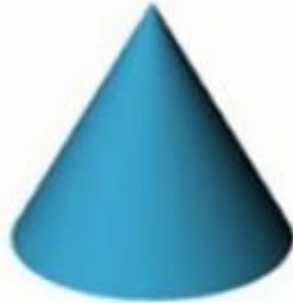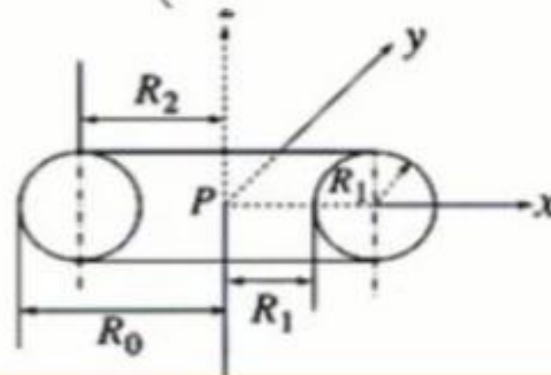
SOLID REPRESENTATION

• Solid representation of an object can support reliably and automatically, related design and manufacturing applications due to its informational completeness.

• The properties that a solid model should capture mathematically are:

1. Rigidity.

2. Homogeneous three dimensionality.

3. Finiteness and finite describability.

4. Closure under rigid motion and regularized Boolean operations.

5. Boundary determinism.

• The mathematical implication of these properties is that valid solid models are bounded, closed, regular, and semi analytic subsets.

Solid Representation

- The solid representation of an object is based on the idea that a physical object divides an n-dimensional space E into two regions: interior and exterior separated by the object boundaries (two-manifold objects)
- From this point of view any solid model is defined mathematically as a point set S in the three dimensional Euclidean space E.

- $S = iS \cup bS$

where iS is the interior point set and bS the boundary set. The universal set is now defined as

$$W = iS \cup bS \cup cS$$

Where cS is the complementary set of iS U bS

Interior, Exterior, Closure

- Following Example will illustrate the Interior, Exterior and Closure
- Consider a Unit Sphere
- It's interior is $\qquad x^2 + y^2 + z^2 < 1$

- Its Boundary is $\qquad x^2 + y^2 + z^2 = 1$

- Solid sphere is Its closure $\qquad x^2 + y^2 + z^2 \leq 1$

Geometrical Closure

- The universe set is defined as

$$W = iS \cup bS \cup cS$$

where cS is the complementary set of iS $\cup$ bS

  - The interior of the solid is geometrically closed by its boundaries $S = kS = iS \cup bS$

$$cS$$

$$W \Rightarrow \mathbf{E}^3$$

$$S$$
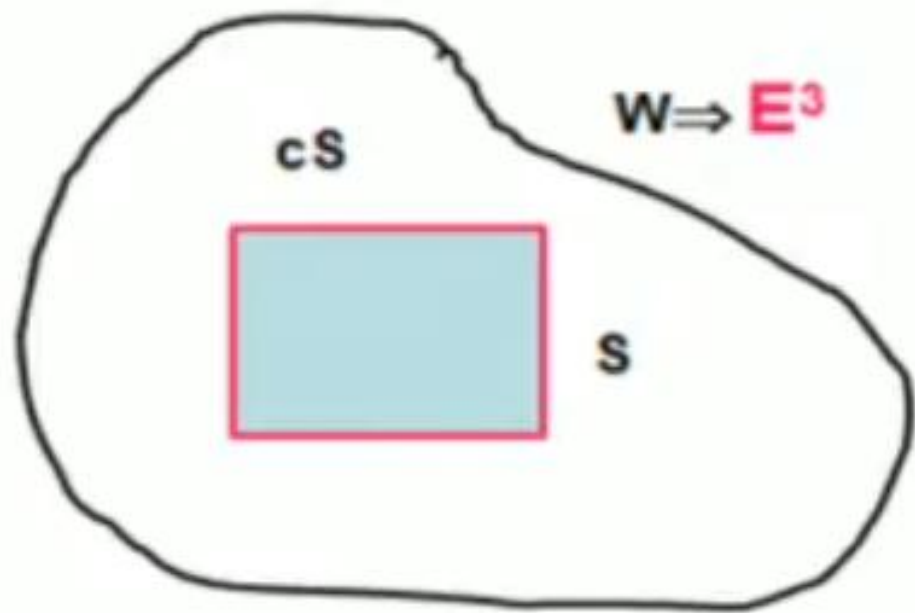
$$iS \quad \mathbf{U} \quad bS \quad = \quad S$$

Solid Modeling Representation Schemes or Techniques

- Half spaces
- Boundary representation (BRep)
- Constructive Solid Geometry (CSG)
- Sweep representation

9.6 Half-Spaces

This section and the next three cover the common four representation schemes of solid modeling (half-space, B-rep, CSG, and sweep). Each scheme views a solid model differently. Thus, each scheme has a set of elements that act as building blocks and a set of operators that go along with them to combine (assemble) the elements to build (create) the solid model.

Half-spaces form a basic representation scheme for bounded solids. By combining half-spaces (using set operations) in a building block fashion, various solids can be constructed. Half-spaces are usually unbounded geometric entities; each one of them divides the representation space into two infinite halves; one is "filled with material" and the other is "empty." Surfaces are viewed as half-space boundaries, and half-spaces are viewed as directed surfaces.

A half-space is defined as a regular point set in E^3 as follows:

$$H = \{P : P \in E^3 \text{ and } f \, P \, 0\} \tag{9.51}$$

where P is a point in E^3 and $f(P) = 0$ defines the surface equation of the half-space boundaries. Half-spaces can be combined using set operations to create complex objects.

Fig. shows various half spaces with their local coordinate systems
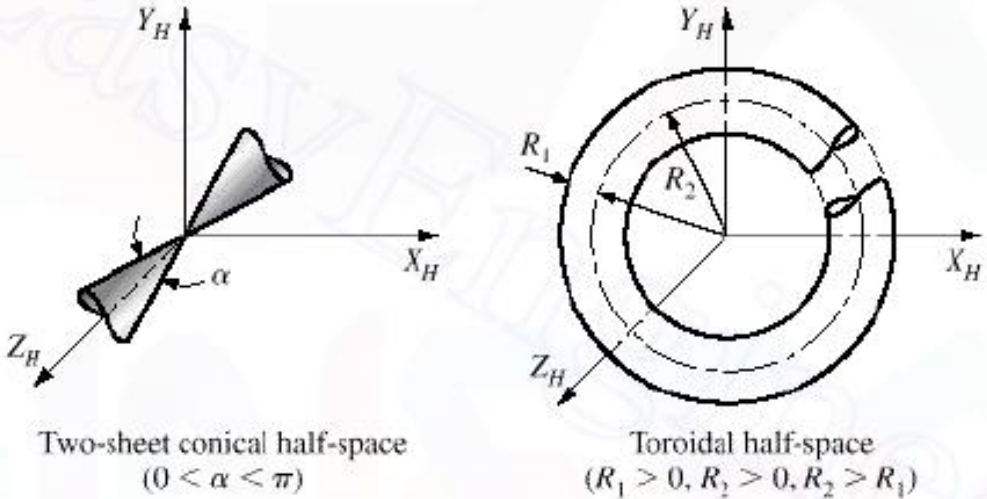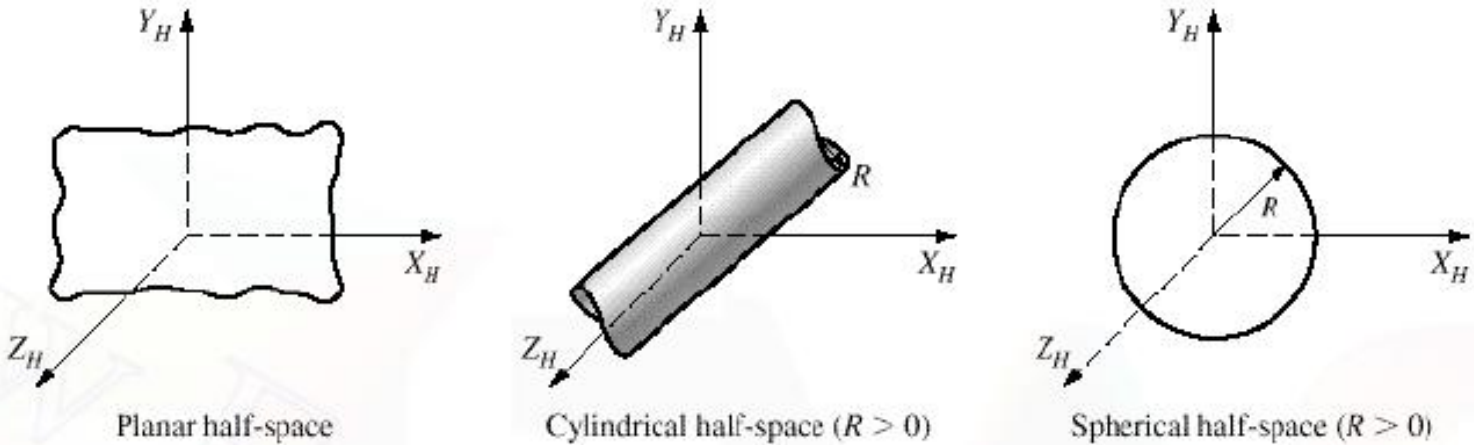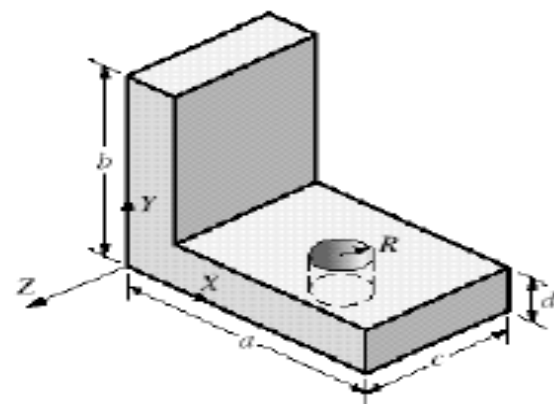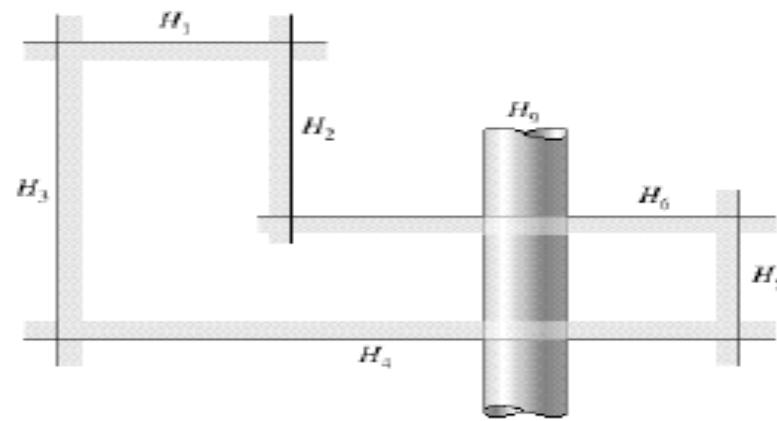

Planar half-space

Cylindrical half-space ($R > 0$)

Spherical half-space ($R > 0$)

Two-sheet conical half-space
$(0 < \alpha < \pi)$

Toroidal half-space
$(R_1 > 0, R_2 > 0, R_2 > R_1)$

Figure 9.16 Half-spaces.

e.g.

(a) Solid S   (b) Half-space representation

Half space representation scheme is the lowest level available to represent a complex object as a solid model. It is concise in representing objects compared to CSG. This representation can lead to unbounded solid models if the user is not careful. Such unboundness can lead to missing faces and abnormal shaded images. It can also lead to system crash or producing wrong results if application algorithms attempt to access databases of unbounded models. It is cumbersome for casual users and designers to use and may be difficult to understand. Therefore half spaces study can be useful for research purposes only.

BOUNDARY REPRESENTATION (BREP)

- Solid model is defined by their enclosing surfaces or boundaries.
- In boundary representation model of an object consist of

  - Vertices
  - Edges
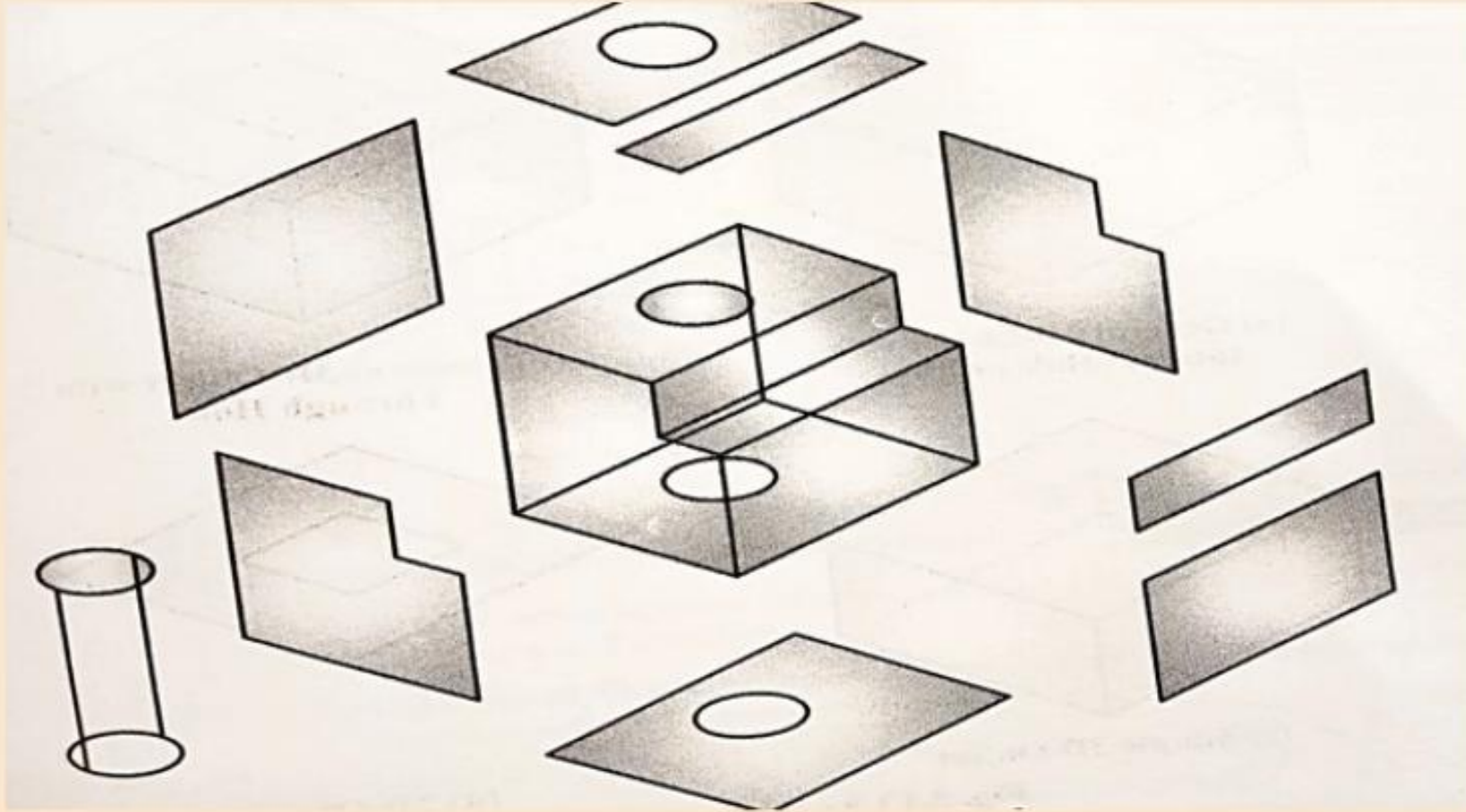 - Faces
  - Loops and
  - Handles
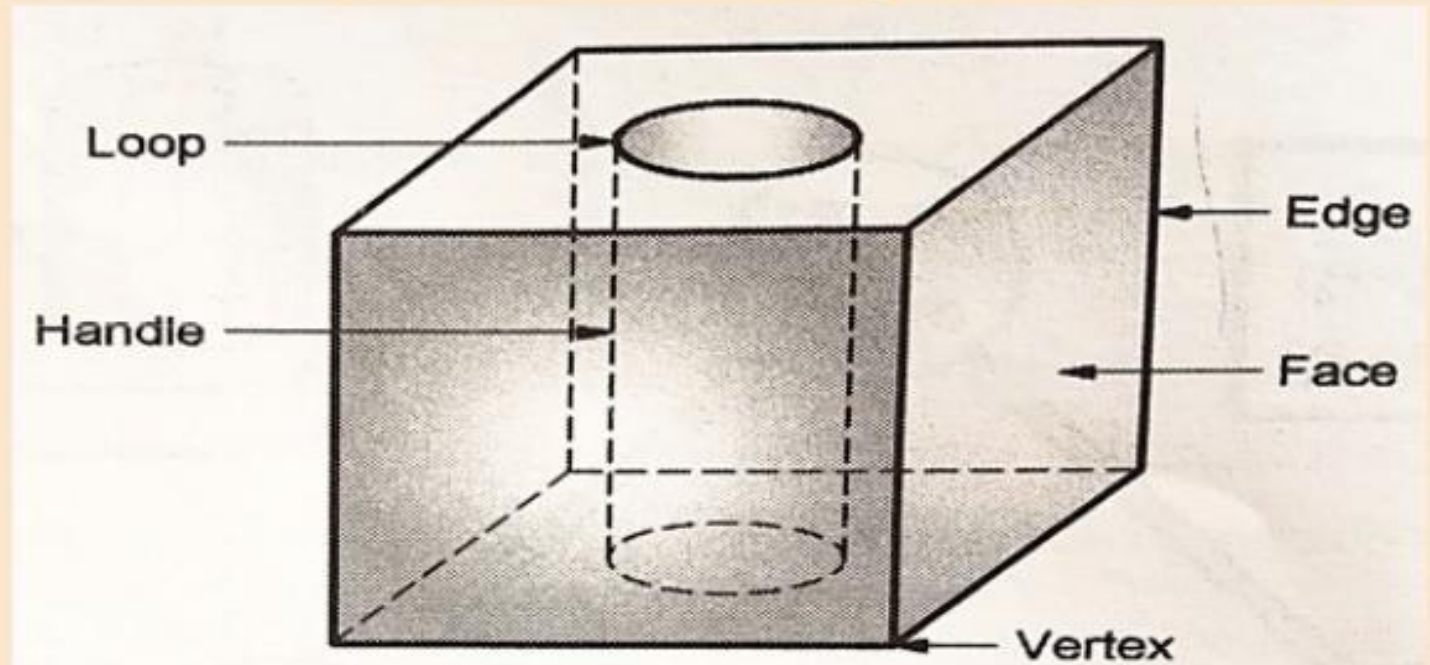
- Boundary representation also contain both its topology and geometry
- B-rep model is created using Euler equation.

BOUNDARY REPRESENTATION (BREP)

- Solid model is defined by their enclosing surfaces or boundaries.

BOUNDARY REPRESENTATION (BREP)
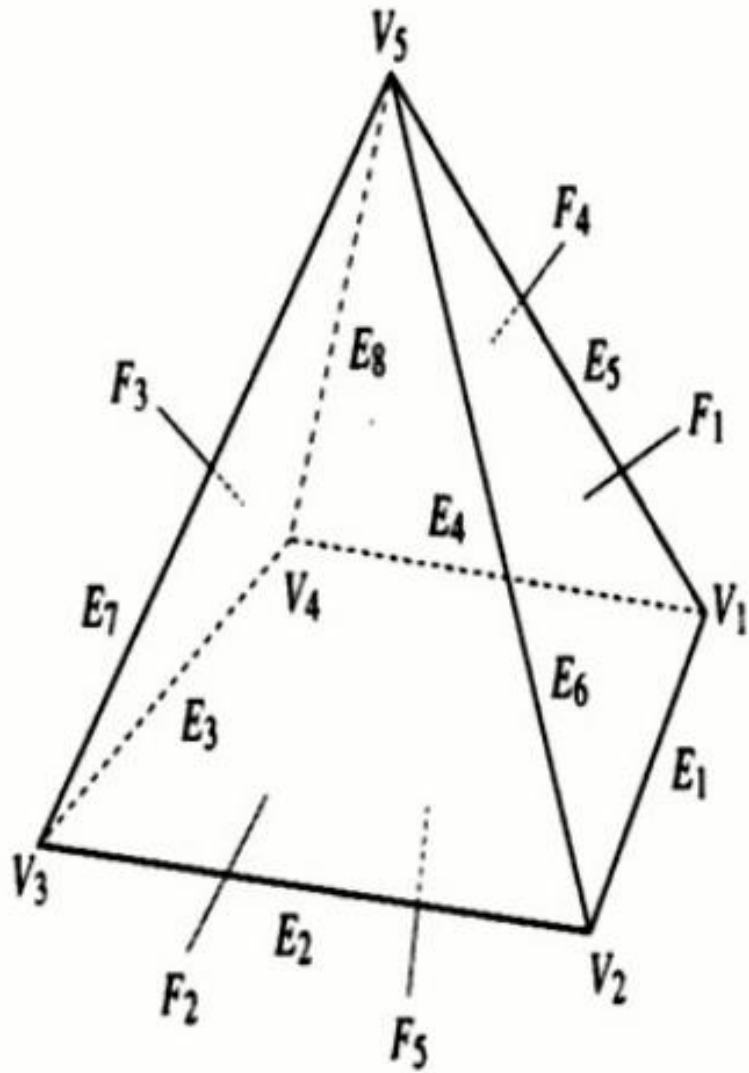
Face Table		Edge Table		Vertex Table	
Face	Edges	Edge	Vertices	Vertex	Coordinates
F_1	E_1, E_5, E_6	E_1	V_1, V_2	V_1	x_1, y_1, z_1
F_2	E_2, E_6, E_7	E_2	V_2, V_3	V_2	x_2, y_2, z_2
F_3	E_3, E_7, E_8	E_3	V_3, V_4	V_3	x_3, y_3, z_3
F_4	E_4, E_8, E_5	E_4	V_4, V_1	V_4	x_4, y_4, z_4
F_5	E_1, E_2, E_3, E_4	E_5	V_1, V_5	V_5	x_5, y_5, z_5
		E_6	V_2, V_5	V_6	x_6, y_6, z_6
		E_7	V_3, V_5		
		E_8	V_4, V_5		

Boundary Representation Validity
Euler's Equation

- The B-rep model are topological valid, only if, it satisfies the Euler's equation.
- Euler's equation for general 3D object is given by

$$F-E+V-L=2(B-G)$$

F=number of faces	E = number of edges
V=number of vertices	L= number of loops
G=number of handles	B = number of bodies

- Euler's equation for simple 3D object is given by

$$F-E+V=2 \qquad L=0 \ G=0 \ B=1$$

- Eulers equation for simple 2D object is given by

$$F-E+V-L=B-G$$

Boundary Representation Validity
Euler's Equation

Evaluation is based upon Euler's Law (valid for simple solid – no hole)

$$F-E+V=2$$
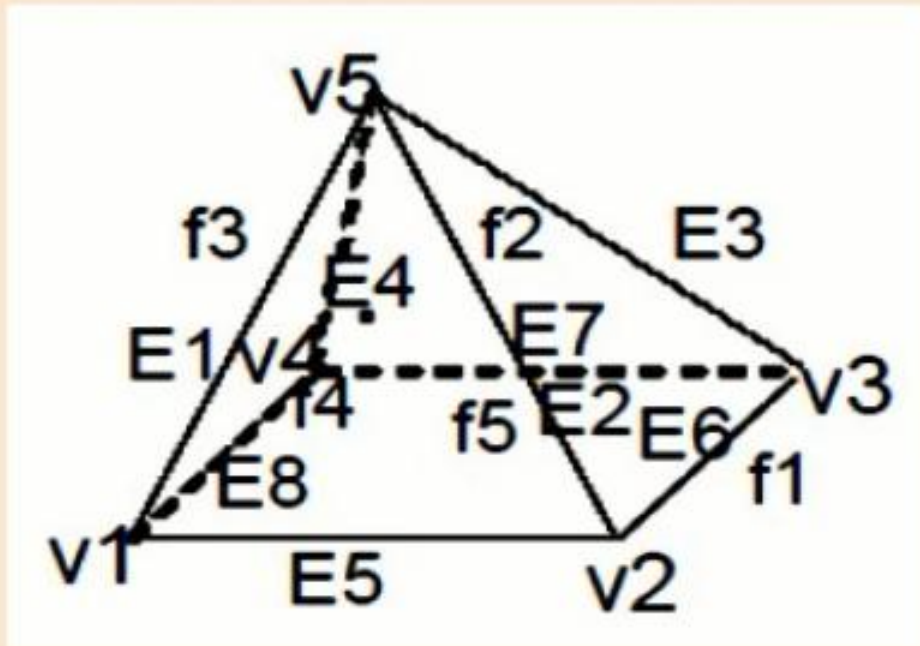
$V = 5, E = 8, F = 5$
$5 - 8 + 5 = 2$

Boundary Representation Validity
Euler's Equation

Expanded Euler's law for complex polyhedrons (with holes)
$$V-E+F-H+2P=2B$$

H – number of holes in face,
P- number of passages or through holes,
B- number of separate bodies.

$V = 24$, $E=36$, $F=15$, $H=3$, $P=1$, $B=1$

$24-36+15-3+2*1=2*1$

$2=2$ (LHS=RHS)

Boundary Representation Validity

Advantages

- B-rep is very appropriate to construct solid models of unusual or complex shapes (like turbine blades, auto body etc.) that are difficult to build using primitives.
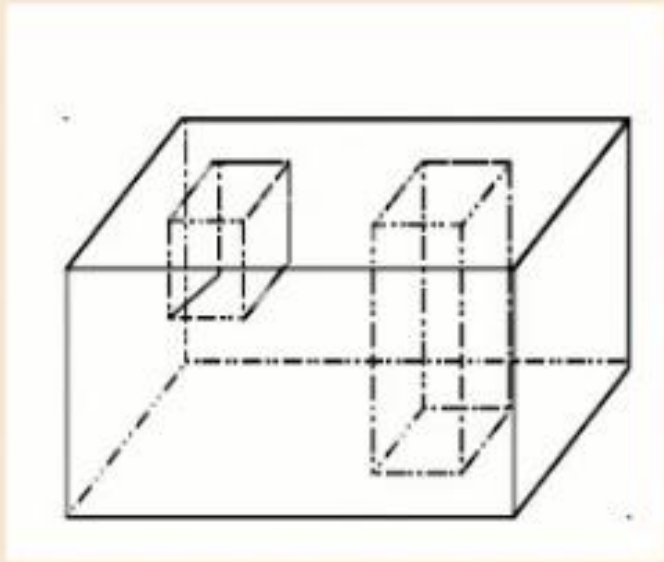
- It is relatively simple to convert a B-rep model into a wireframe model because the model's boundary definition is similar to the wireframe definition.

Disadvantage

- It requires large amounts of storage because it stores the explicit definition of model boundaries i.e. faces, edges & vertices which tend to grow fairly fast for complex model.

COMPARISON

CSG APPROACH	B-REP APPROCH
Simple object can be model	Complex shape model can be model
Boolean operations are used	Represented by face edge and vertices
requires less storage but more computation	This requires more storage less computation effort
it is difficult to convert back and forth between the CSG model and corresponding wire frame model.	simple to convert back and forth between a boundary representation and a corresponding wire-frame model.

1) Write a short note on solid modeling approach and list advantages of it with other modeling approach.

2) Explain the terms geometry and topology for solid model.

3) Explain the various primitives used in solid modeling approach.

4) Write a short note on constructive solid modeling approach.

5) With example, explain the formation of CSG tree.

6) Write a short note on boundary representation solid modeling approach.

7) Compare CSG approach and B-rep Approach of solid modeling.

Constructive Solid Geometry (CSG)

- CSG approach object is created by using primitives

- Two or more primitives are combined by set of Boolean operation to create desired object.

- CSG tree gives complete information about the process of combining the individual primitive by Boolean operations to generate solid model.

BOOLEAN OPERATIONS IN CSG APPROACH

Boolean operations on two primitives, a block(A) and a cylinder(B)
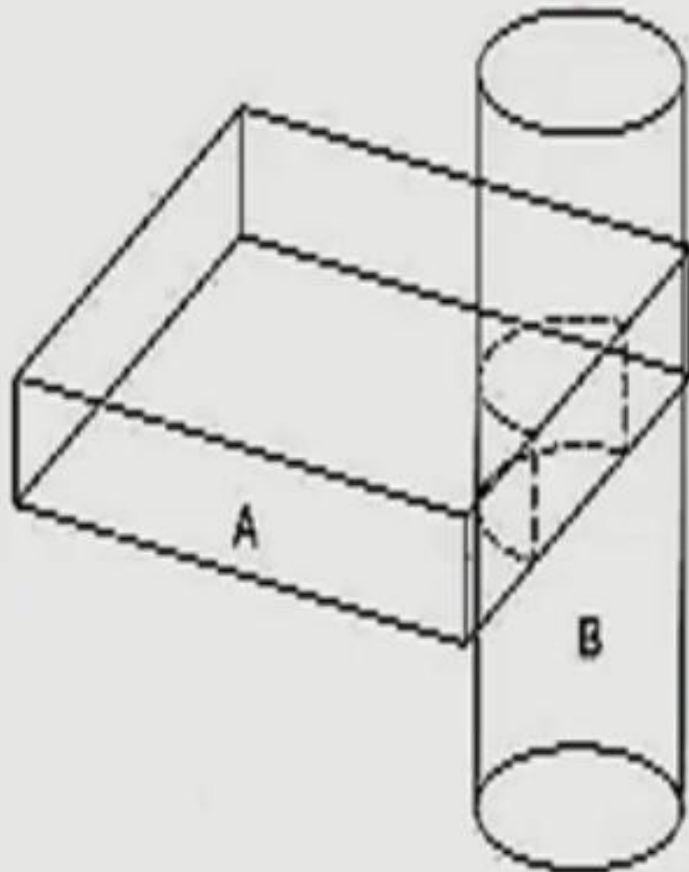
Union (U or +)	A∪B
Subtract (-)	A-B, B-A
Intersection (∩ or I)	A∩B
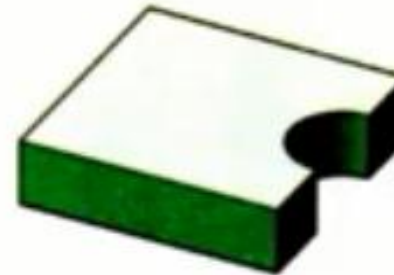
CSG Tree

CSG tree gives complete information about the process of combining the individual primitive by Boolean operations to generate solid model.

Example of CSG Tree

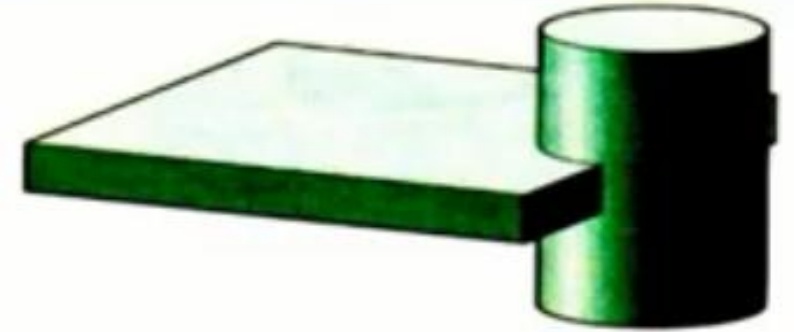- Primitives : P_1, P_2, P_3, P_4
- Operations : $(P_1 - P_2)$, $(P_3 + P_4)$
  $(P_1 - P_2) + (P_3 + P_4)$

$(P_1 - P_2)$
$+$
$(P_3 + P_4)$

$(P_1 - P_2)$

$(P_3 + P_4)$

$(P_1 - P_2)$
$+$
$(P_3 + P_4)$

$(P_3 + P_4)$

P_1

P_2

P_3

P_4
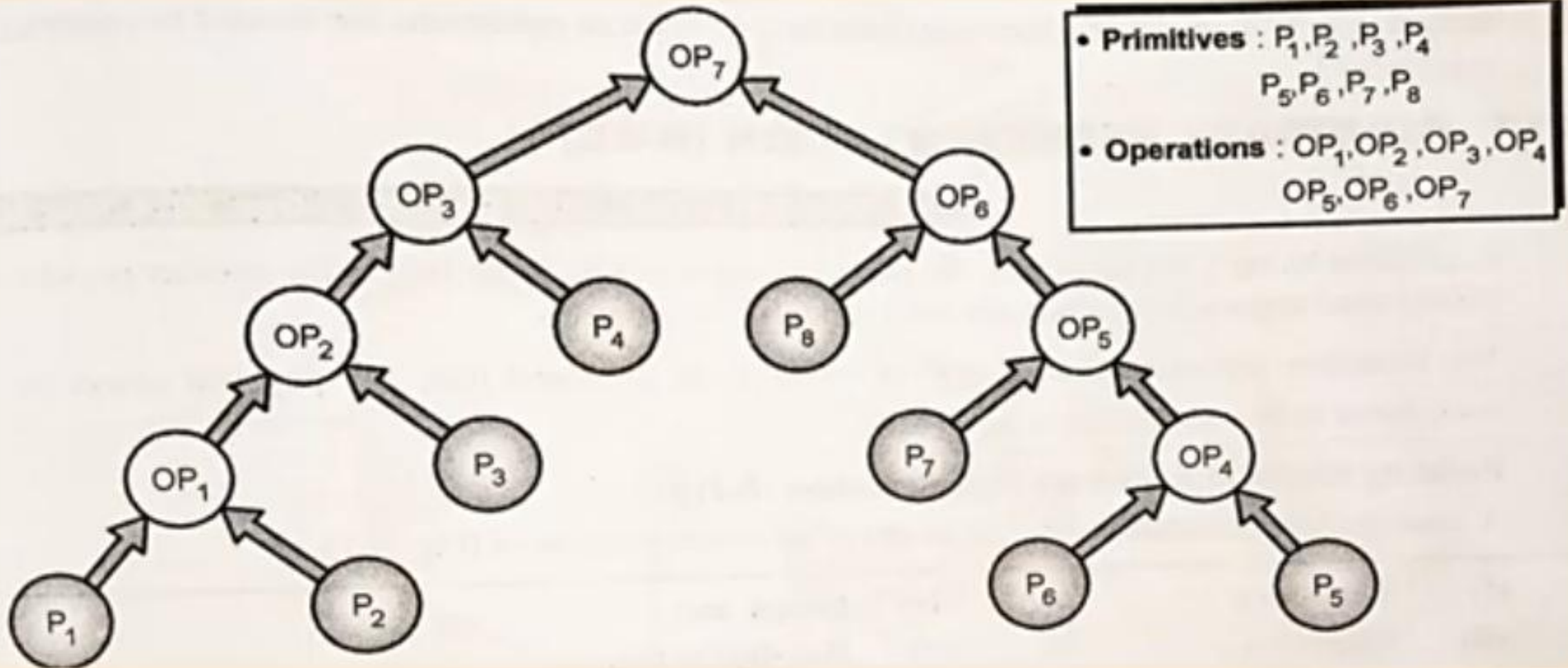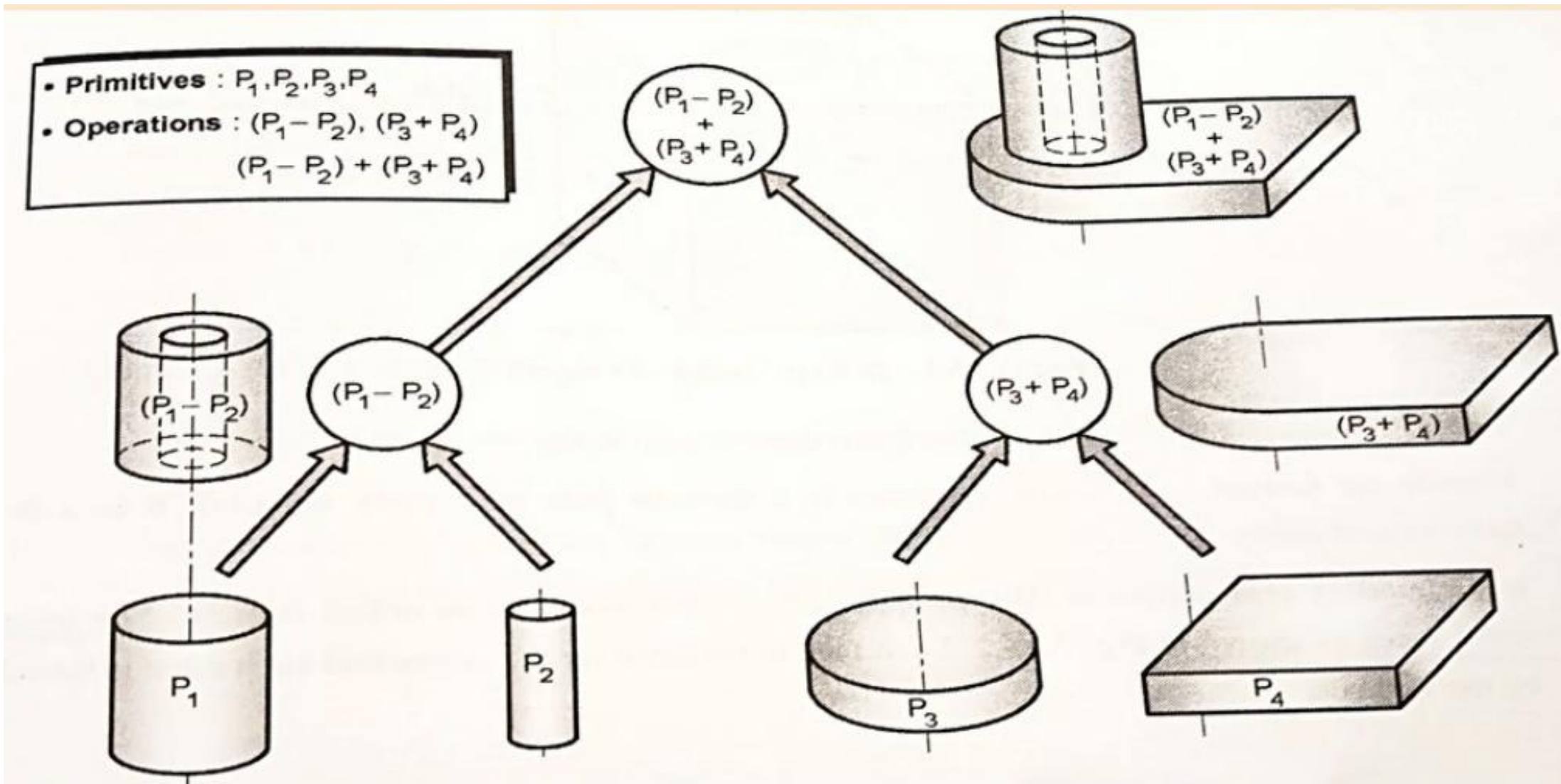
Advantages

- It is easy to construct out of primitives & Boolean operation.

- It is concise & requires minimum storage

Disadvantage

- Major disadvantage of CSG is in its inability to represent sculptured surfaces i.e. non-analytical (synthetic surface) cannot be modeled using CSG scheme

SWEEP REPRESENTATION

9.9 Sweeps

Sweep operations are popular in the features approach. We sketch a cross section and sweep it to create a solid. These operations are useful in creating solid models of 2½D objects. The class of 2½D objects includes both solids of uniform thickness in a given direction and axisymmetric solids. The former are known as extruded solids and are created via linear or translational sweep; the latter are solids of revolution which can be created via rotational sweep.

Sweep is based on the notion of moving a point, curve, or surface along a given path. There are three types of sweep: linear, nonlinear, and hybrid. In linear sweep, the sweeping path is a linear (for extrusions) or circular (for axisymmetric solids) vector described by a parametric linear equation. In nonlinear sweep, the path is a curve described by a higher order (quadratic, cubic, or higher) equation. Hybrid sweep combines linear and nonlinear sweeps.

Types of Geometric models - 2½ extrusions, axisymmetric, composite, 3D objects
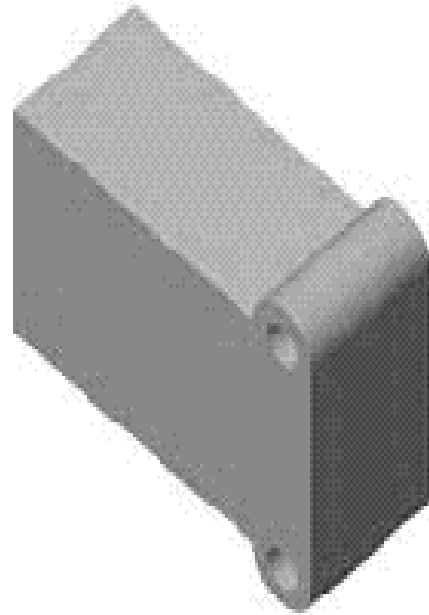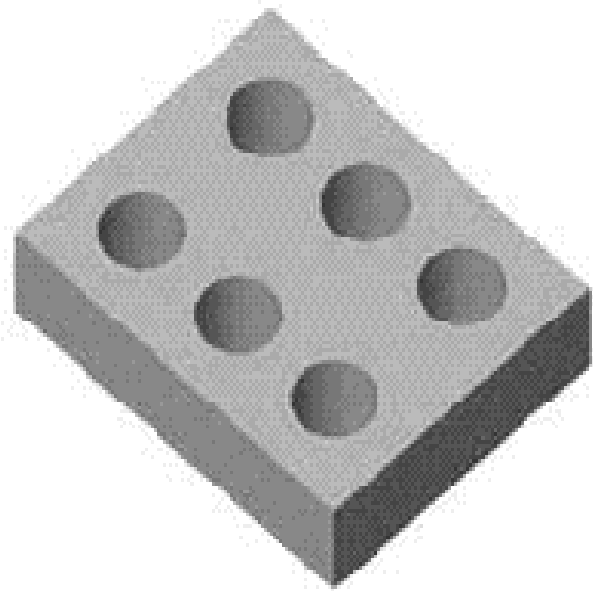
Uniform thickness models
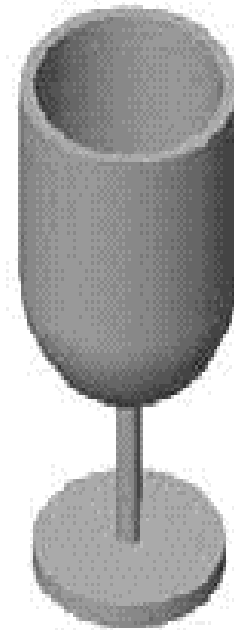
Axisymmetric model
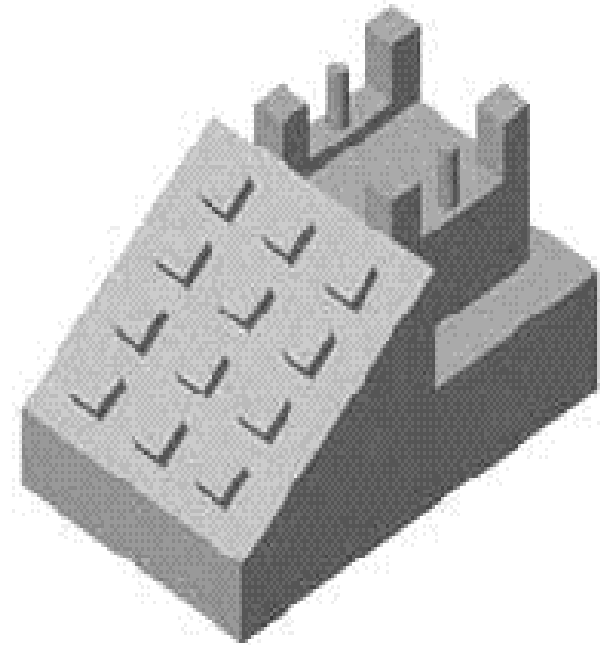
Composite model

Sample 2 1/2D models

Linear sweep can be divided into translational and rotational sweep. In translational sweep, a planar 2D point set described by its boundary (or contour) can be moved a given distance in space in a perpendicular direction (called directrix) to the plane of the set as shown in Figure 9.32a. The boundary of the point set must be closed otherwise invalid solids (open sets) result. In rotational sweep, the planar 2D point set is rotated about an axis of rotation (axis of symmetry of the object to created) a given angle as shown in Figure 9.32a.

Nonlinear sweep is similar to linear sweep but with the directrix being a curve instead of a vector as shown in Figure 9.32b. Hybrid sweep tends to utilize some form of set operations. Figure 9.32c shows the same object shown in Figure 9.32a but with a hole. In this case, two point sets are swept in two different directions and combined (added or subtracted) to create the final solid. Invalid solids or nonregular sets may result if the sweeping direction is not chosen properly as shown in Figure 9.32d.

Boundary of point
set to translate

Translational sweep

Rotational axis

Boundary of point
set to rotate

Rotational sweep

(a) Linear sweep

Directrix

Boundary of point
set to move

(b) Nonlinear sweep

Directrix

Gluing area

Directrix

(c) Hybrid sweep

Directrix

Dangling
face

(d) Invalid sweep

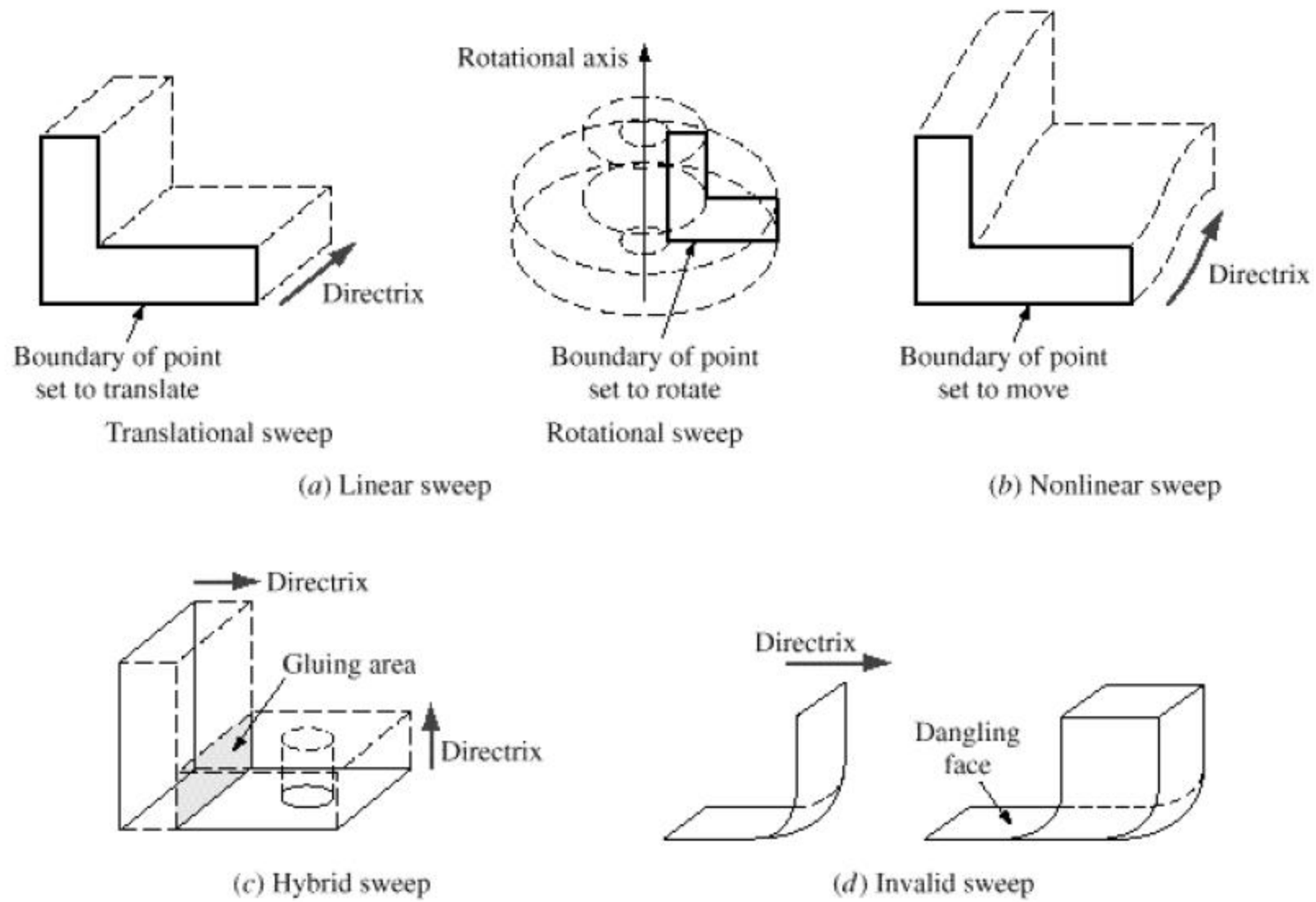**Figure 9.32   Types of sweep.**

SWEEP REPRESENTATION

- Sweep representation is useful in creating **two and a half** dimensional solid models.

PROFILE
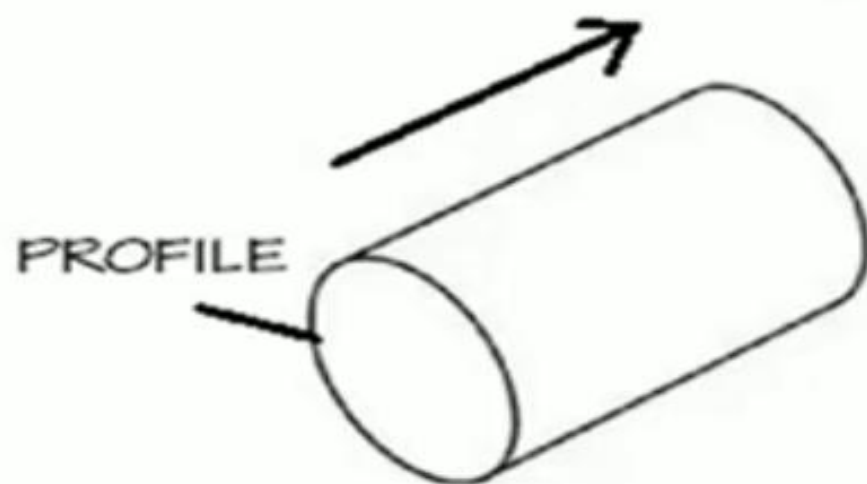
- Two categories of solids are considered of this kind;

  - Solid of uniform thickness – Extruded solid

  - Axisymmetric solids – Solids of revolution

- Sweeping is based on the notion of moving a given point, curve or a surface along a given path.

2

TYPES OF SWEEP REPRESENTATION

- **Linear** – the path is **linear or a circular** vector described by a linear, most often parametric equation.

- **Non Linear** – the path is a **curve** described by a curve of higher order equation (quadratic, cubic or higher).

- **Hybrid** – This combines **linear and/or nonlinear** sweep via set operations

LINEAR SWEEP

- **Translational sweep**
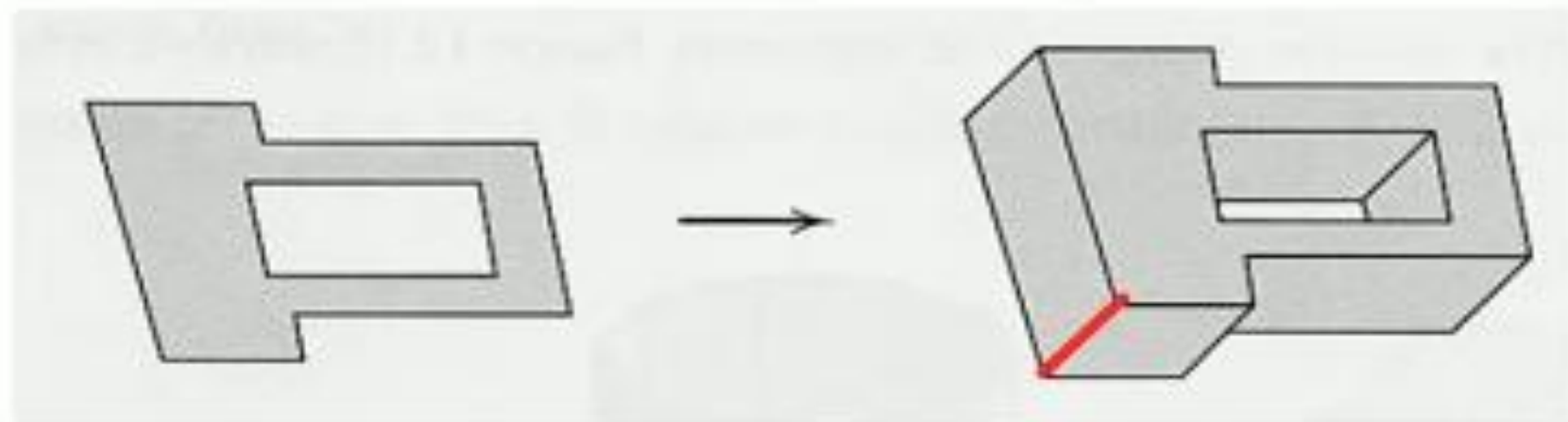
- **Rotational sweep**

NON LINEAR SWEEP

- the path is a **curve** described by a curve of higher order equation (quadratic, cubic or higher).

directrix

HYBRID SWEEP

- This combines **linear and/or nonlinear** sweep via set operations

A-*B

INVALID SWEEP

- Invalid solids or non-regular set may result if the sweeping direction is not chosen properly

Dangling face

Box

Dangling edge

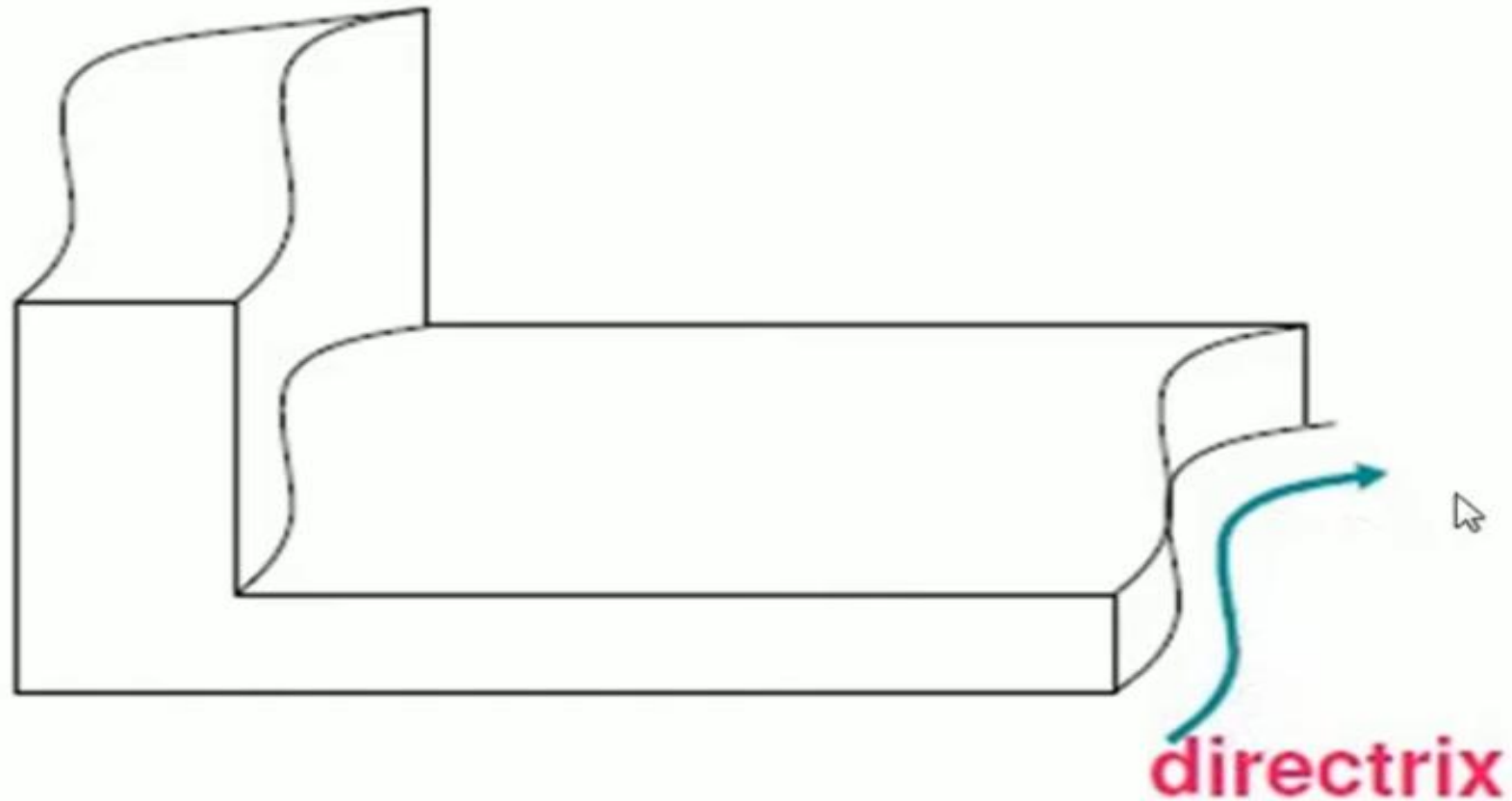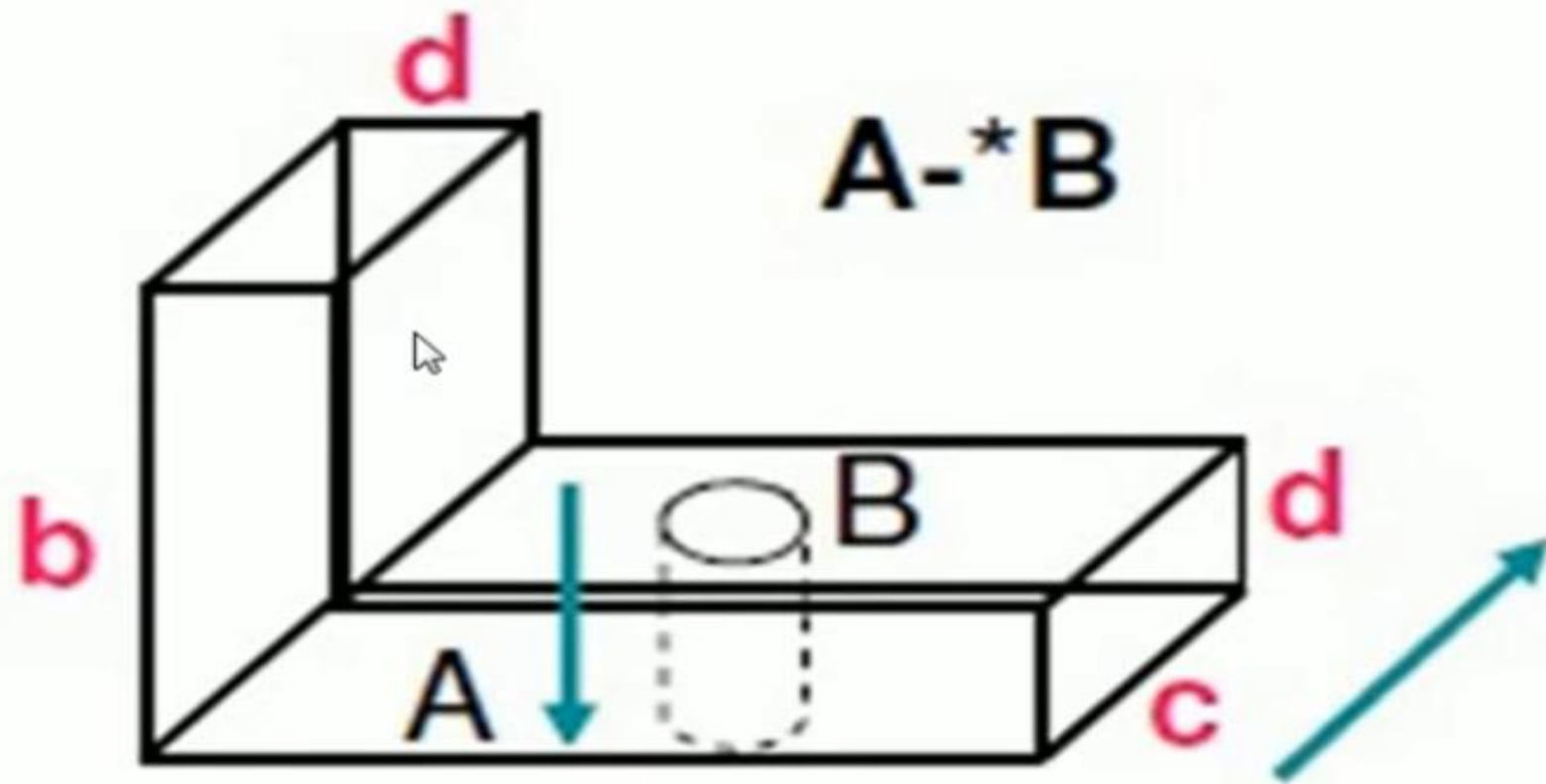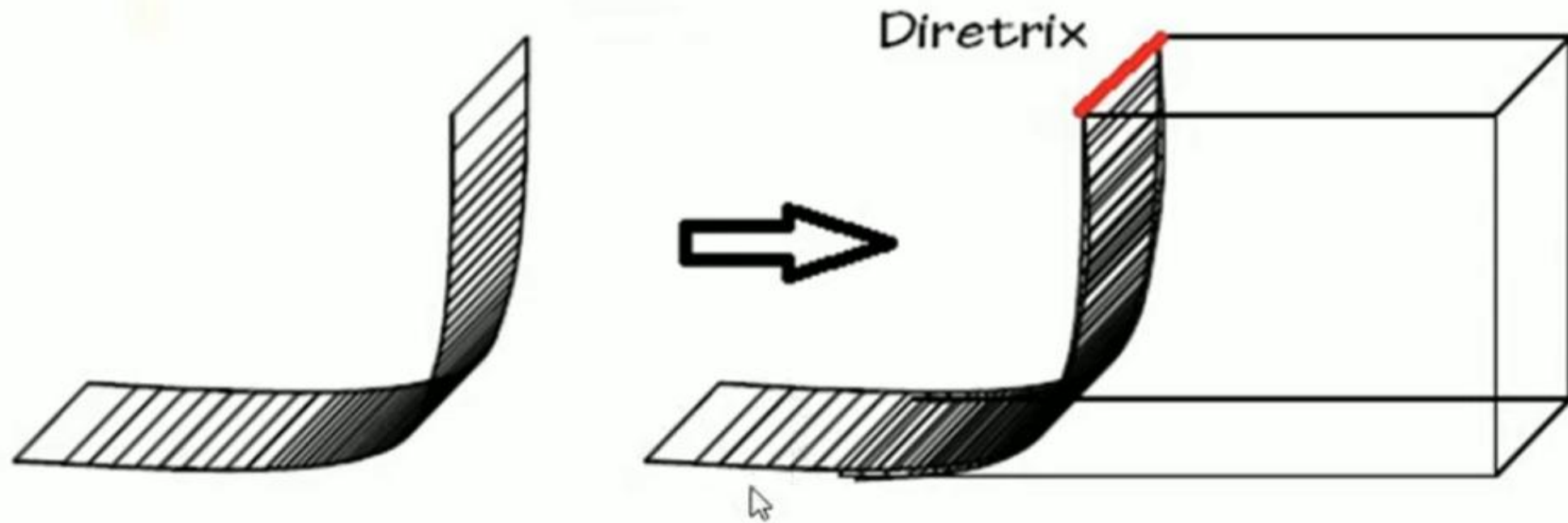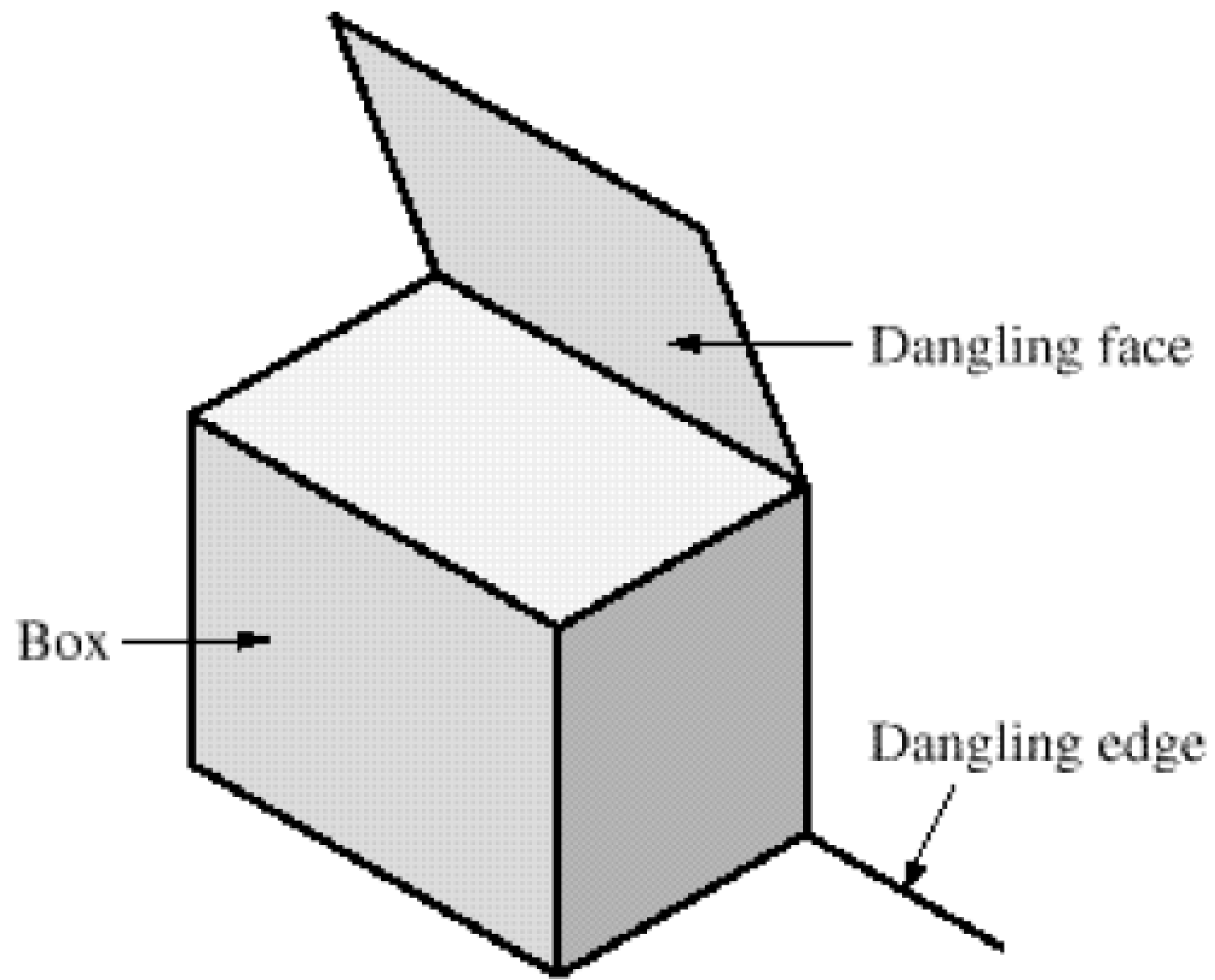# Mass Property Calculations

- Mass property calculation was one of the first engineering applications to be implemented in CAD/CAM systems.
- This is perhaps due to the strong dependence of these calculations on the geometry and topology of objects. These calculations typically involve masses, centroids (centers of gravity), and inertial properties (moments of inertia). They form the basis for the study and analysis of both rigid and deformable body mechanics (statics and dynamics).
- For various objects, one can create their geometric models first, and then use them to calculate their mass properties, which can later he used for analysis.
- Mass property calculations usually involve evaluating various integrals. Exact evaluation of these integrals is only possible for simple shapes. For complex shapes, approximate methods are usually used to evaluate these integrals.
- These methods have the important property that they monotonically converge to the exact solution which is, of course, not known. Mass property algorithms that utilize these methods are fully automatic and require no additional input except mass attributes, such as the density of the model.

Geometric Properties,	Mass Properties
1. Curve length	1. Mass
2. Cross sectional area	2. Centroids
3. Surface area	3. First moment of inertia
4. Volume	4. Second moment of inertia

Feature Based Modelling (FBM)

- Feature = combination of shape and operation to build the parts.

- Shape
  - It is a 2D sketch
  - Eg. Rectangle, square, triangle, circle, ellipse, etc.

- Operation
  - it is an activity that converts the sketch into a three dimensional shape.
  - Eg. Extrude, revolve, sweep, fillet, shell, chamfer, etc

- Steps in feature based modelling
  1) Create shapes (Sketch)
  2) Create features
  3) Combine features

Steps in FBM

1) Create shapes (Sketch)
   - First step is to create the shapes (sketches). A shape (sketch) is a 2D profile or a cross section.
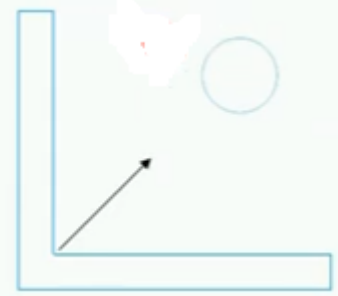
2) Create features
   - Apply feature operations to the shapes to create the features.
   - Eg. Extrude, revolve, sweep, loft
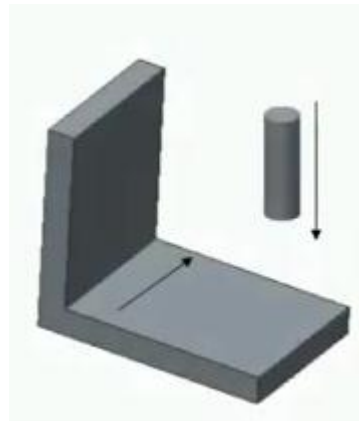
3) Combine features
   - Different features are combined (added or subtracted) to form the solid model of an object.
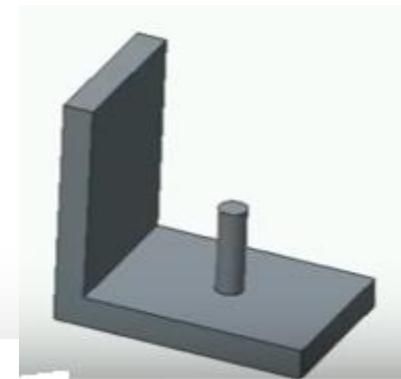
Feature Operations

- Commonly used feature operations in CAD systems are as follows

1) Extrude

2) Revolve

3) Sweep

4) Loft

5) Shaft

6) Pipe

7) Bose

8) Cut

9) Hole

10) Slot

11) Shell

12) Fillet

13) Chamfer

14) Draft

15) Spiral

16) Spring

17) Thread

Parametric solid modeling:

• Parametric modeling is a modeling process with the ability to change the shape of model geometry as soon as the dimension value is modified. Parametric modeling is implemented through the design computer programming code such as a script to define the dimension and the shape of the model.

• *Parametric* is a term used to describe a dimension's ability to change the shape of model geometry as soon as the dimension value is modified.

Featurebased is a term used to describe the various components of a model.

For example, a part can consists of various types of features such as holes, grooves, fillets, and chamfers. A 'feature' is the basic unit of a parametric solid model.

• **Parametric modeling** uses the computer to design objects or systems that model component attributes with real world behavior. Parametric models use featurebased, solid and surface modeling design tools to manipulate the system attributes.

Parametric modeling allows the designer to define entire classes of shapes, not just specific instances. Before the advent of parametric, editing the shape was not an easy task for designers.

• For example, to modify a 3D solid, the designer had to change the length, the breadth and the height. However, with parametric modeling, the designer need only alter one parameter; the other two parameters get adjusted automatically. So, parametric models focus on the steps in creating a shape and parameterize them. This benefits product design engineering services providers a lot.

• **Advantages**
1. These are the benefits offered by 3D parametric modeling over traditional 2D drawings:
2. Capability to produce flexible designs
3. 3D solid models offer a vast range of ways to view the model
4. Better product visualization, as you can begin with simple objects with minimal details
5. Better integration with downstream applications and reduced engineering cycle time
6. Existing design data can be reused to create new designs
7. Quick design turnaround, increasing efficiency.
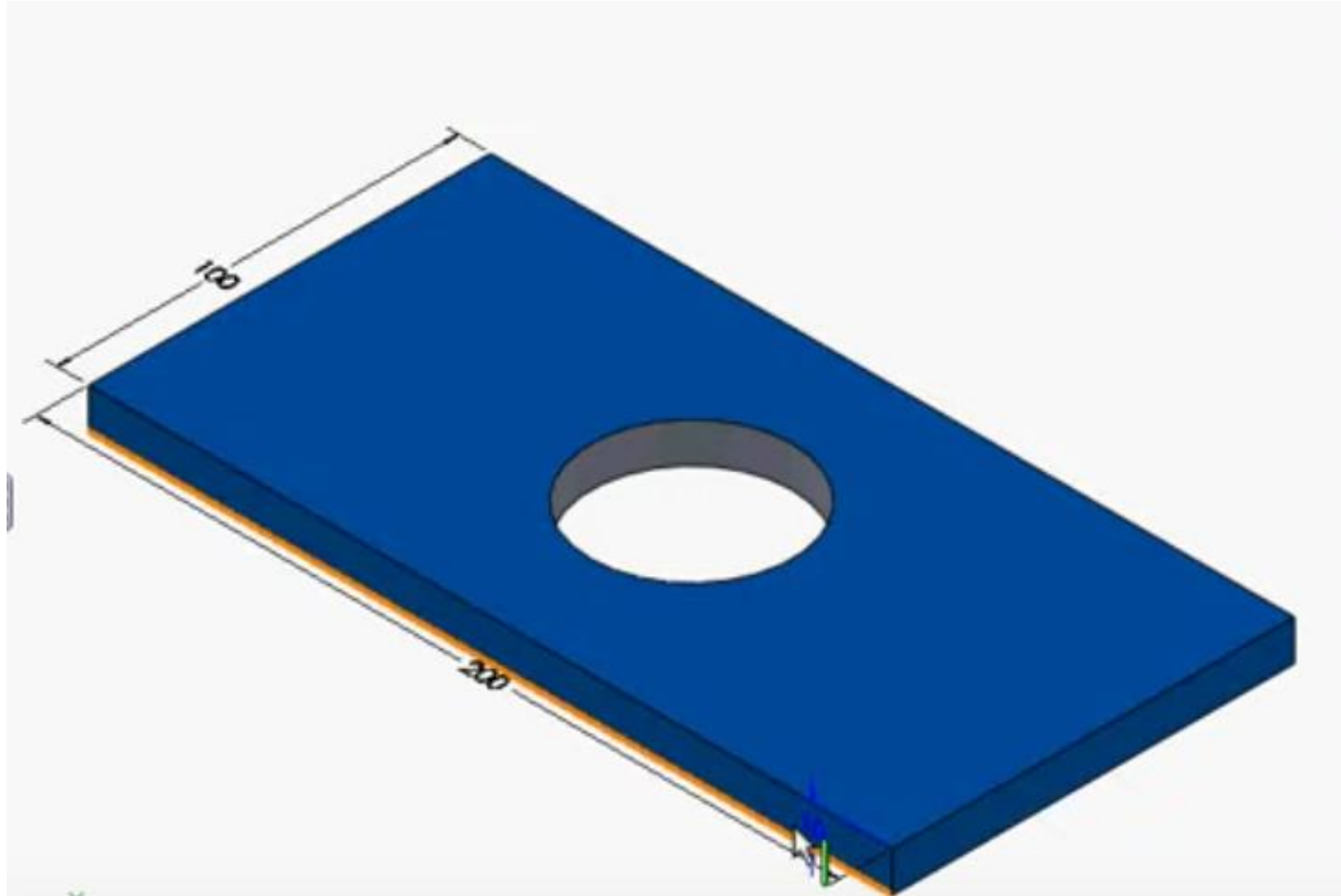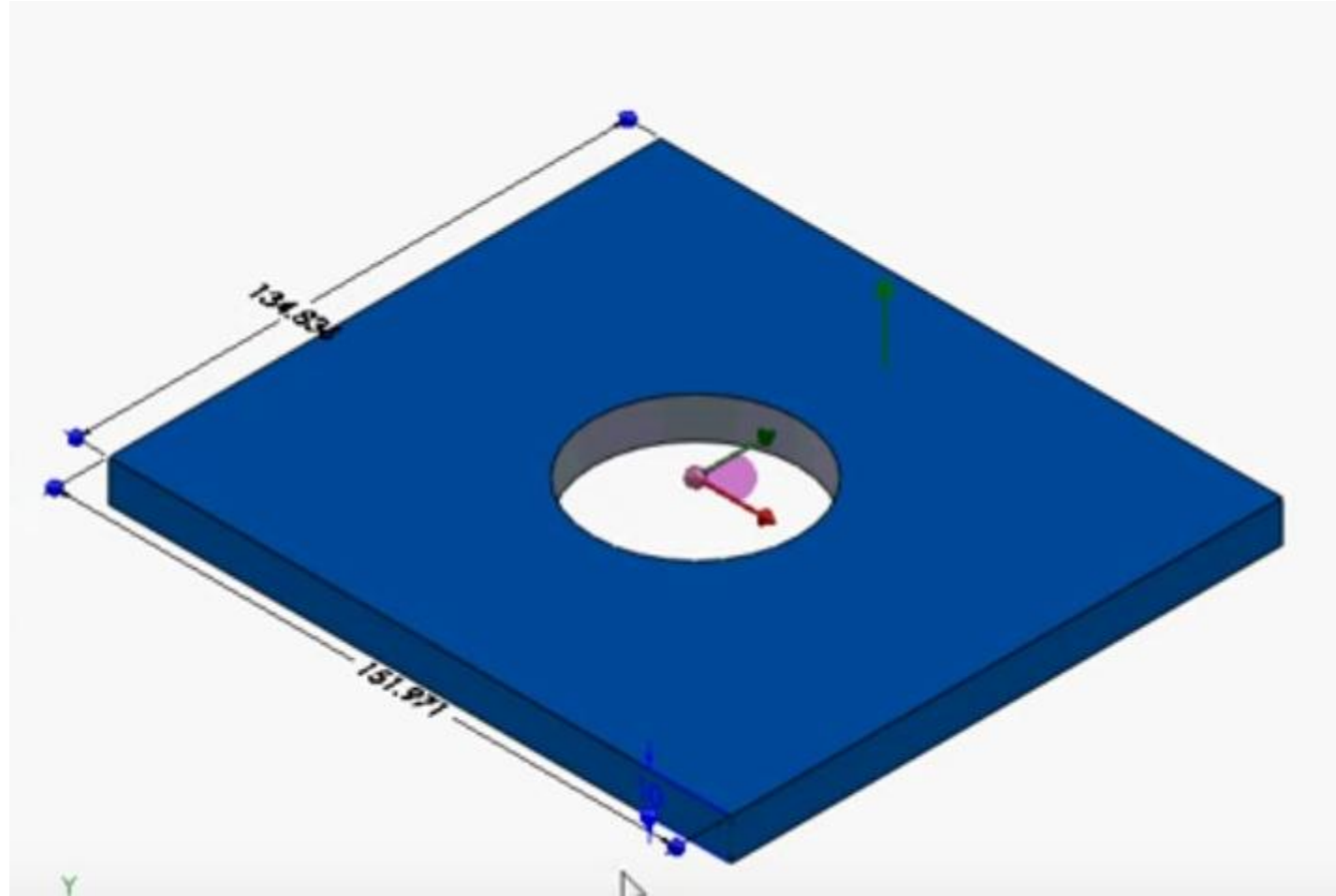
Analytical solid modeling:

• ASM is closely related to finite element modeling. It is developed to aid designers in the arduous task of modeling complex geometry commonly found in design applications.

• It can be viewed as more of a representation scheme for design than for manufacturing purposes due to its formulation, which does not involve orientable surfaces as does brep or CSG.

• ASM uses the parametric representation of an object in 3D space that is a mapping of a cubical parametric domain into a solid described by the global coordinates.

• ASM is mainly for design applications and not suited for manufacturing. It does not involve orientable surfaces as in Brep and CSG.

• ASM has now a wide range of applications such as mass property calculations, composite material modeling, and computer animation.

• It is use in FEA due to the efficiency and flexibility of mesh generation algorithms that operate on hyperpatches, which facilitates uniform transition or non uniform mesh and division in hexahedral elements.

• The technique for creating spline or patch curve segments or surface patches is valid in ASM.

ASM is appearing in design and analysis applications that require information inside as well as on the boundary of a given object.

This is desirable, for example, in modeling and studying composite materials and fracture mechanics problems.

• However, ASM is not adequate for manufacturing applications such as tool path generation, because face surfaces of hyperpatches (parametric solid) are not explicitly stored and are not orientable, i.e. normal to face surfaces cannot indicate the interior or exterior of the object.

• Applications:

1) Mass property calculation

2) Composite material modeling

3) Computer Animation

4) FEM mesh generation with hyperpatch concepts.

E.g. PATRANG is based on ASM and has interface to various FEA packages.

Introduction to Assembly Modeling

• Assembly modeling is considered an extension of part modeling.

• Assembly modeling raises two modeling issues that do not exist at the part modeling level: hierarchy and mating.

• Individual parts and subassemblies must be assembled in the right hierarchy (sequence) which is captured (stored) in an assembly tree for each assembly or product.
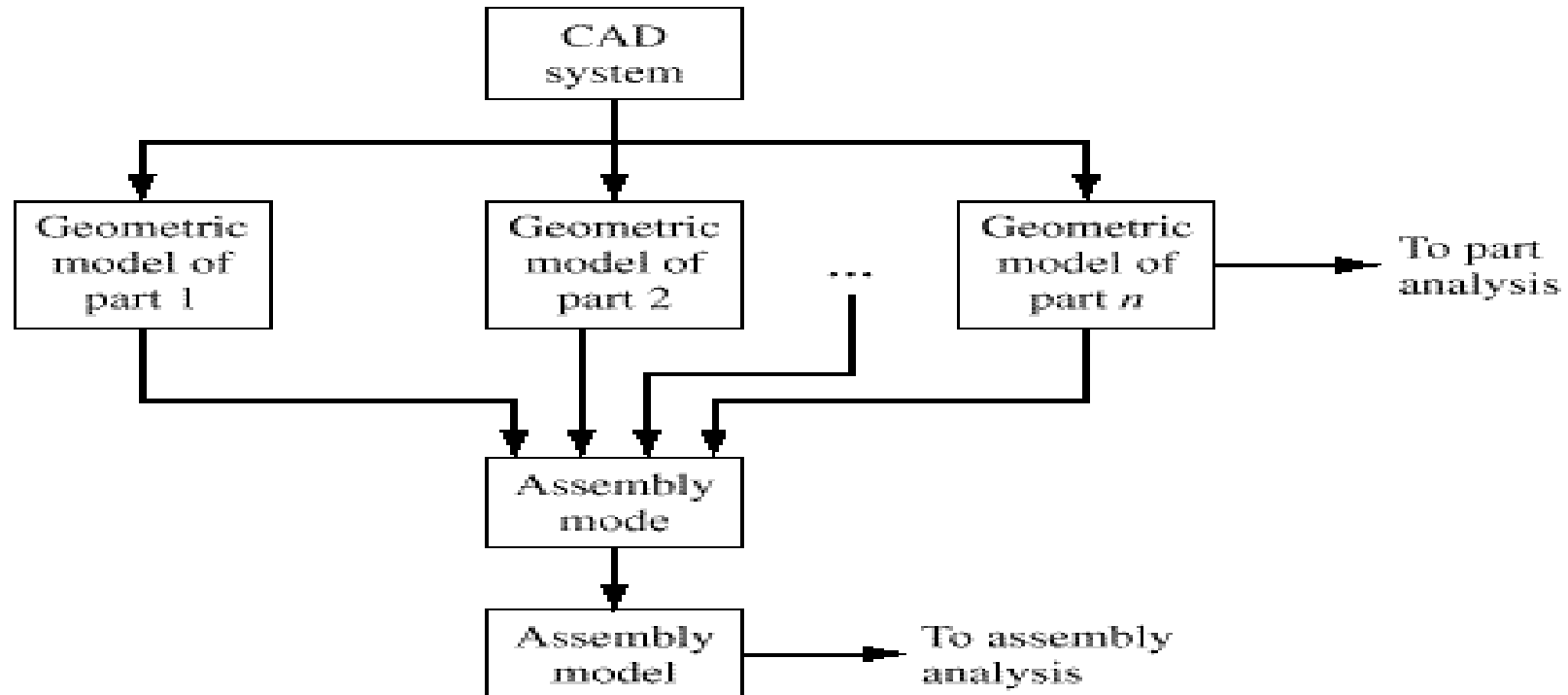
Example

Assembly of Pulley block -:

Exploded view	Assembly view
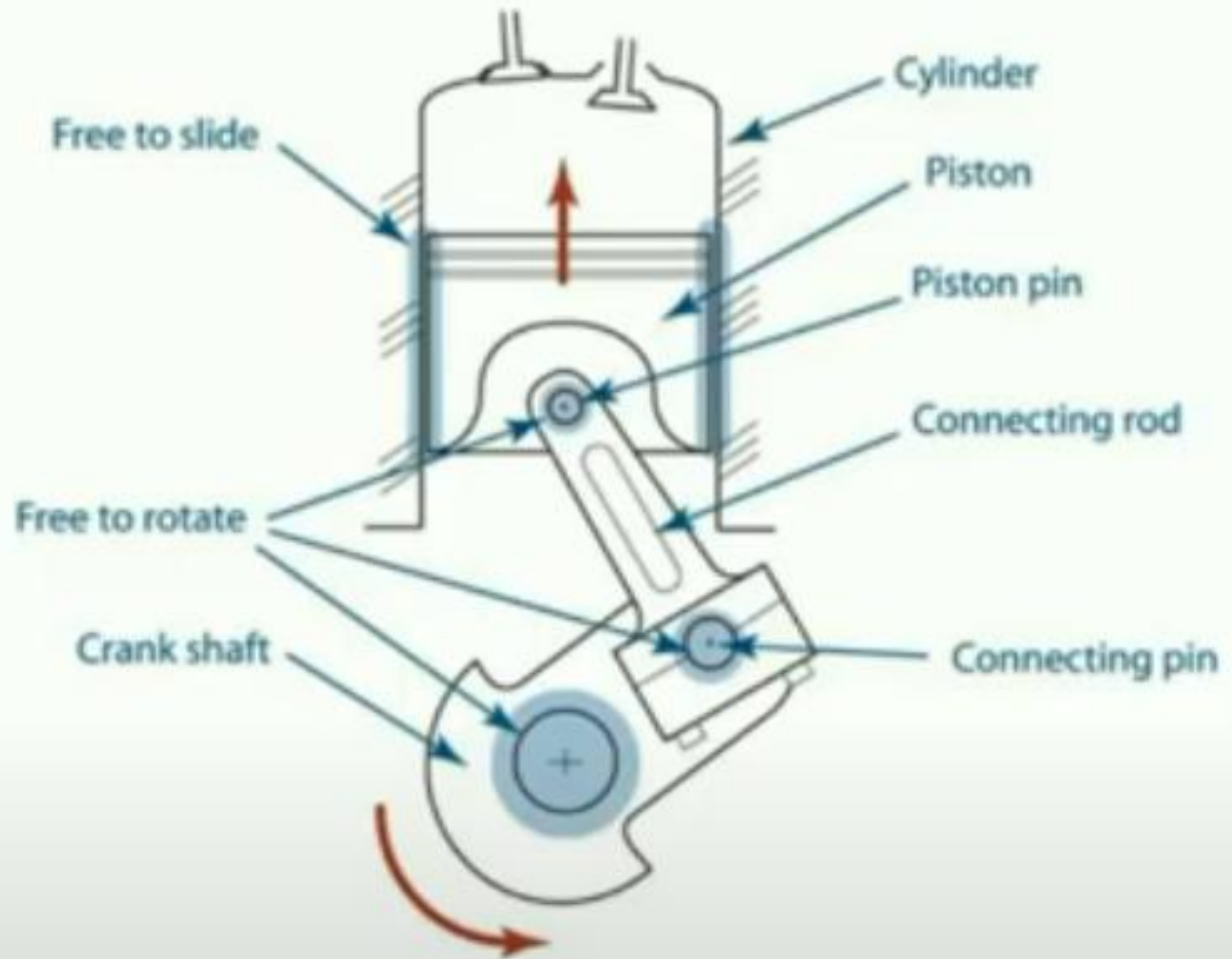
Points to be considered before assembly,
- Identify the dependencies between the components of the assembly.
- Identify the dependencies between the features of each part.
- Analysis of the order the assembly of the parts.

Mating Conditions:
- Coincident
- Concentric
- Tangent
- Coplanar
- Parallel and perpendicular faces
- Symmetry
- Pattern etc.

Concentric Constraints

Axes of cylindrical features and holes can be selected

Center axis of hole

Center axis of bolt
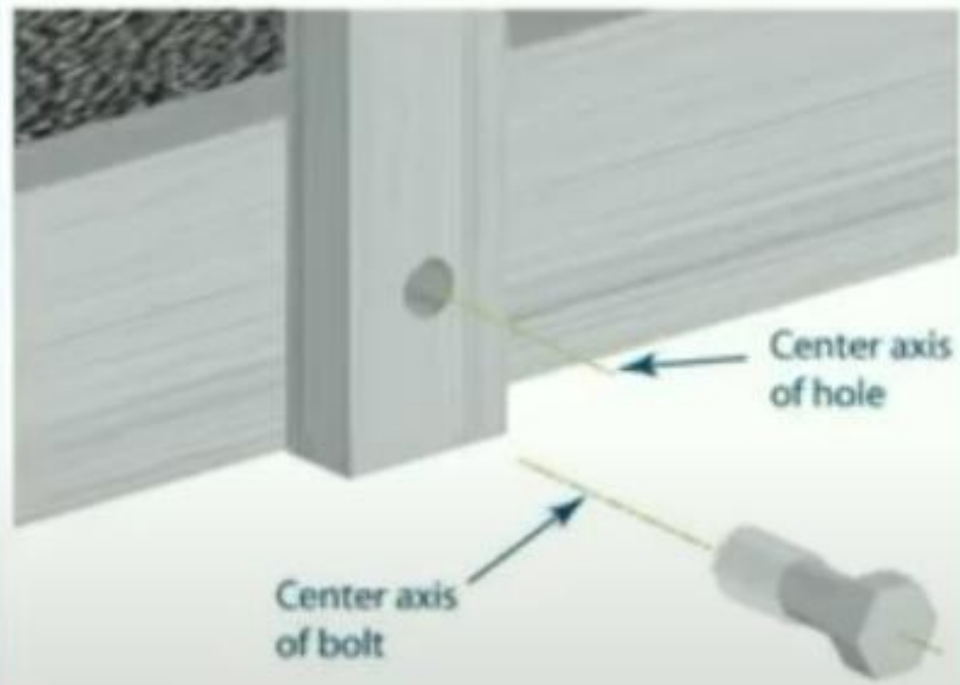
Concentric constraints align centerline axes

Center axis of bolt and hole

Mating Surfaces
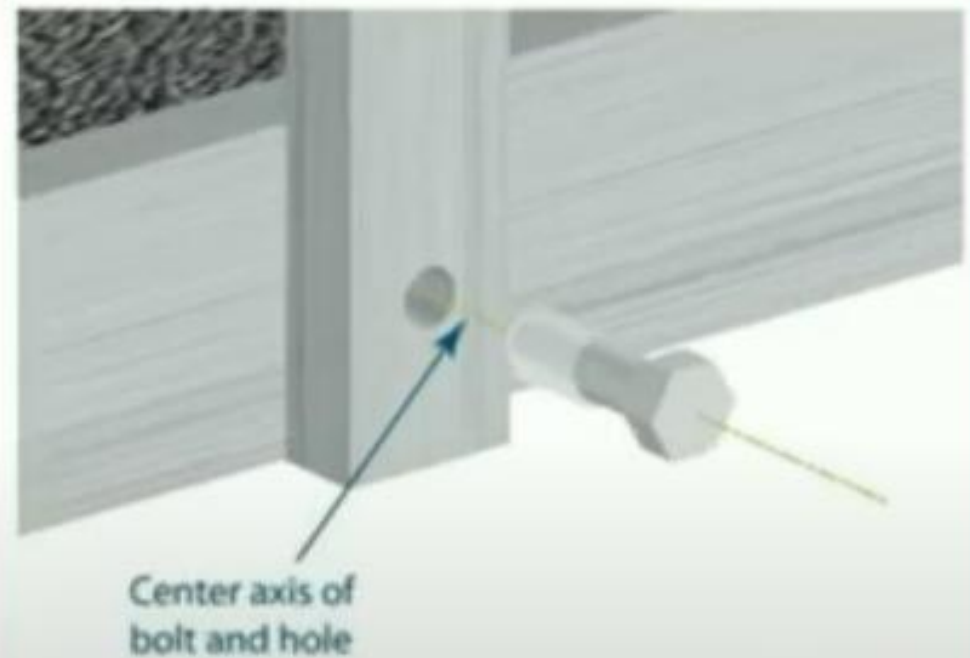
Surfaces to be mated
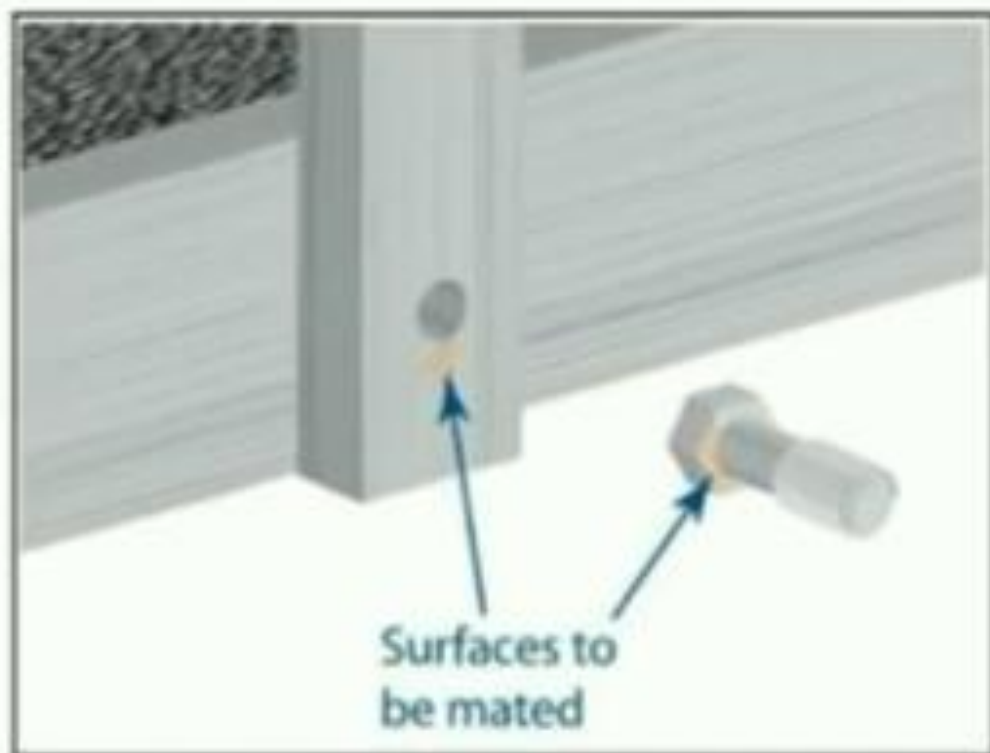
2D surfaces can be mated to become flush with one another but the correct direction must be given to the computer

Surfaces incorrectly mated

Surfaces correctly mated
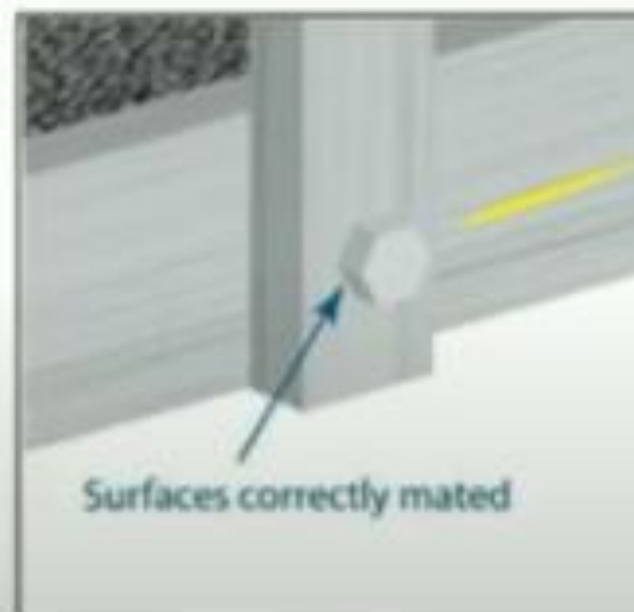
Assembly Modeling

- **Bottom-Up Assembly Approach**

- **Top-Down Assembly Approach**

Bottom-Up Assembly Approach

• In this approach, we create the individual parts independently, insert them into an assembly and use the mating conditions to locate and orient them in the assembly as required by the assembly design.

• The assembly modeling process itself begins with creating a blank assembly model (file) using the assembly mode of a CAD system. We import (insert) the assembly parts into this model, one at a time. The first part we insert is known as the base part or the host, on top of which other parts are assembled. We use the proper mating conditions to place and orient each inserted part correctly in the assembly model.

• It is the preferred technique if the parts have already been constructed, as in the case of offtheshelf parts. It also allows designers to focus on the individual parts. It also makes it easier and simpler to maintain the relationships and regeneration behavior of pails than in the topdown approach.

Top Down Assembly Approach

- In the top-down assembly design approach, components are created inside the **Assembly Design** workbench. Therefore, there is no need to create separate part files of the components.
- This design approach is completely different from the bottom-up design approach. Here you have to start the product file first and then, one by one, create all components.
- Note that even though the components are created inside the product file, they are saved as individual part files and can be opened separately later.
- Adopting the top-down design approach gives the user the distinctive advantage of using the geometry of one component to define the geometry of the other.
- Here the construction and assembly of the components takes place simultaneously. As a result of this, the user can view the development of the product in real time.
- This design approach is highly preferred, while working on a conceptual design or a tool design where the reference of previously created parts is required to develop a new part.

Design for Manufacturing [DFM]

• Design for Manufacturing (DFM) is the process of designing parts, components or products for ease of manufacturing with an end goal of making a better product at a lower cost.

• This is done by simplifying, optimizing and refining the product design. The acronym DFMA (Design for Manufacturing and Assembly) is sometimes used interchangeably with DFM.

• Five principles are examined during a DFM. They are:

1. Process
2. Design
3. Material
4. Environment
5. Compliance/Testing

• Properly executed DFM needs to include all the stakeholders — engineers, designers, contract manufacturer, mold builder and material supplier.

PRINCIPLES OF DFM

- *Process:* The manufacturing process chosen must be the correct one for the part or product.
- *Design:* The actual drawing of the part or product has to conform to good manufacturing principles for the manufacturing process you've chosen.
- *Material:* it includes Mechanical, Thermal, electrical properties.
- *Environment:* Your part/product must be designed to withstand the environment it will be subjected to.
- *Compliance/Testing:* All products must comply with safety and quality standards.

Outcomes of An Effective DFM

1. Minimize the number of product parts.

2. Minimize variety of parts

3. Use standardized parts wherever possible

4. Use a modular design

5. Design multi-functional parts

6. Design multi-use products.

7. Select least costly material

8. Design for ease of fabrication or manufacture

9. Design your product to join without using screws, fasteners or adhesives.

10. Design your part to minimize handling, especially during production and assembly.

Design for Assembly [DFA]

• Design for assembly (DFA) is a process by which products are designed with ease of assembly in mind. If a product contains fewer parts it will take less time to assemble, thereby reducing assembly costs.

• Design for assembly (DFA) seeks to simplify the product so that the cost of assembly is reduced with improved quality and reliability and a reduction in production equipment and part inventory.

• In principle, recognizes the need to analyze the design of both the part and the whole product for any assembly problems early in the process to cut costs during the entire product cycle.

• Different methods of assembly are

1. Manual
2. Automated
3. Fixed or hard automation
4. Robotic Assembly

- **_The Hitachi assembly evaluation method_**_:_ This method aims to facilitate design Improvements by identifying weaknesses in the design at the earliest stage in the process by using an assemble ability evaluation score and an assembly cost ratio. The objective of the Hitachi assemblability evaluation method (AEM) is to facilitate design improvements by identifying weaknesses in product design at the earliest possible stage.

- **_The Lucas DFA method_**_:_ Analysis is carried out in three sequential stages— functional, feeding, and fitting. The Lucas method is based on a point scale that gives a relative measure of the difficulty associated with assembly.

- **The Boothroyd-Dewhurst DFA method**: This method seeks to reduce the number of parts by consideration of manual handling and manual insertion times. The BoothroydDewhurst

  method of assembly evaluation is based on two

  principles: the application of criteria to each part to determine if it should be separate from all other parts, and the estimation of the handling and assembly costs for each part using the appropriate assembly process.

- **_A DFA method based on MTM standards_**

- An improved assembly methodology takes into consideration numerous factors,

Design for disassembly

• It is the process of designing products so that they can be easily, cost effectively and rapidly taken apart at the end of the product's life so that components can be reused and/or recycled.

• *Total disassembly:* The entire product is disassembled into its constituent components. This may not be economically feasible due to the imposition of external constraints, such as time, economic factors, and presence of hazardous materials.

• *Selective disassembly:* Selective disassembly is the reversible dismantling of complex products into less complex subassemblies or single parts. It involves the systematic removal of desirable constituent parts from an assembly while ensuring that there is no impairment of parts due to the process.

• *Disassembly process planning involves,* Product analysis, Assembly analysis, Usage, mode, and effects analysis, Determination of dismantling strategy etc.
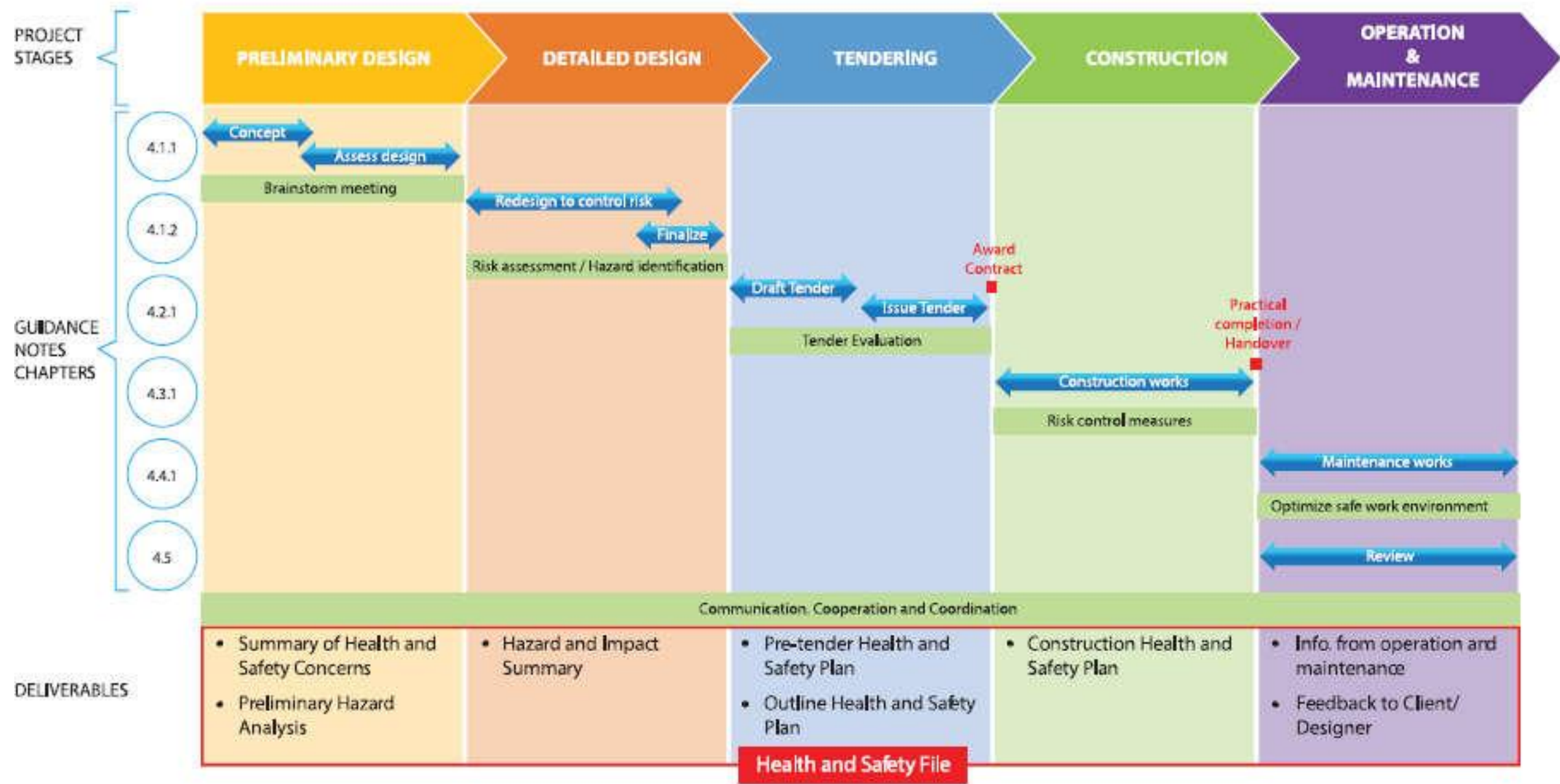
Design for disassembly guidelines
1) If possible, similar elements need to be combined in a group.
2) Material variability should be minimized to predict disassembly procedures with a degree of certainty.
3) As far as possible, compatible materials should be used to facilitate disassembly.
4) Any harmful materials, if functionally important, should be grouped together into subassemblies for fast disposal.
5) Any valuable, reusable, and harmful parts need to be easily accessible. This saves a lot of time and effort.
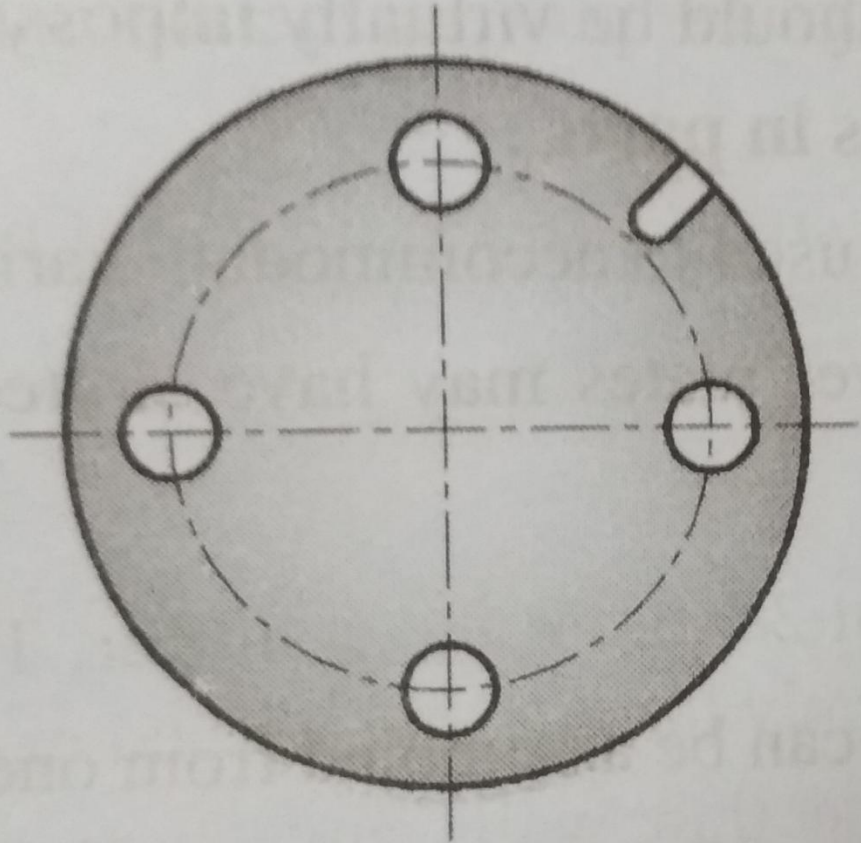
DESIGNING FOR SAFETY

• The principle of "Design for Safety" is to bring the consideration of the actual potential hazards and risks to each project to the forefront of a designer's work. Safe Design is the most effective risk control measure which is achieved by eliminating the hazards at source.

• Its main objectives are,

1. Promote early involvement, effective cooperation and communication of all stakeholders through the timely provision of relevant and necessary information.

2. Improve clarity on the demarcation of the roles and responsibilities of the parties responsible for coordinating and providing relevant project data on risks at all stages of a project.

3. Identifying the outputs of the "Design for Safety" application process and the specific risk reduction measures.
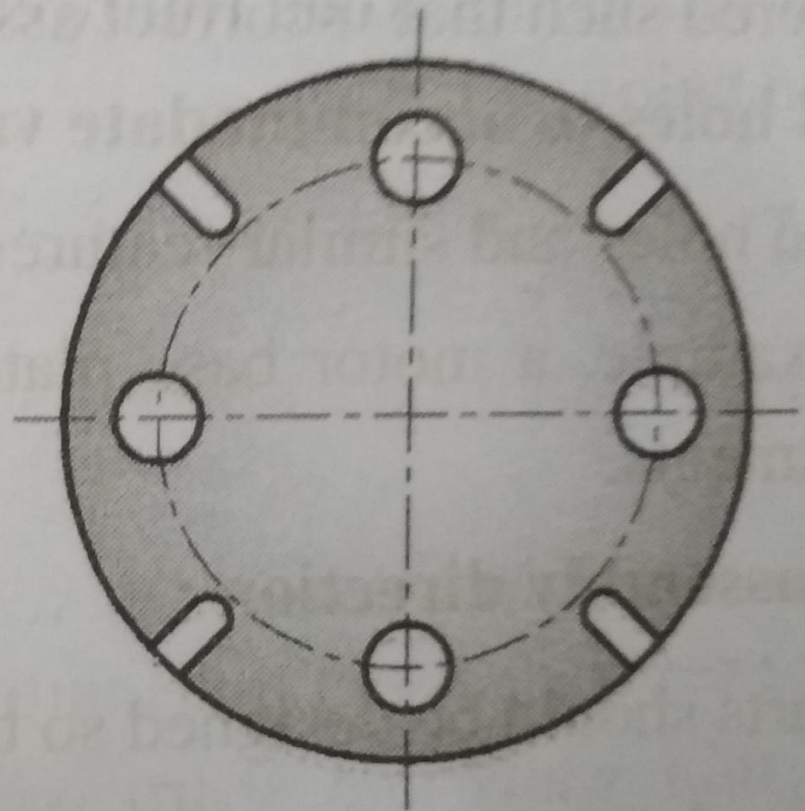
DESIGN FOR SAFETY PROCESS

PROJECT STAGES	PRELIMINARY DESIGN	DETAILED DESIGN	TENDERING	CONSTRUCTION	OPERATION & MAINTENANCE

GUIDANCE NOTES CHAPTERS

- 4.1.1
- 4.1.2
- 4.2.1
- 4.3.1
- 4.4.1
- 4.5

Concept

Assess design

Brainstorm meeting

Redesign to control risk

Finalize

Risk assessment / Hazard identification

Draft Tender

Issue Tender

Tender Evaluation

Award Contract

Practical completion / Handover

Construction works

Risk control measures

Maintenance works

Optimize safe work environment

Review

Communication, Cooperation and Coordination

DELIVERABLES

- Summary of Health and Safety Concerns
- Preliminary Hazard Analysis

- Hazard and Impact Summary

- Pre-tender Health and Safety Plan
- Outline Health and Safety Plan

- Construction Health and Safety Plan

- Info. from operation and maintenance
- Feedback to Client/ Designer

Health and Safety File
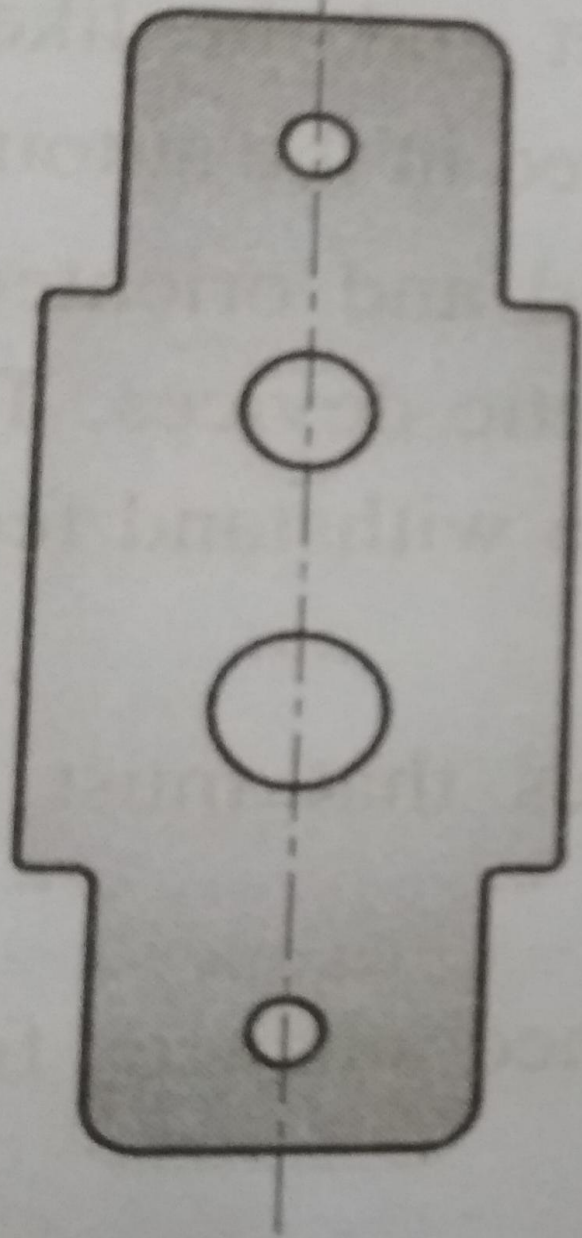
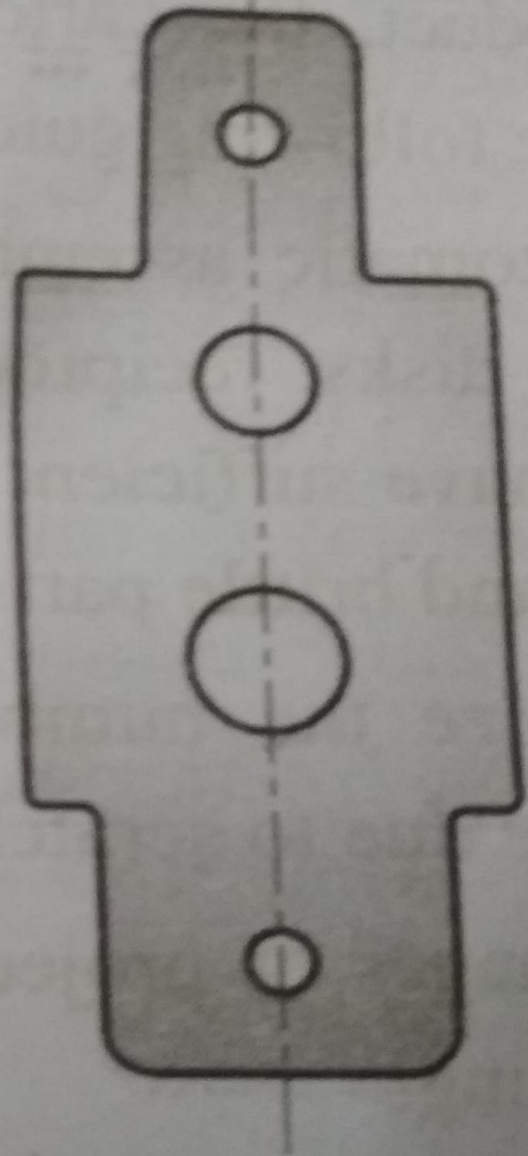# Use Symmetrical parts in product

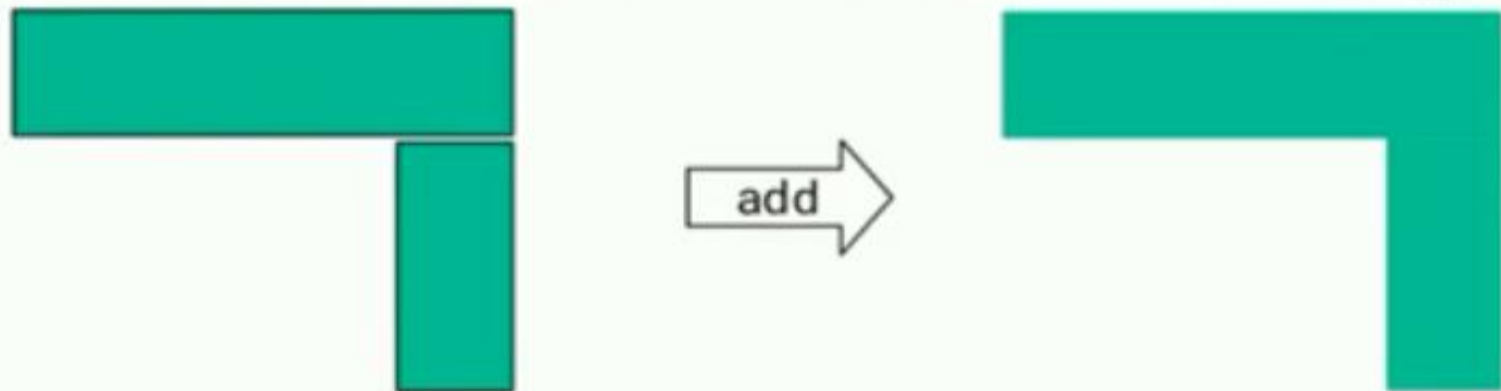(a) Asymmetrical Part   (b) Symmetrical Part

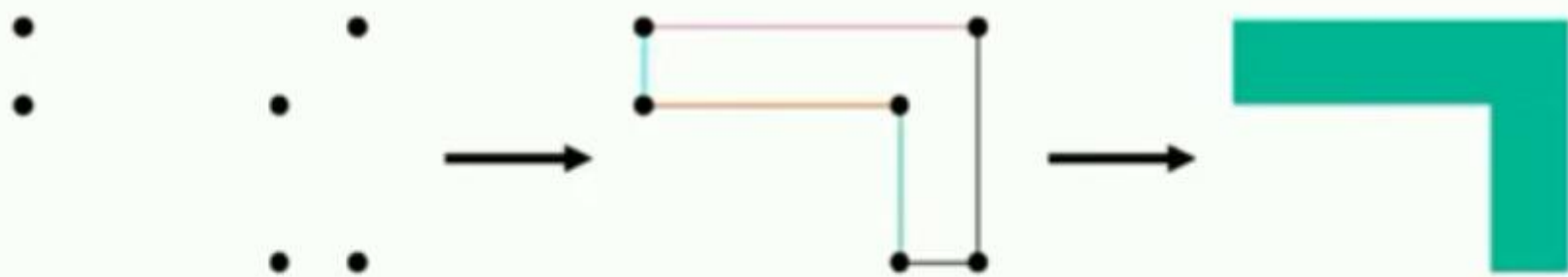(a) Asymmetry   (b) Exaggerated Asymmetry

Modeling Approaches

- Two approaches to creating a solid model:
  - Top-down
  - Bottom-up

- *Top-down modeling* starts with a definition of volumes (or areas), which are then combined in some fashion to create the final shape.

Approaches

- *Bottom-up modeling* starts with keypoints, from which you "build up" lines, areas, etc.

- You may combine both methods.

Top-Down Modeling

- Top-down modeling starts with a definition of volumes (or areas), which are then combined in some fashion to create the final shape.

  - The volumes or areas that you initially define are called *primitives*.

  - Primitives are located and oriented with the help of the *working plane*.

  - The combinations used to produce the final shape are called *Boolean operations*.

Assembly Modelling

Introduction

- Assembly modeling is a combination of two or more components using parametric relationships.
- Typically a designer would start with a base part
- Add other components to the **base part** using merge commands.

References

1. Ibraim Zeid, —Mastering CAD/CAM – Tata McGraw Hill Publishing Co. 2000

2. Ibrahim Zeid and R. Sivasubramanian - CAD/CAM - Theory and Practice Tata McGraw Hill Publishing Co. 2009