Lecture 16, 17

COMPUTER AIDED DESIGN (CAD)

SMU 3742

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Outline

1. Introduction

- The paradigm of engineering is undergoing a major evolution throughout the world.
- The use of computers and the Internet has changed the way that we engineer and manufacture products.
- Among the recent trends in manufacturing are trends where products are subject to a shorter product life, frequent design changes, small lot sizes and small in-process inventory.

1. Introduction

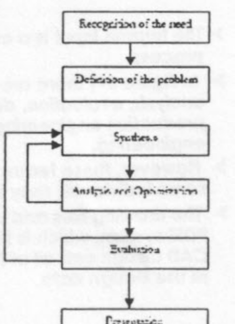
- The first step employed to remain competitive with our international counterparts was the application of Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) to design and manufacture sophisticated products.
- Linking CAD, CAM and Manufacturing Resource Planning had produced a concept known as Computer Integrated Manufacturing (CIM) systems.

2. Introduction to CAD

- **What is CAD?**
  - CAD involves the use of computers in ***the design process*** (to create design drawing and produce models).
  - CAD is usually associated with interactive computer graphic known as CAD system.
  - CAD systems are powerful tools and are used in mechanical design and geometric modeling of products and components.
  - When using CAD the designer can conceptualize the object to design more easily on the graphics screen and consider alternative design or modify a particular design quickly to meet the necessary design requirements or changes.

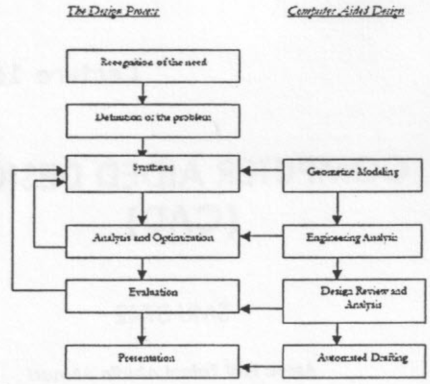
The Design Process

1. Recognition of need – involves the realization by something that a problem exists for which some corrective action should be taken.
2. Definition of problem – involves a thorough specification of the item to be designed. This specification includes physical and functional characteristics, cost, quality and operating performance
3. Synthesis – synthesis and analysis are closely related and highly iterative in the design process.



4. Analysis and optimization – the synthesized data is improved through analysis procedure and redesign, this process is repeated until the design has been optimized with in the constraints imposed on the designer.
5. Evaluation – concerned with measuring the design against the specification established in the problem definition phase. This evaluation often requires the fabrication and testing of prototype model to assess operating performance, quality, reliability, and other criteria.

Presentation – the final phase in the design process, includes documentation of the design by mean of drawings, material specifications, assembly lists and so on



Application of computers to the design process

2. Introduction to CAD

- CAD is a critical technology for an integrated product development process in a CIM organization.
- The design department was one of the first areas in the enterprise to receive automation hardware and software.
- ***CAD is the application of computers and graphics software to aid or enhance the product design from conceptualization to documentation.***
- The relationship between design process and the processes used in production and manufacturing engineering is illustrated in Figure 5-1.

2. Introduction to CAD

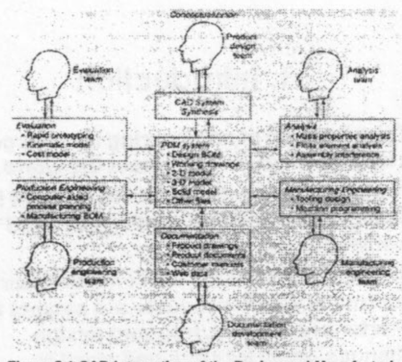


Figure 5-1 CAD Integration of the Design and Manufacturing Elements in the Enterprise

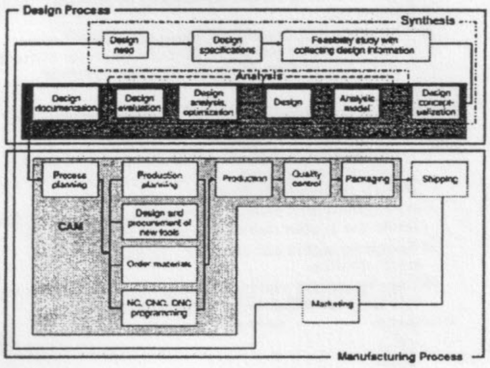
2. Introduction to CAD

- The human input is a critical part of the design process.
- In Figure 5-1 there are six teams: ***product design, analysis, evaluation, documentation development, production engineering,*** and ***manufacturing engineering.***
- However, these teams may not be unique because some individuals may be on more than one team.
- The drawing files and design data are stored in a PDM system, which is the interface between the CAD design and all of the other elements that need to use design data.

2. Introduction to CAD

- The analysis team uses analysis software tools, 2-D drawing files, and solid-model data of the product to determine the viability of the design.
- The evaluation team uses drawing data to create operational models of the new product for testing and to develop product cost.
- CAD is the glue that holds together many of the other elements in the design and production of the product.
- CAD technology enhances productivity because data are created once but used many times.

The Design and Manufacturing Process



2. Introduction to CAD

What Is CAD? (Retrospective)

- 1982 Solid modeling has proliferated to CAD systems
- 1983 3D developed in Sweden
- 1986 Autodesk's AutoCAD is the most popular microcomputer design program
- 1989 NASA develops high-end data visualization programs
- 1990 Manufacturers take advantage of NC simulation software to graphically depict tool paths to detect machining errors before actual metal cutting commences

2. Introduction to CAD

What Is CAD? (Retrospective)

- 1998 Chrysler becomes the first automaker to adopt a fully digital, "Cyber-synthesis" process.
- 1998 Mechanical CAD vendors battle for a share of the midrange market
- 2000 Moving design engineering from the desktop to the Web
- 2001 The same CAD data used to design cars is also used to market them

2. Introduction to CAD

CAD systems can be classified in several ways:

- By system hardware
  - Mainframe
  - Minicomputer
  - Engineering workstation
  - microcomputer
- By application area
  - Mechanical engineering
  - Circuit design and board layout
  - Architectural design and construction engineering
  - Cartography – map making
- By modeling method
  - Two-dimensional drafting
  - Three-dimensional drawing
  - Sculptured surface
  - Three-dimensional solid modeling

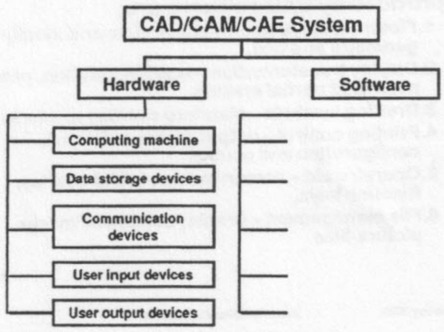
✓

Rapid Prototyping by CAD/CAM/CAE

- -Catia, Euclid, AutoCAD, ProEngineer Solidworks
- - MasterCAM, PowerMill
- - Moldflow, C-Flow, ANSYS, I-DEAS

✓

3. Components of CAD Systems



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3. Components of CAD Systems

➢ CAD Hardware

- ❖ In CAD the conventional drawing board is replaced by CAD hardware.
- ❖ Two major types of hardware used in CAD system are
  - ✓ Computers
  - ✓ Input/output (I/O) devices

➢ Computers

- ❖ Can be mainframe computer, workstations or normal PC, depending on the complexity of the CAD package (software).
- ❖ The more functionalities, the more powerful the computer need (example 3D solid modeler require higher power than 2D or 3D drafting systems.

➢ Several parameters and components concerning computer

- ❖ Random access memory (RAM) capacity – actual physical memory of the computer, small memory means slow processing.
- ❖ Permanent disk storage capacity – small disk storage limits the system to the storage of few drawings.
- ❖ Special graphic accelerator – to increase the performance.
- ❖ Tape back-ups – large drawing files are stored in back-ups tape for better performance of the system.

➢ Input/Output (I/O) Devices

Input devices are generally used to transfer information from a human or storage medium to a computer where "CAD functions" are carried out

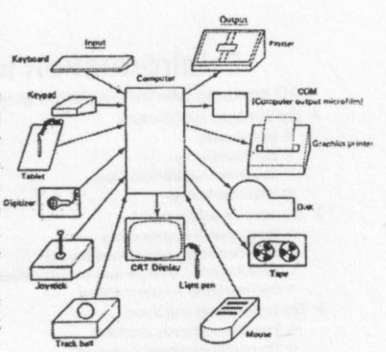


Figure 3.7 I/O peripherals of a CAD system.

3. Components of CAD Systems

CAD Software

➢ CAD software is what gives a CAD system its functionality and personality. Software can be classified based on the technology used:

- ❖ 2-D Drawing
- ❖ Basic 3-D drawing
- ❖ Sculptured surfaces
- ❖ 3-D solid modeling
- ❖ Engineering Analysis

CAD Software

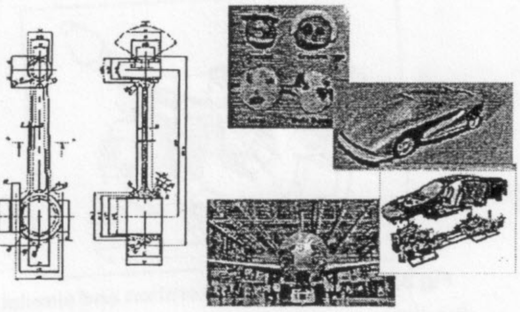
➢ Some of the commonly available functions provided by CAD software are;

1. Picture manipulation – add, delete and modify geometry and text.
2. Display transformation – scaling, rotation, pan, zoom and partial erasing
3. Drafting symbols – standard drafting symbols.
4. Printing control – output device selection, configuration and control
5. Operator aid – screen menus, tablet overlay, function keys.
6. File management – create, delete and merge picture files

CAD Software - *2-D Drawing*

- ❖ The softwares are designed as a substitute for manual drafting. The early CAD systems are mostly of this type.
- ❖ Applications of 2-D drawing systems include:
  - ✓ Mechanical part drawing
  - ✓ Wiring diagram
  - ✓ PCB design and layout
  - ✓ Pattern nesting (sheet metal and garment)
  - ✓ Facilities layout
  - ✓ Architectural design and construction engineering
  - ✓ Graphic art, technical publication
  - ✓ Cartography

2-D Drafting vs Digital Technology



CAD Software - *3D Drawing*

- Basic 3D drawing systems include 3D wire frame, 2-1/2 drawing and cartography.
- A 3D wire frame model describes the edges and outlines of curves (Fig 3.8a).
- A 2-1/2 model is a 2D model with a constant Z-axis dimension.
- Basic 3D models are easy to generate and work with, simple to store and manipulate in computers, and useful as visual aids.

3D object geometric modeling

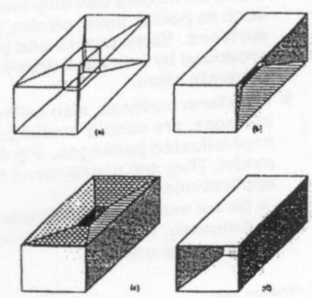
Wireframe

Surface modeling

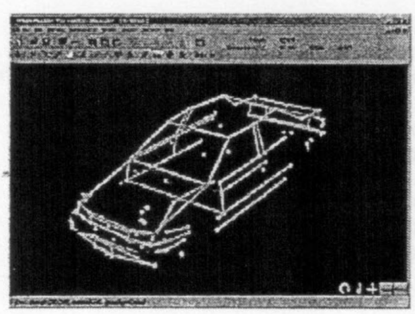
Solid modeling ?

CAD Software - *3D Drawing...Cont*

- However, there is no information on the surfaces nor the inside or outside of the object.
- A wire frame model is ambiguous. The object represented by a wire frame model in (a) can be b, or c or d.



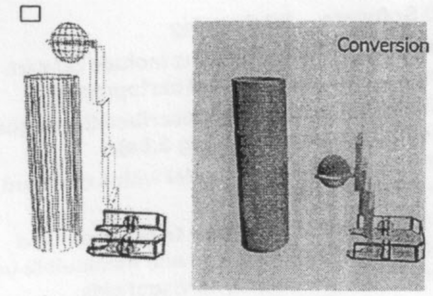
Wire Frame



CAD Software - *3D Drawing....cont*

- Despite these limitations, 3D wire frame models are useful for many applications. Some of the applications include the following
  - Mechanical Engineering – *part design, assembly design, NC tool path (Fig 3.9), robot programming*
  - Architectural and Construction – *building design, structural analysis, piping layout and analysis, site planning, interior design*
  - Electrical and electronic engineering – *IC chip layout, PCB layout*
  - Cartography – *map preparation*

Wire Frame to surface



CAD Software - *3D Drawing ...cont*

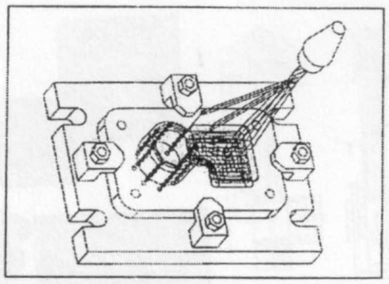


Fig 3.9 NC tool path generation and simulation

CAD Software - *Free form curves and Surface Modeling*

- Basic 3D models can only model simple geometries such as points, lines, circles, planes and analytical surfaces. Some curves and surfaces that are produced by free hand drawing belong to a separate class.
- Free form surfaces, also called sculptured surfaces, are usually available in more sophisticated packages. Fig 3.10 shows a surface model. They are usually used for the following applications
  - Die and mold design and manufacturing
  - Automobile, ship and aircraft body design
  - Commercial artwork

CAD Software - *Free form curves and Surface Modeling ... cont*

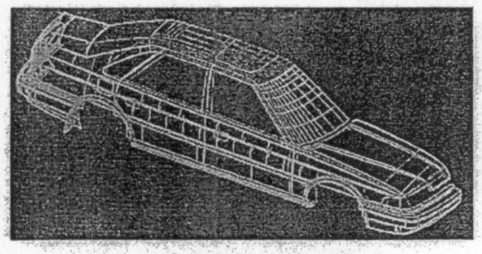
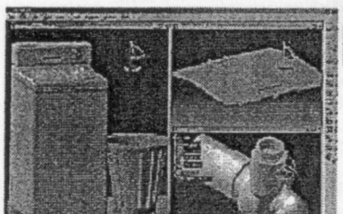


Figure 3.10 Surface model from "CAD CAM: From Principles to Practice", by Chris McMahon and Jimmie Browne. (Courtesy Addison-Wesley.)

Surface Modeler



CAD Software - *3D Solid modeling*

- The solid model is a mathematically complete and unambiguous representation of part geometry.
- The solid model of the object has all the properties of the actual part, including *physical* (size, mass, and material), *mechanical* (strength and elasticity), *electrical* (resistance, capacitance, and inductance), and *thermal* (conductivity and expansion coefficient) properties.

CAD Software - *3D Solid modeling*

- All the CAD modeling methods discussed so far can produce only drawings. There is no volume information stored in the model. For many applications, it is essential that the volume information can be derived from the design. 3D soled modeling is a solution to this requirement.
- A 3D solid model not only captures the complete geometry of an object, but it also can differentiate the inside and the outside of the space occupied by the object in three dimensional space.
- By using this property, the volume of an object and the intersection between two objects can be calculated. Hidden surface/line removal and a shaded image can be produced as well.

CAD Software - *3D Solid modeling..cont*

- When classifying a solid model, its internal representation is usually used. The internal representation is how a computer stores the model. It is different from the external representation, which is how the picture or image is displayed. There are six different types of solid internal representation schemes (Figure 3.11)
  1. Primitive instancing
  2. Spatial occupancy enumeration (SOE)
  3. Cell decomposition
  4. Constructive solid geometry (CSG)
  5. Boundary representation (B-rep)
  6. Sweeping

Primitive instancing

- The concept of primitive instancing is to construct more complex objects from simpler primitive shapes. This concept is utilized in many commercial CAD solid modeling systems.
- Blocks, cylinders, spheres, and cones are some of the typical primitive solids that these systems offer.
- For fairly simple objects, it can be easy to model their shapes using combinations of these primitives. However, for the components with complex shapes, it can be difficult or very tedious to describe their shapes starting with primitive solids.

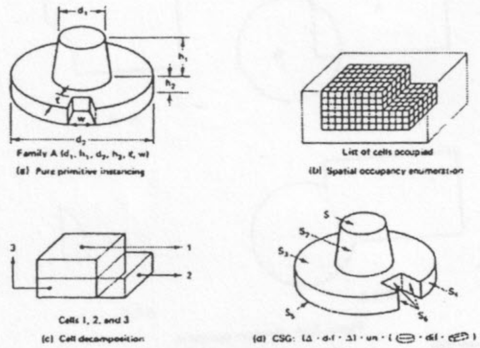
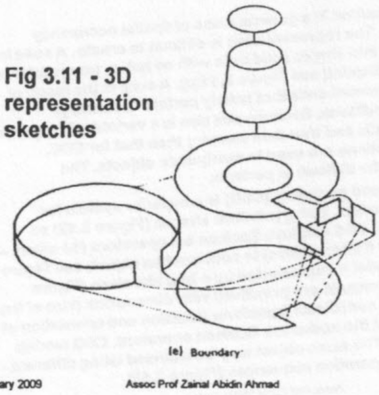
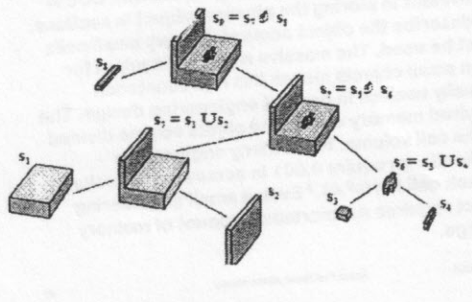


Fig 3.11 - 3D representation sketches

Fig 3.11 - 3D representation sketches



- CSG modelers allow designers to combine a set of primitives through Boolean operations:



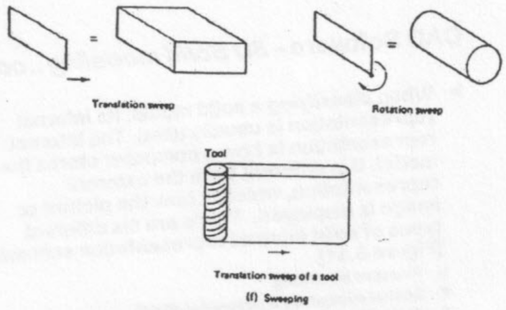
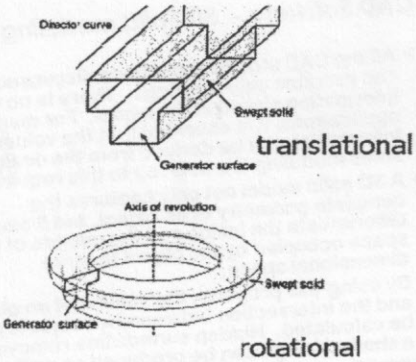


Fig 3.11 - 3D representation sketches



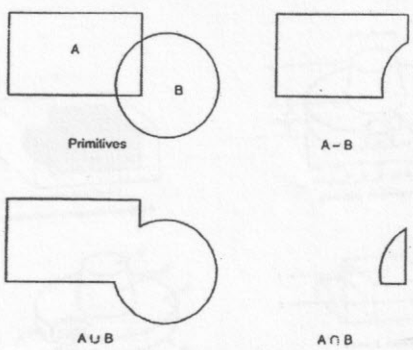


Figure 3.13 Boolean operators.

- Primitive instancing is one kind of solid representation; see Figure 3.11(a). It can be used to represent a family of objects. This family of objects is parameterized. An object instance can be defined by assigning values to the parameters. It can be used effectively to represent standard parts with different dimensions. GT coding can be also considered as an application of pure primitive instancing. The model is extremely concise because it only has a model name and a set of parameters. For this reason, it is difficult to do geometric operation directly on the pure primitive instancing model. The model must be converted into another model, such as a B-rep model, before any operation can be performed.

- Spatial occupancy enumeration (SOE) is a technique that records all spatial cells that are occupied by the object; see Figure 3.11(b). SOE is equivalent to storing the physical object in sections. To describe the object accurately, very small cells must be used. The massive memory required for even small objects makes this representation virtually useless in general engineering design. The required memory equals the object volume divided by the cell volume. When many engineering applications require 0.001 in accuracy, the volume of each cell is 10^{-9} 41.^{3} Even a small engineering object requires an enormous amount of memory storage.

- Cell decomposition is a general class of spatial occupancy enumeration. The representation is difficult to create. A solid is decomposed into simple solid cells with no holes, whose interiors are pairwise disjoint; see Figure 3.11(c). A solid is the result of "gluing" component cells that satisfy certain "boundary-matching" conditions. Because cell size is a variable, it requires many fewer cells and thus less memory than that for SOE. Boolean operations are used to manipulate objects. The operation can be difficult to perform.
- Constructive solid geometry (CSG) is a superior system for creating 3-D models. Using primitive shapes (Figure 3.12) as building blocks, CSG employs Boolean set operators (1J union, — difference, and fl intersection) to construct an object; see Figure 3.13. A CSG model is represented by a tree structure (Figure 3.14). At the ter-minals are primitives with dimensions (size of the primitive) and a coordinate transform (location and orientation of the primitive). At the nodes are Boolean operators. CSG models are not unique. The same object may be modeled using different primitives and operation sequences (Figure 3.15).

- A CSG model may be displayed by using the ray-tracing technique. Parallel rays cast toward the object either hit the object or miss the object. When a ray hits the object, it reflects the light back to the observer. Depending on the lighting. object texture, and the intersection angle between the ray and the object surface, the light reflection can be calculated. The reflection is displayed on the screen. Because a simple ray has the form of *x = a*, *y = b*, the intersection can be calculated very easily and often implemented in firmware (burned into a chip installed in the computer or terminal).

- Ray trac-ing can be done on individual primitives. Then the proper Boolean operation is done to determine the final result. Therefore, there is no need to convert the CSG tree model into some other model before it is displayed.
- An alternative way of displaying the object that is more frequently used is to con-vert the CSG tree into B-rep first, and then the B-rep is drawn. The process is called "boundary evaluation." Because B-rep has many useful properties, the conversion not only makes the display easy, but also provides other benefits. Figure 3.16 illustrates the CSG operations. The user of a CSG system has to work only with the primitives and Boolean operators. The rest is taken care of by the modeler.

- Boundary representations (B-rep) are also used to identify an object. In these sys-tems, objects are represented by their bounding faces. Faces are further divided and represented by edges and vertices; see Figure 3.11(e). A set of operators, called Euler operators, are available to build a B-rep from the ground up. To build a B-rep model by hand is very tedious. Most B-rep models are derived from a CSG model through bound-ary evaluation. More details of the B-rep will be presented in Section 3.7.
- Sweeping is another powerful modeling tool for certain types of geometry. There are two types of sweeping: translation and rotation; see Figure 3.11(f). Translation sweeping of a rectangle produces a box. Rotation sweeping of the same rectangle pro-duces a cylinder. Rotation sweeping can be used to create turned parts. In some design systems, an arbitrarily drawn face can be swept along either a line or a curve (translation sweeping). Very complex shapes can be created through this process. A manufacturing application of sweeping is NC cutting simulation. The removal volume can be represented by the sweeping of a tool.

- Currently, the majority of 3-D solid modelers are based on either CSG or B-rep representations. CSG data input is the most popular. Often, many face types can be used in the solid model. The 3-D solid models discussed so far are called "manifold" models (2-manifold). In a 3-D manifold model, the dimensionality is maintained. The B-rep of an object consists only of bounded faces with no loose edges or faces. Each edge is bounded by exactly two vertices and is adjacent to exactly two faces. Each vertex be-longs to one disk (traveling from one adjacent face to another, it will never cross the vertex itself). The manifold model does not allow any dangling faces or edges. It satis-fies the Euler formula (Section 3.7.]).
- However, there are also "nonmanifold" modelers. A nonmanifold model allows additional faces and edges to exist in a solid model. To track the inside and outside is more complex. A nonmanifold modeler such as ACIS (used in many CAD systems including AutoCAD R13) allows much more flexibility. More of the design intention can be saved in the design model.

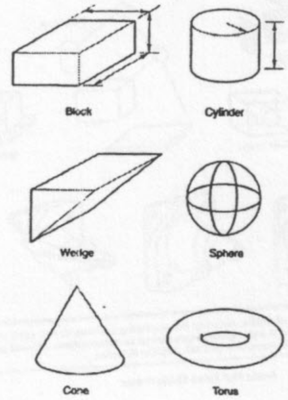


Fig 3.12 Some CSG primitives

- When solid-model representation is complete, engineering analysis can be performed directly with the model. The solid-model representation also provides a common linkage among design, analysis, and manufacturing. The existence of solid modelers is essential for automated manufacturing environs.

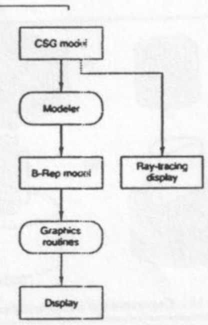
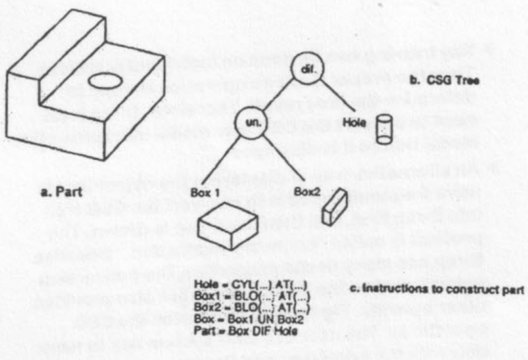


Fig 3.16 CSG Operations



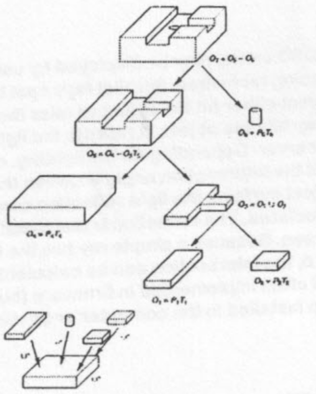
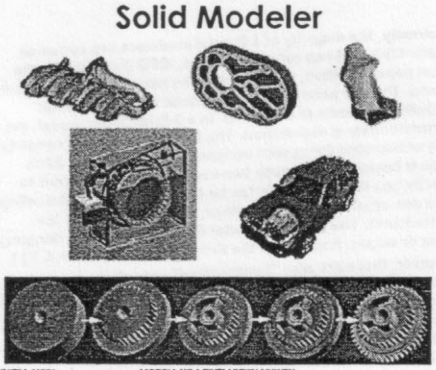


Figure 3.15 Alternative CSG models of an object.

Solid Modeler



- A Constructive Solid Geometry (CSG) modeller has an internal representation that consists of the definition of a set of parametric primitives associated by Boolean operators. Figure 14.1 shows an example of the principle as it is seen by the user. The first step (a) is to create a small Cylinder (probably by defining its diameter and height), followed by the creation (b) of a Block (defined by its three dimensions) which is placed such that one of its faces bisects the cylinder.
- (c)A Difference operation is then carried out between the block and cylinder (d). A larger cylinder is created and lzated relative to the previously created half cylinder. A Union is formed between the cylinders. bong cylinder is created and positioned (f) and Differenced from the object to create the final solid.

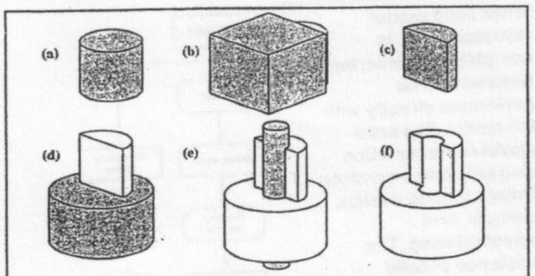


Figure 14.1. Construction of a CSG model using Primitives and Boolean operators

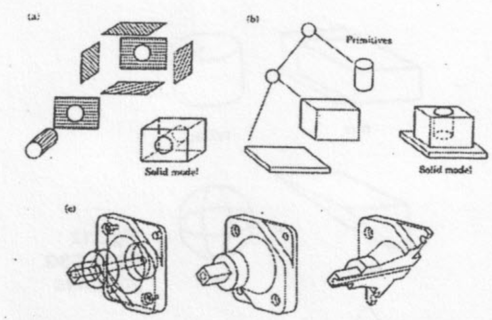


FIGURE 39.4
(a) Boundary representation of solids, showing the enclosing surfaces of the solid model and the generated solid model. (b) A solid model represented as compositions of solid primitives. (c) Three representations of the same part by CAD. Source: P. Ranky.

4. Advantages of CAD

- Easier Creation and Corrections - Working/detail drawings may be created more quickly and makings changes is more efficient than correcting drawings made by hand.
- Better Visualisation of drawings - Many systems allow different views of the same object and 3D pictorial view.
- Database of Drawing Aids - Designs and symbols can be stored for easy recall and reuse.
- Increased Accuracy - Using the computer, the drawing can be produced with more accuracy.
- Improved Filing - Drawings can be more conveniently filed, retrieved and transmitted on disks and tape.
- Quick Design Analysis
- Simulation and Testing

4. Advantages of CAD

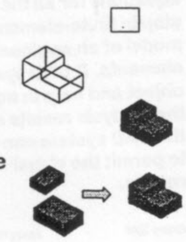
- ➢ Reduce the lead time for new product introduction
- ➢ Products can be tested more quickly
- ➢ Costly mistakes in design or production can be avoided
- ➢ Time to manufacture can be reduced
- ➢ Documentation can be printed in various forms for multiple users
- ➢ The quality of designs and the products manufactured from them is improved

5. History of CAD

- Charles Barbage (1883) - developed idea for computer.
- IC Chip Revolution => Micro-Computers and CAD.
- 1st CAD demon by Ivan Sutherland (1963) - SKETCHPAD.
- A year later IBM produced the first commercial CAD system.
- Many changes has taken place since then, with the advancement of powerful computers.
- With these developments, it is now possible to do all the designs using CAD including two-dimensional drawings, solid modeling, complex engineering analysis, production and manufacturing.
- New technologies are constantly invented which make this process quicker, more versatile and more powerful.

5. Evolution of CAD

- ➢ 2D Wireframe – Points and Lines
- ➢ 3D Wireframe – Points and Edges
- ➢ Surface Modeling – Adding a surface to 3D Wireframe
- ➢ Solid Modeling – Constructive Solid Geometry
  - ❖ Assembling primitive solids by adding or subtracting



- ➢ Feature-Based Parametric Solid Modeling
  - ❖ A design process
    - ✓ Sketch a 2D shape
    - ✓ Add Dimensions for size
    - ✓ Extrude or revolve the shape to make a solid
    - ✓ Repeat as needed while adding or cutting away features
  - ❖ Dimensions can be changed at any time in the design process and the part will be updated
  - ❖ This approach is typical for parametric modeling programs – these include Inventor by Autodesk, Pro Engineer, Solid Works, Solid Edge, CATIA, and other software packages.

Modern CAD/CAM/CAE Practice

Information from all product lifecycle activities is available from a single database.

CAD, CAM, CAE

- *Computer-Aided Design* (CAD) is the technology concerned with the use of computer systems to assist in the creation, modification, analysis, and optimization of a design. [Groover and Zimmers, 1984]
- *Computer-Aided Manufacturing* (CAM) is the technology concerned with the use of computer systems to plan, manage, and control manufacturing operations.
- *Computer-Aided Engineering* (CAE) is the technology concerned with the use of computer systems to analyze CAD geometry, allowing the designer to simulate and study how the product will behave.

Stop here.

Engineering Analysis

➢ **Engineering analyses commonly conducted on a design include finite-element analysis (FEA), volume and weight calculations, kinematic simulation, and circuit analysis and simulation. The most widely used group of methods for analysis is finite-element analy-sis, which is widely used in the following:**
  - **Static and dynamic analysis of complex structures such as aircraft, bridges, build-ings, cars, dams, and so on**
  - **Fluid flow, diffusion and consolidation problems**
  - **Lubrication problems**
  - **Heat conduction and thermal stresses**

➢ **In finite-element analysis, a complex body is decomposed into basic elements, each having a geometric shape and made of a single material (Figure 3.17). The physi-cal characteristics of each element can be determined by classical theories. The prob-lem is then solved as a set of simultaneous equations for all the elements. Therefore, the first step in finite-element analysis is to partition the model of an engineering ob-ject into discrete elements. A CAD system can be used to design the object and help in automatic mesh generation. After the analysis results are returned by the software, the CAD system can display the results graphically to permit the visual interpretation of analysis results.**

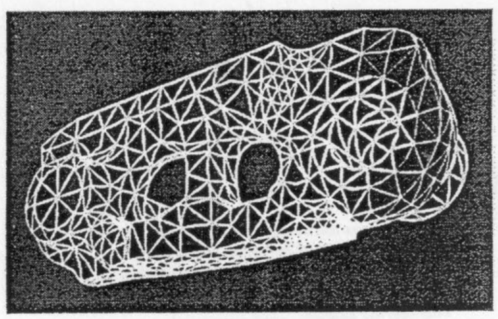


Figure 3.17 Finite-element analysis. (*a*) A finite-element model is constructed from a part design stored in the database (in this case, a wheel). (b) The nodes and elements are inter-actively constructed from the part-design geometry. (Courtesy of Structural Dynamics Re-search Corporation.)

Computer Aided Engineering

➢ ***CAE is the analysis and evaluation of the engineering design by using computer-based techniques to calculate product operational, functional, and manufacturing parameters too complex for classic manual methods.***

➢ **CAE fits into the design process at the synthesis, analysis and evaluation levels and is also consistent with the concurrent engineering principles.**

➢ **At the synthesis level, the primary CAE activity is focused on manufacturability using design for manufacturing and assembly principles.**

➢ **The output from the CAE operation at the analysis and evaluation levels is used by the CE team to determine the quality of the product design.**

➢ **Software to support GT, CAPP, and CAM are grouped under the broad heading of CAE.**

6. Application of CAD to Manufacturing Systems

➢ **CAD is used most often in two application areas: *concept and repetitive design* and *drafting.***

➢ ***Concept and Repetitive Design***

➢ **CAD software is used for a large percentage of the design function in manufacturing, including the design of product plus the design of all systems required to support the production process.**

➢ **The design data captured in CAD are reused often by many other departments and systems in the manufacturing process.**

➢ ***Drafting***

➢ **The second major application for CAD is in the creation of all the working drawings required for product manufacturing.**

➢ **CAD is used to create the documents that will be referenced during design verification and ordering of raw material and component parts.**