CAD/CAM Principles and Applications

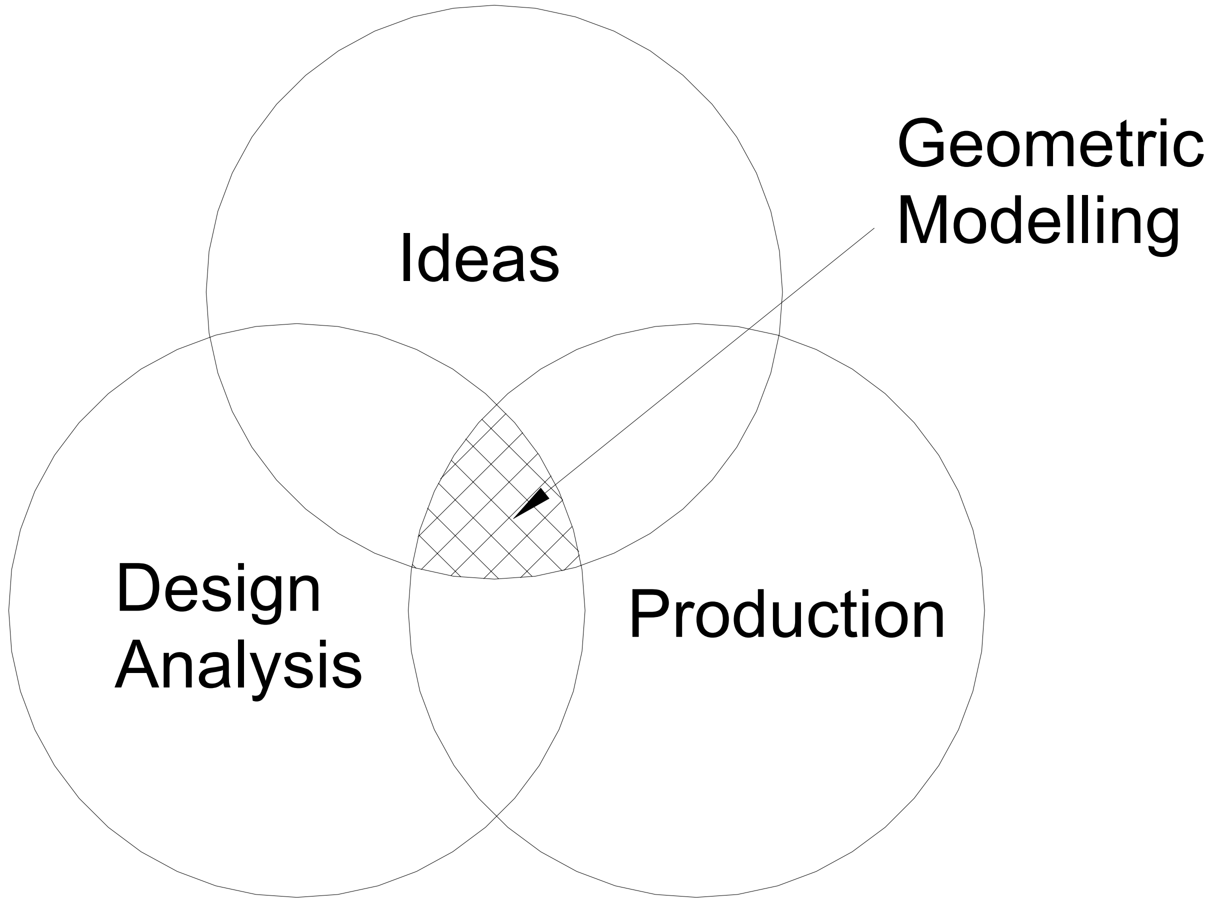
Ch 4 Geometric Modelling

Objectives

- Understand the various requirements for the information that is generated during the geometric modeling stage.
- Study various types of geometric models possible and their applications
- Develop various methodologies used for geometric construction such as sweep, surface models, solid models, etc.
- Recognize the various types of surfaces and their application as used in geometric modelling
- Appreciate the concept of parametric modeling which is the current mainstay of most of the 3D modeling systems
- Develop the various mathematical representations of the curves used in the geometric construction
- Discuss the various CAD system requirements that need to be considered while selecting a system for a given application
- Understand the concept of rapid prototyping and the various methods available for the purpose.

4.1 Requirements of Geometric Modelling

Fig. 4.1 Total product cycle in a manufacturing environment



Functions of Geometric Modelling

- Design analysis:
  - Evaluation of areas and volumes.
  - Evaluation of mass and inertia properties.
  - Interference checking in assemblies.
  - Analysis of tolerance build-up in assemblies.
  - Analysis of kinematics — mechanics, robotics.
  - Automatic mesh generation for finite element analysis.

Functions of Geometric Modelling

- Drafting
  - Automatic planar cross sectioning.
  - Automatic hidden line and surface removal.
  - Automatic production of shaded images.
  - Automatic dimensioning.
  - Automatic creation of exploded views for technical illustrations.

Functions of Geometric Modelling

- Manufacturing
  - Parts classification.
  - Process planning.
  - Numerical control data generation and verification.
  - Robot program generation.

Functions of Geometric Modelling

- Production Engineering
  - Bill of materials.
  - Material requirement.
  - Manufacturing resource requirement.
  - Scheduling.

- Inspection and Quality Control:
  - Program generation for inspection machines.
  - Comparison of produced part with design.

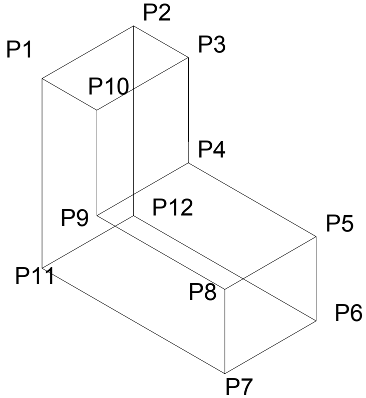
Requicha and Voelker [1981] specified the following properties to be desired of in any geometric modelling (solids) system.

- The configuration of solid (geometric model) must stay invariant with regard to its location and orientation.
- The solid must have an interior and must not have isolated parts.
- The solid must be finite and occupy only a finite shape.
- The application of a transformation or other operation that adds or removes parts must produce another solid.
- The model of the solid in E3 (Euler space) may contain infinite number of points. However, it must have a finite number of surfaces, which can be described.
- The boundary of the solid must uniquely identify which part of the solid is exterior and which is interior.

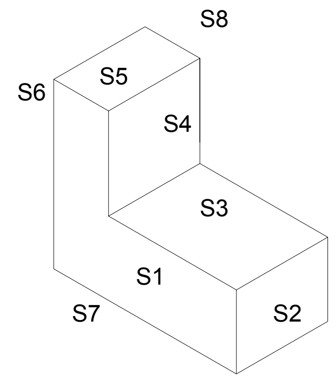
4.2 Geometric Models

- Two-dimensional, and
- Three-dimensional.
- The three principal classifications can be
  - The line model,
  - The surface model, and
  - The solid or volume model

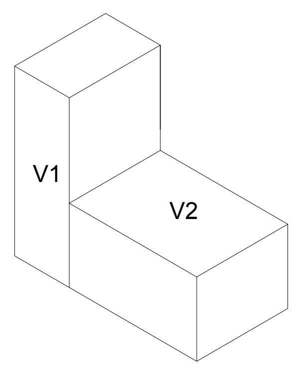
Fig. 4.2 3D geometric representation techniques



(a) LINE MODEL



(b) SURFACE MODEL



(c) VOLUME MODEL

Fig. 4.3 A geometric model represented in wire-frame model

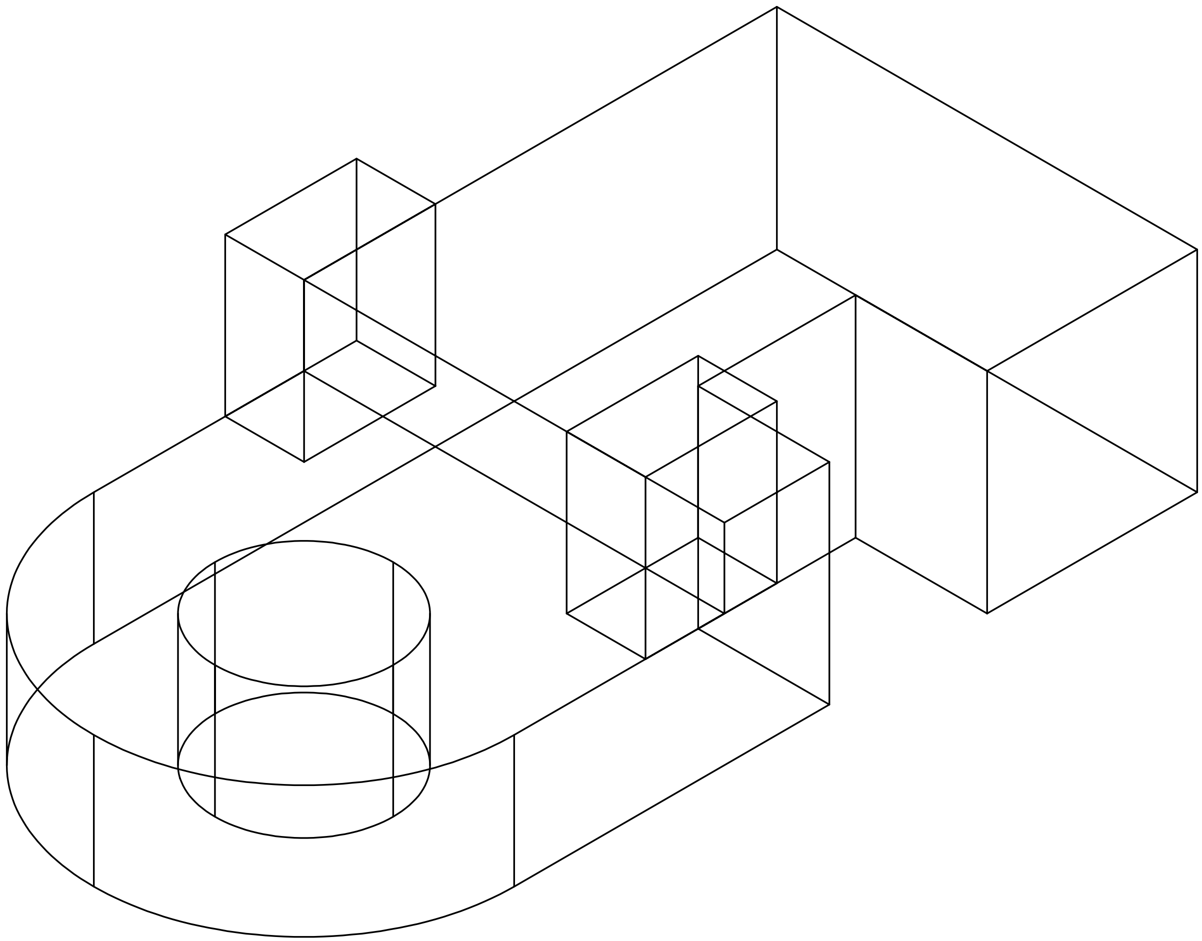


Fig. 4.4 Ambiguities present in the wire-frame model

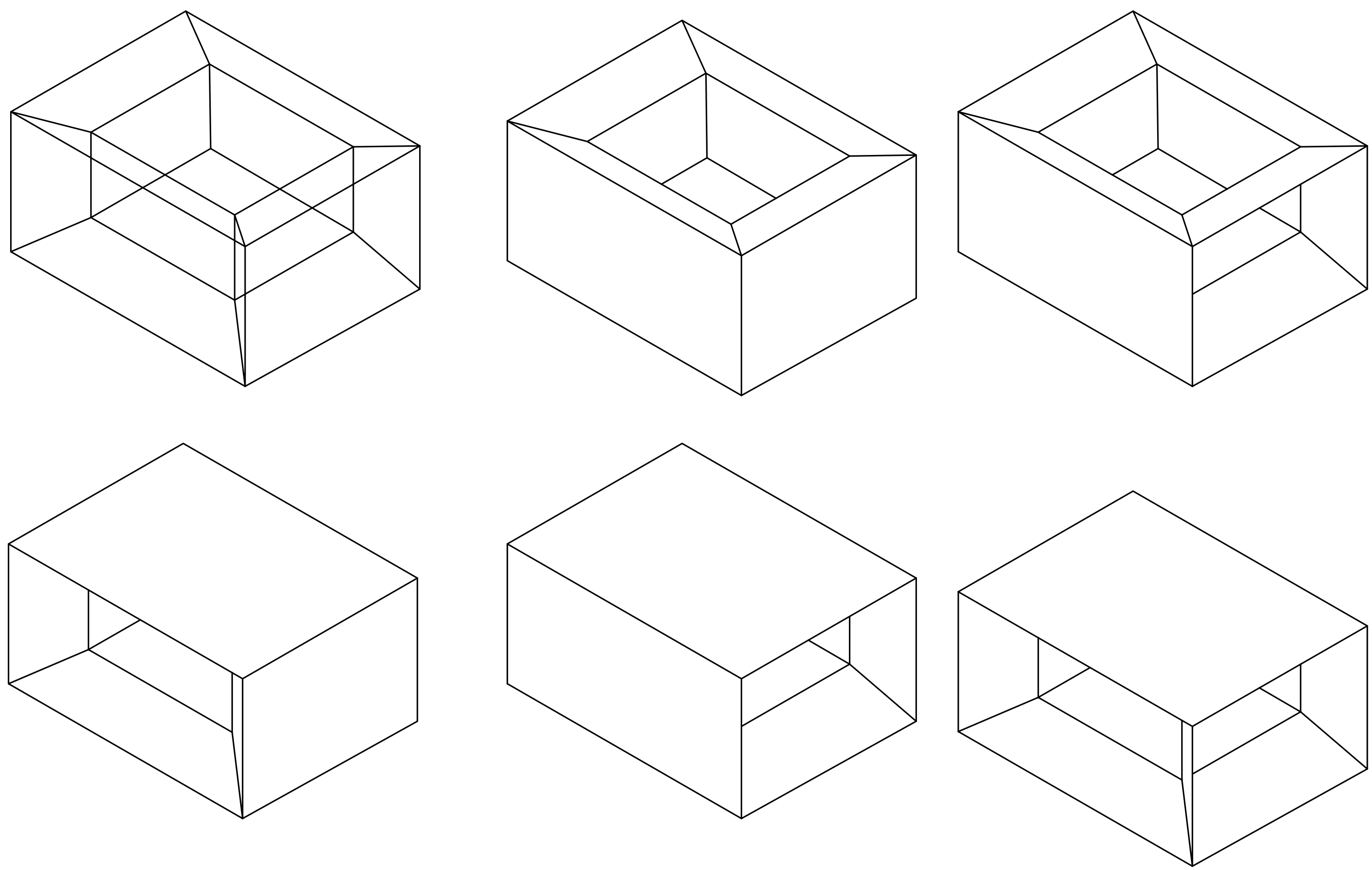


Fig. 4.5 Impossible objects that can be modelled using a wire-frame model

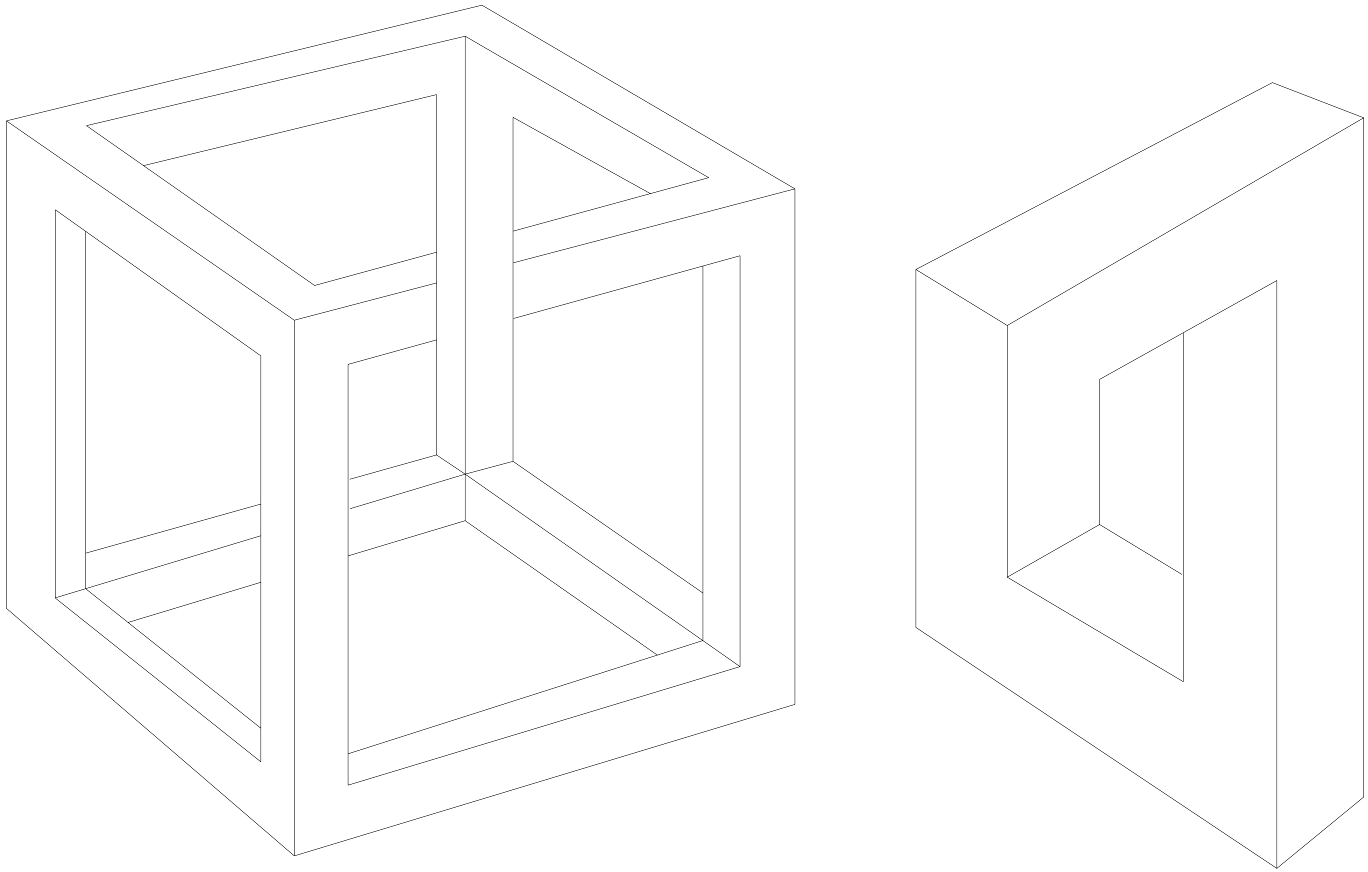
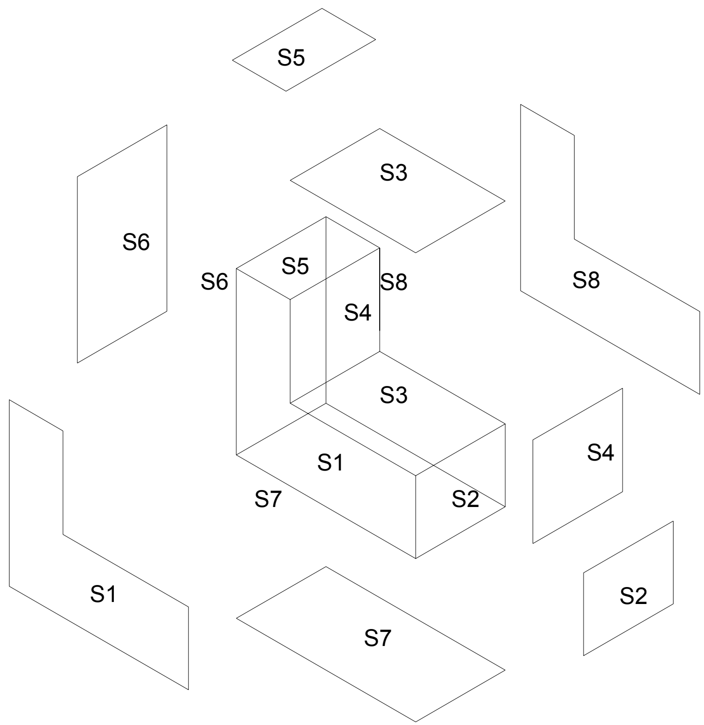


Fig. 4.6 Generation of 3D geometry using planar surfaces



(b) SURFACE MODEL

4.3 Geometric Construction Methods

- The three-dimensional geometric construction methods which extend from the 2D that is normally used are:
  - Linear extrusion or translational sweep, and
  - Rotational sweep.

Fig. 4.8 Component model produced using translational (linear) sweep (extrusion)

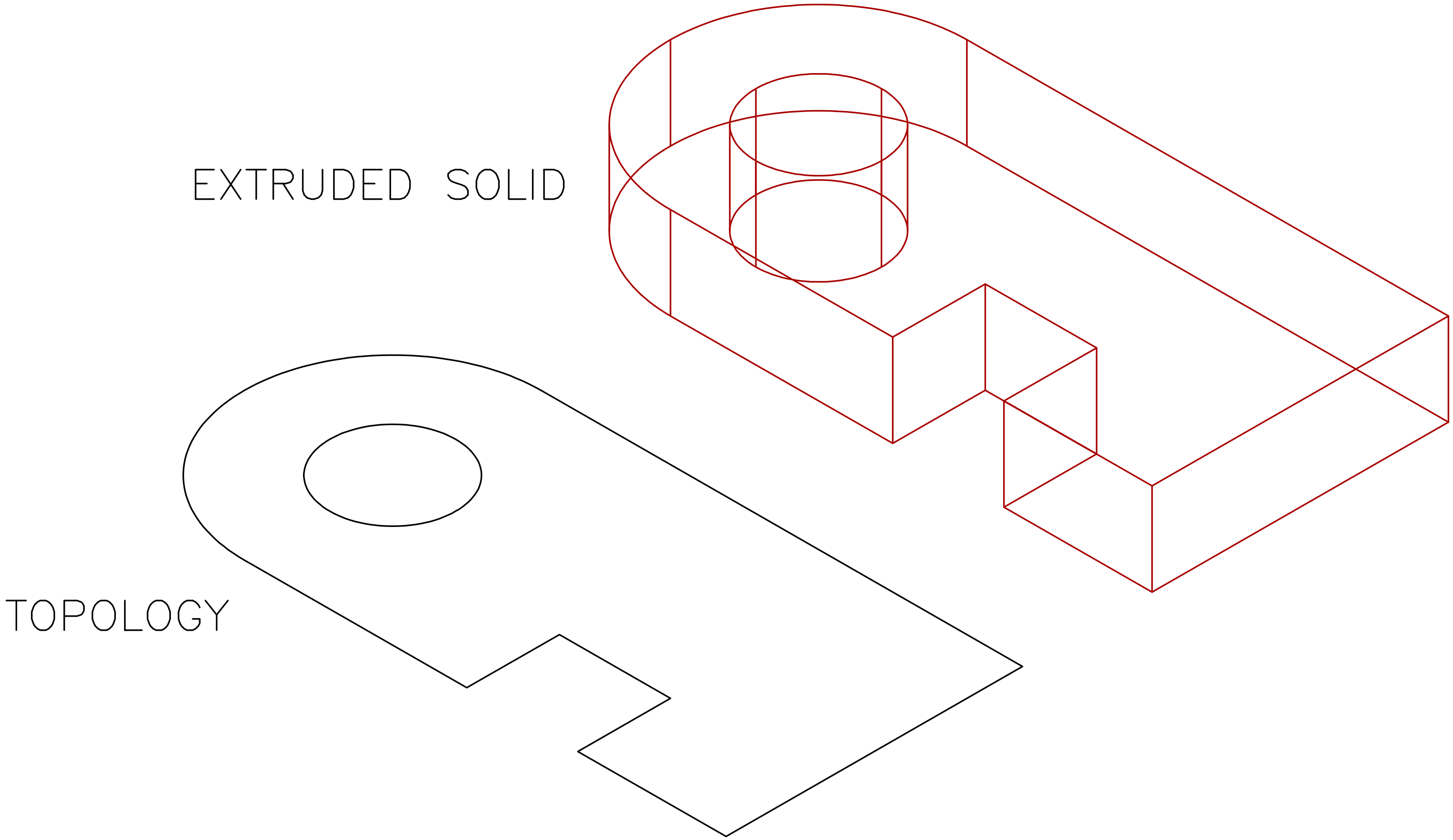


Fig. 4.9 Component model produced using translational (linear) sweep with taper in sweep direction

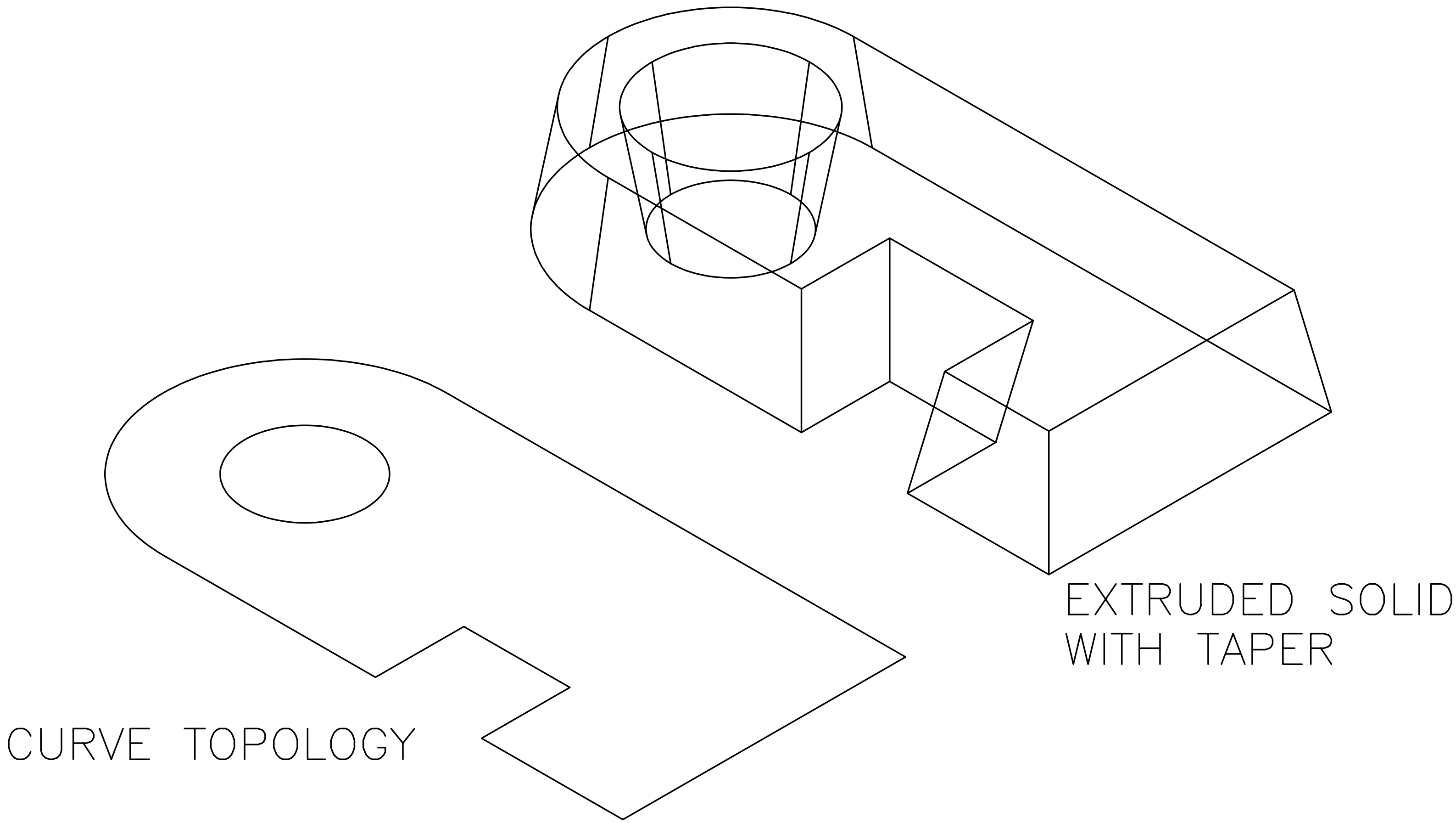


Fig. 4.10 Component model produced using linear sweep with the sweep direction along a 3D curve

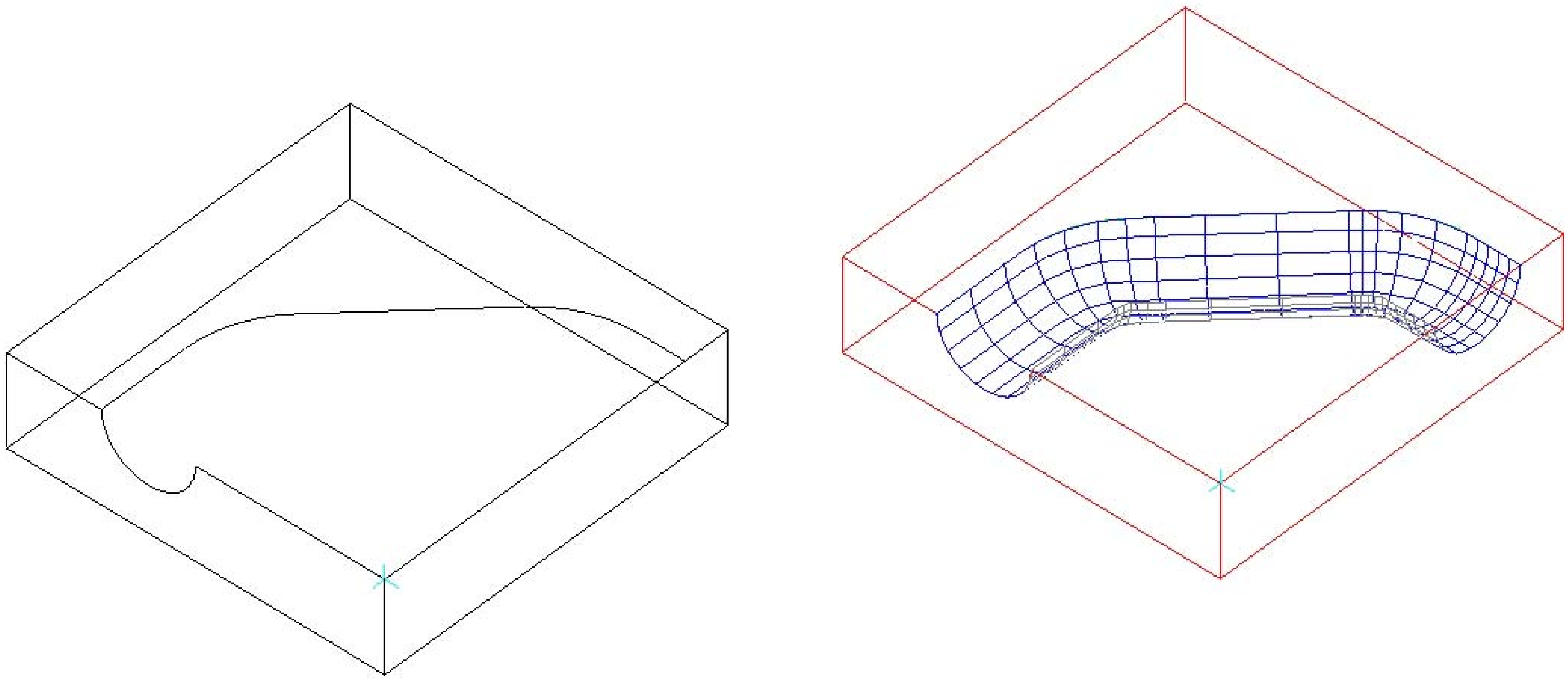


Fig. 4.11 Component model produced using translational (linear) sweep with an overhanging edge

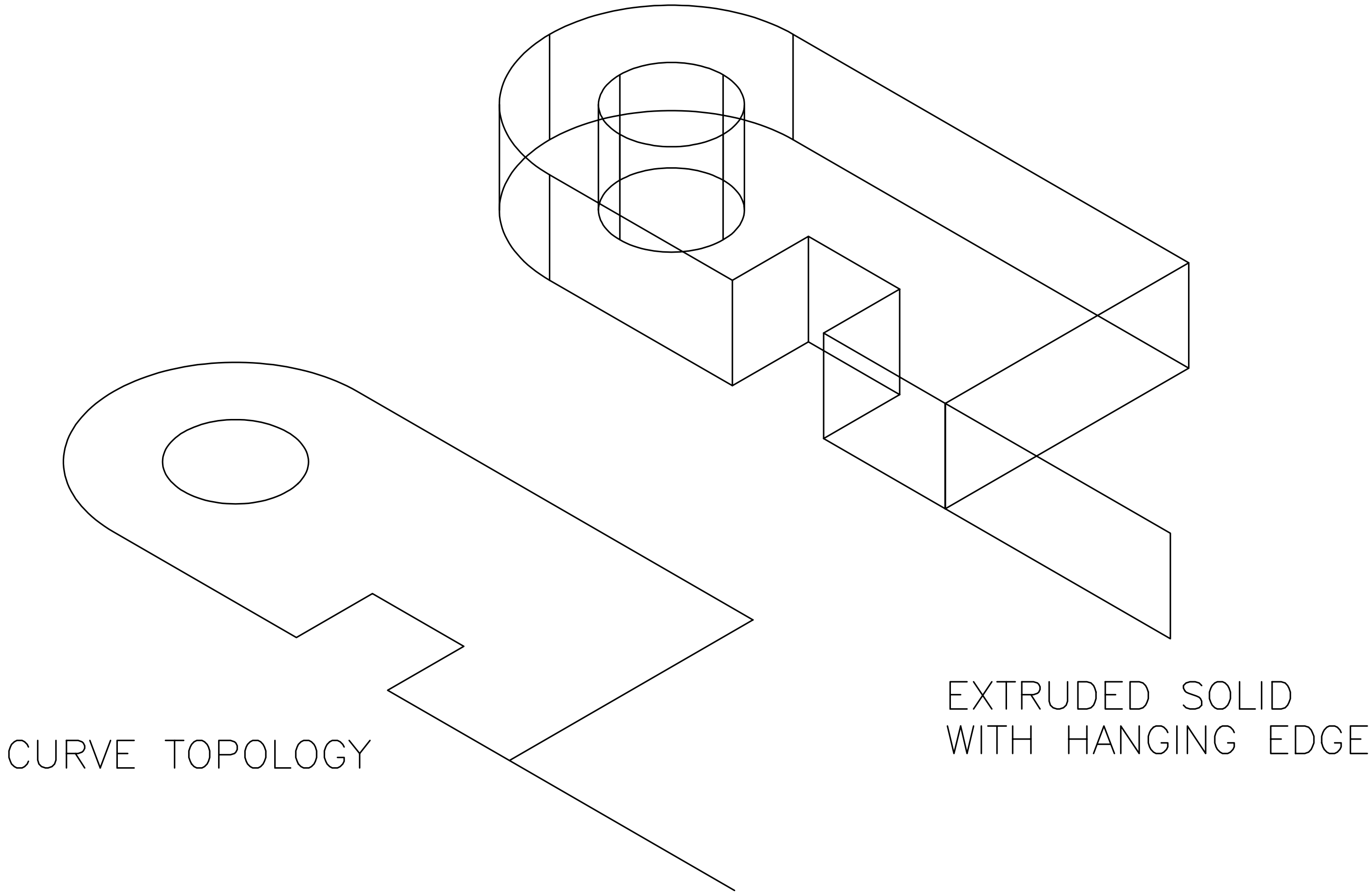


Fig. 4.12 Component produced by the rotational sweep technique

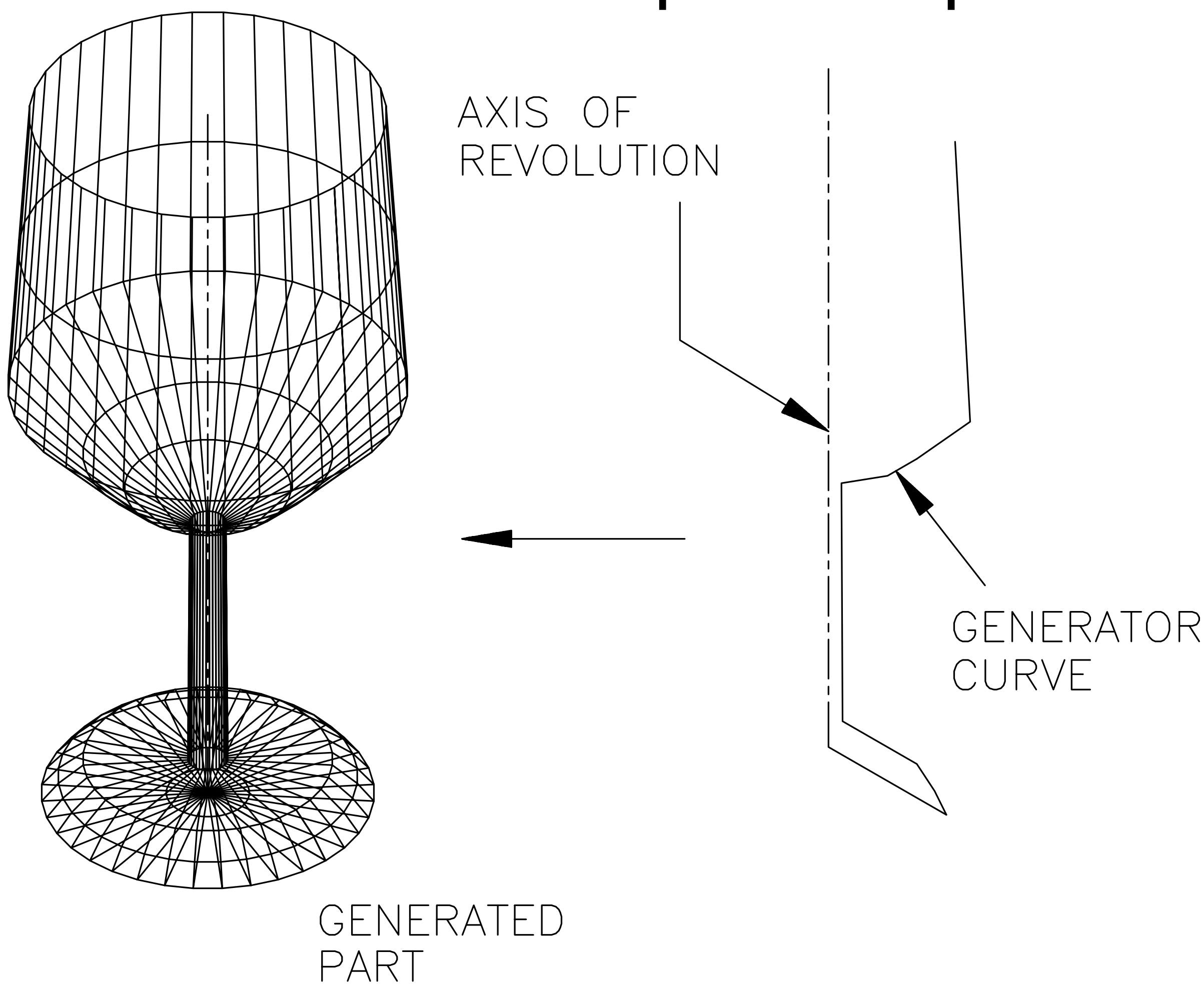


Fig. 4.13 Various solid modelling primitives

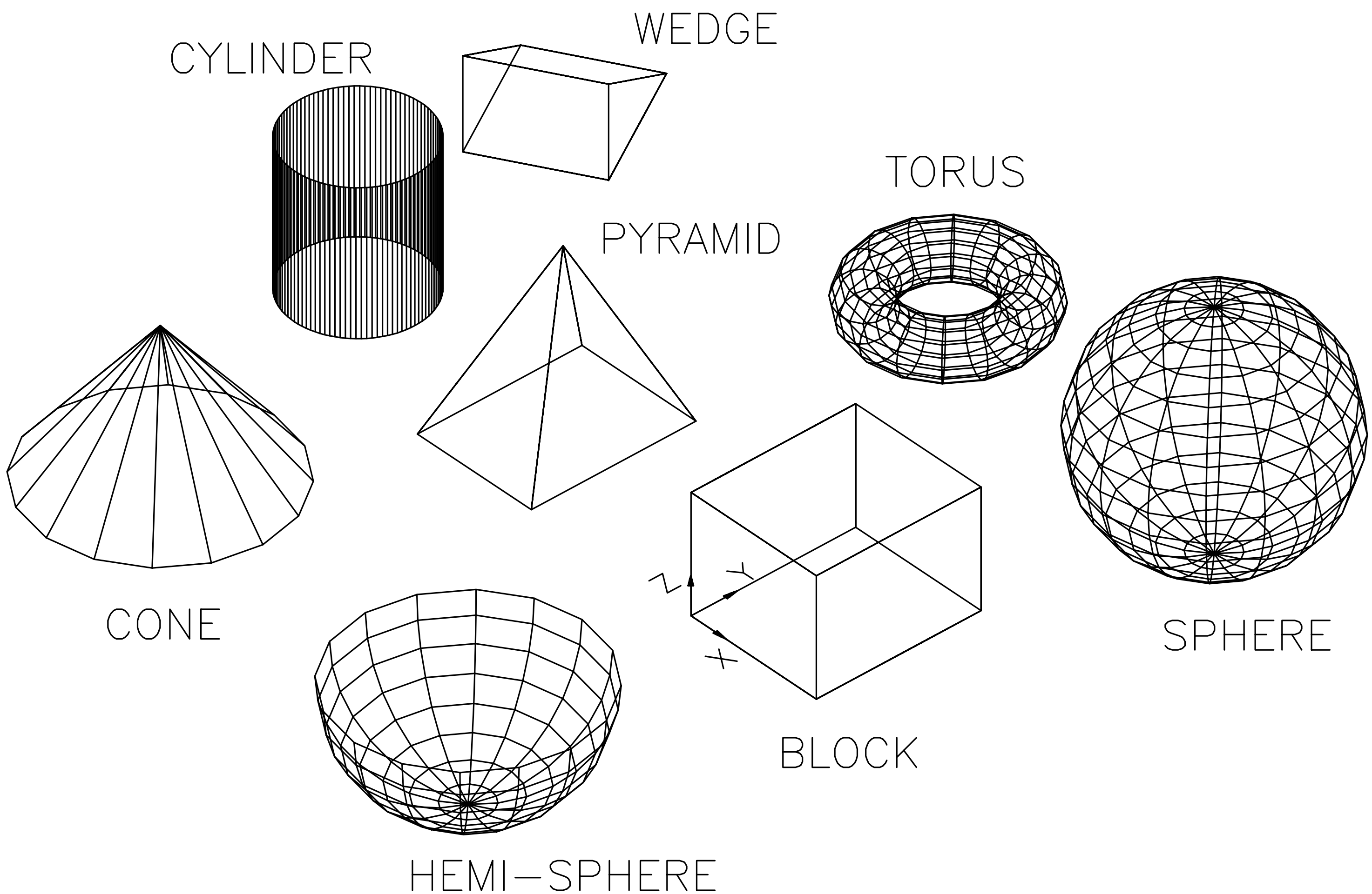


Fig. 4.14 The Boolean operators and their effect on model construction

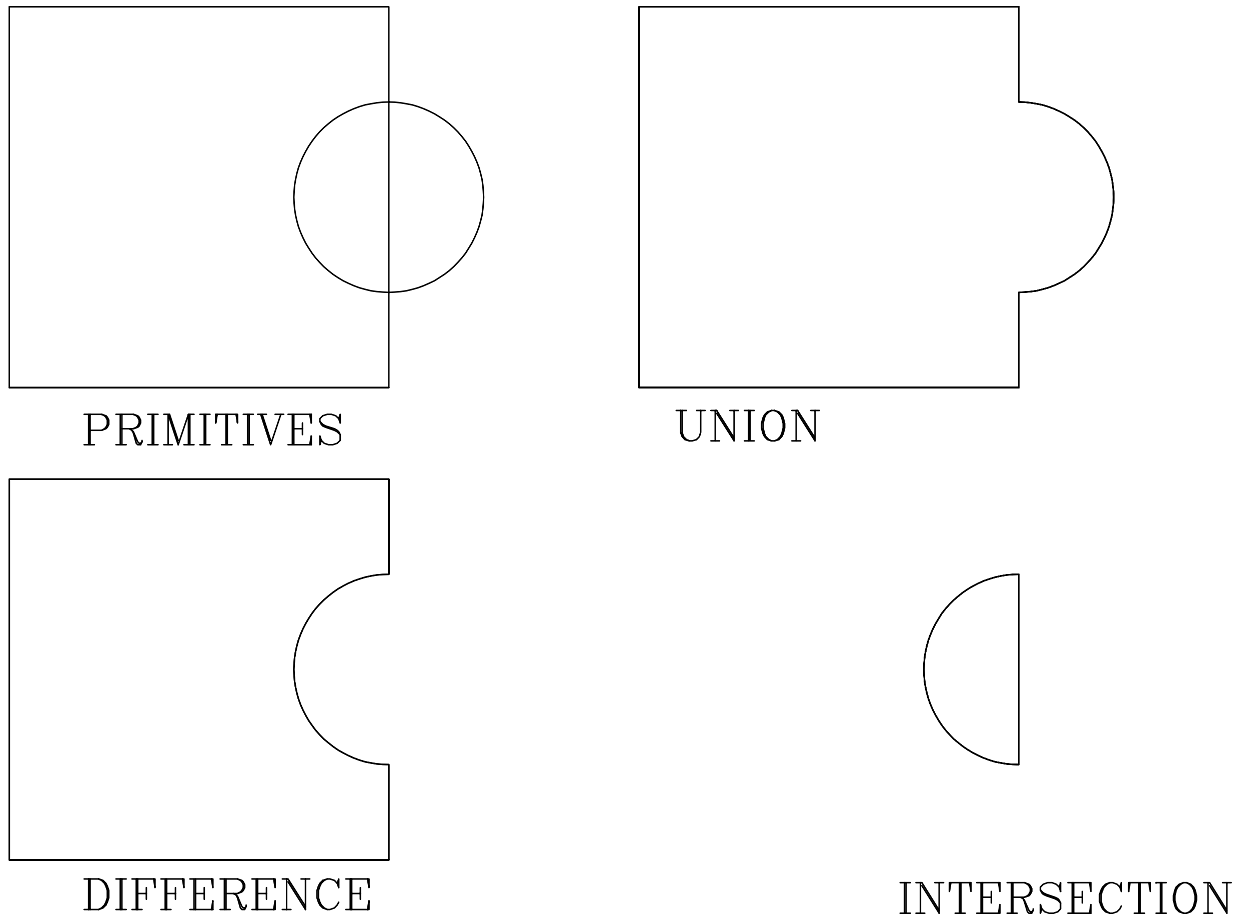


Fig. 4.15 The Boolean operators and their effect on model construction

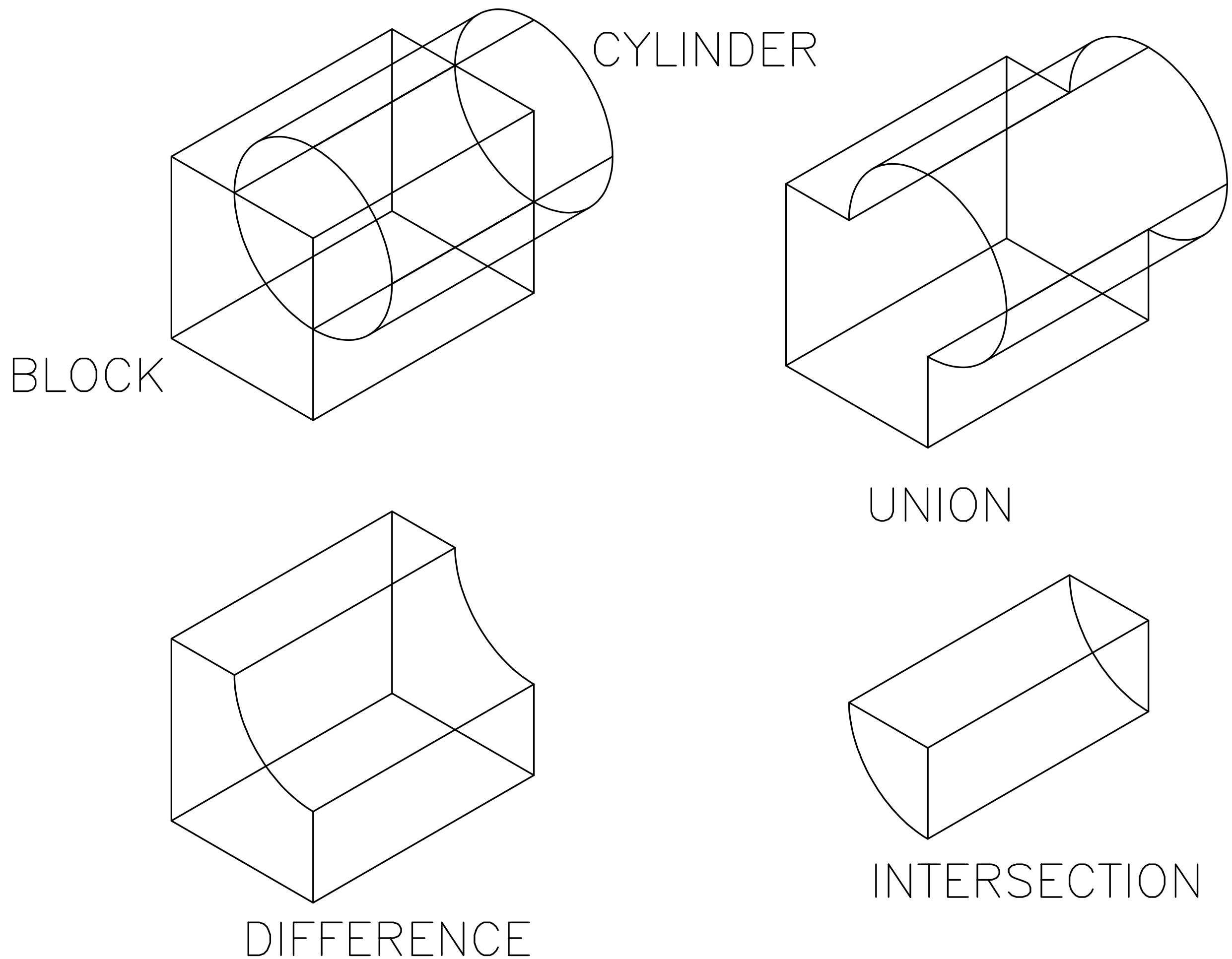


Fig. 4.16 Creating a solid with the 3D primitives in solid modelling and the model shown in the form of Constructive Solid Geometry (CSG)

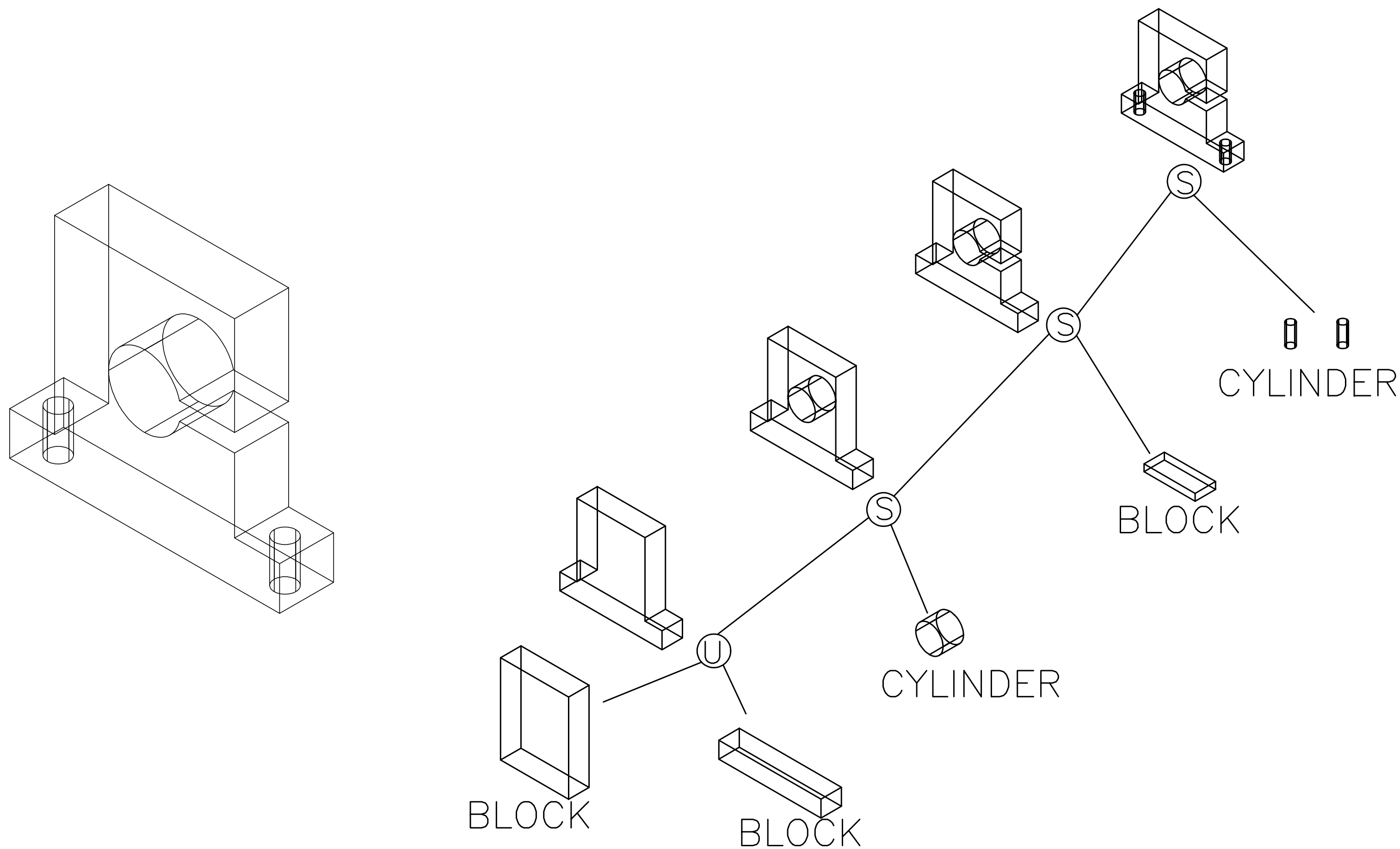


Fig. 4.17 Model generated using the sculptured surfaces (Image appears with the permission of IBM World Trade Corporation/Dassault

Systems - Model generated using CATIA)

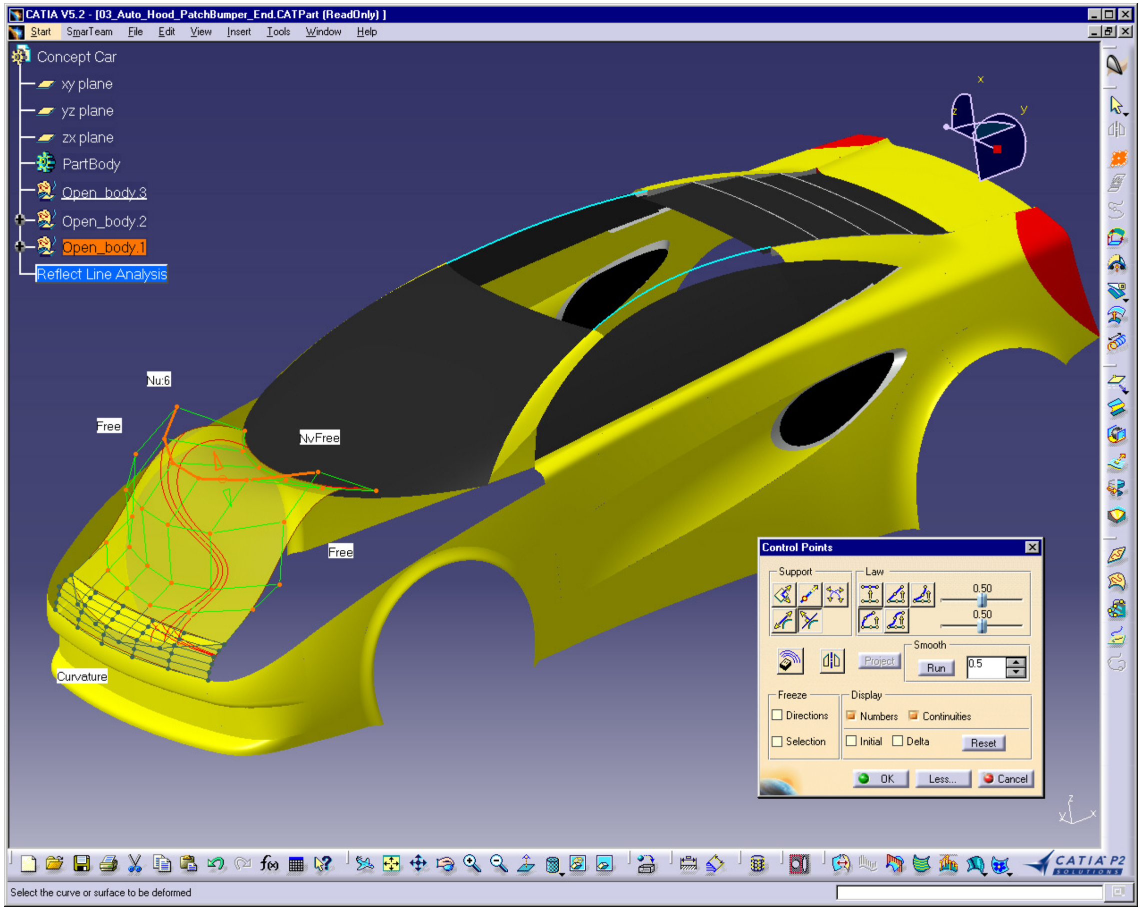


Fig. 4.18 The various types of surfaces used in geometric modelling

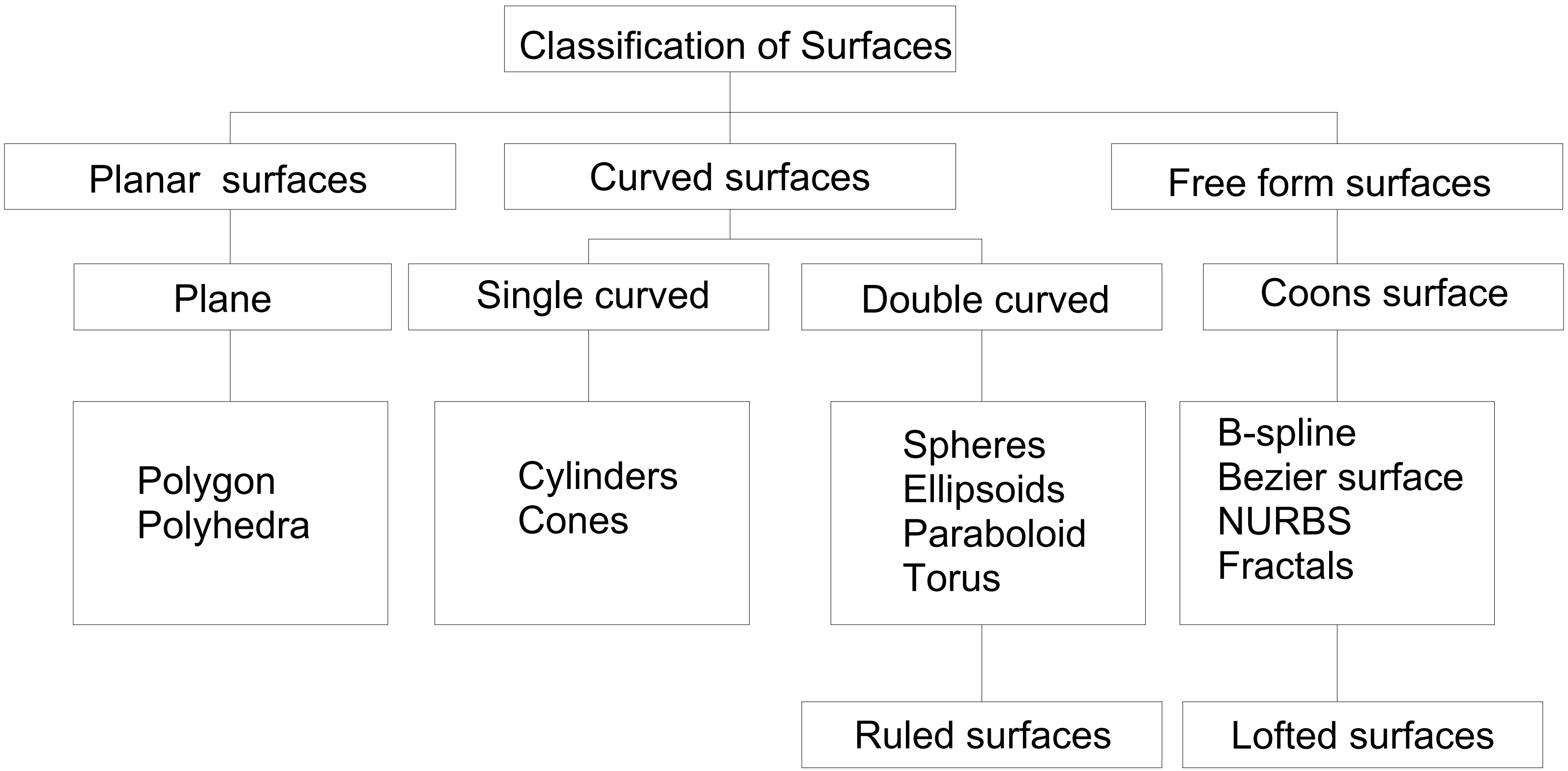


Fig. 4.19 Ruled surface on the left is shown the curves from which the ruled surface on the right is formed.

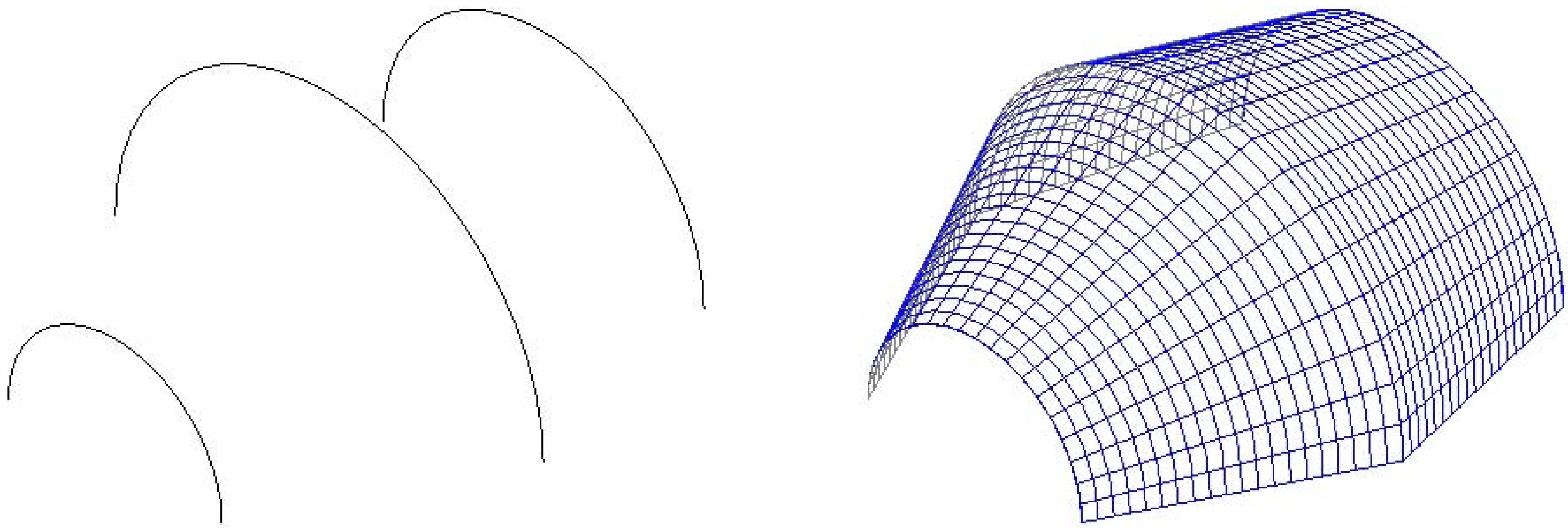


Fig. 4.20 Coons surface generation

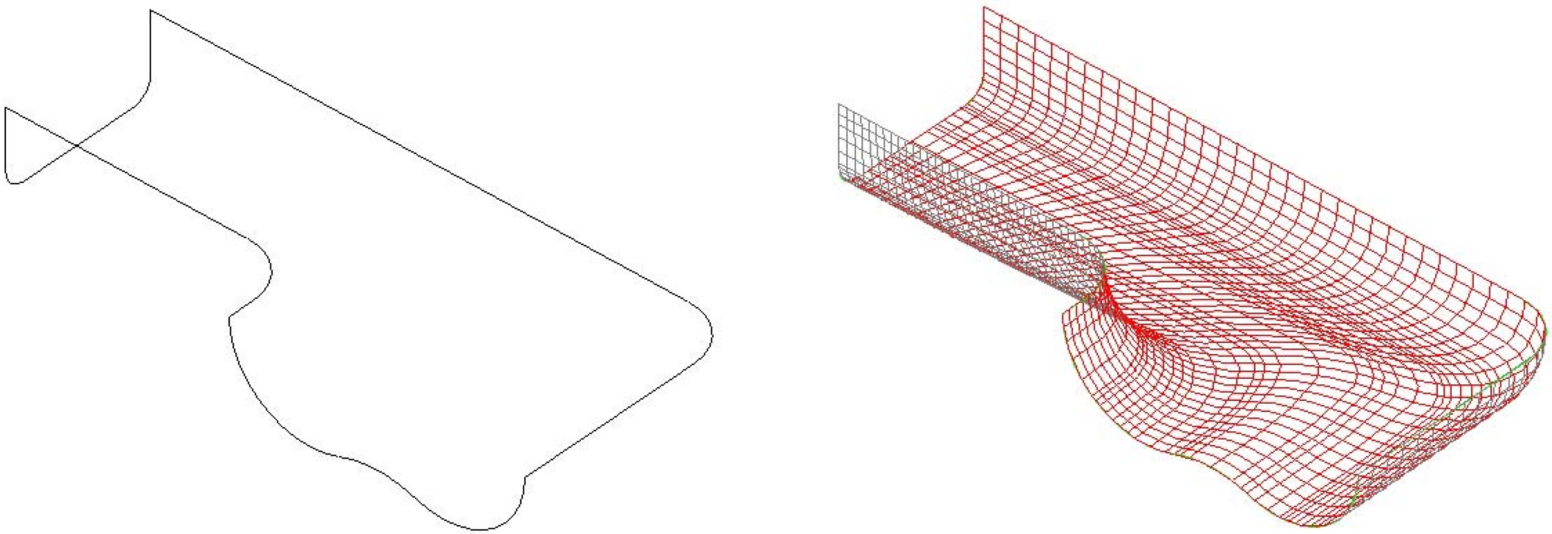


Fig. 4.21 The Bézier curve and the associated control polygon

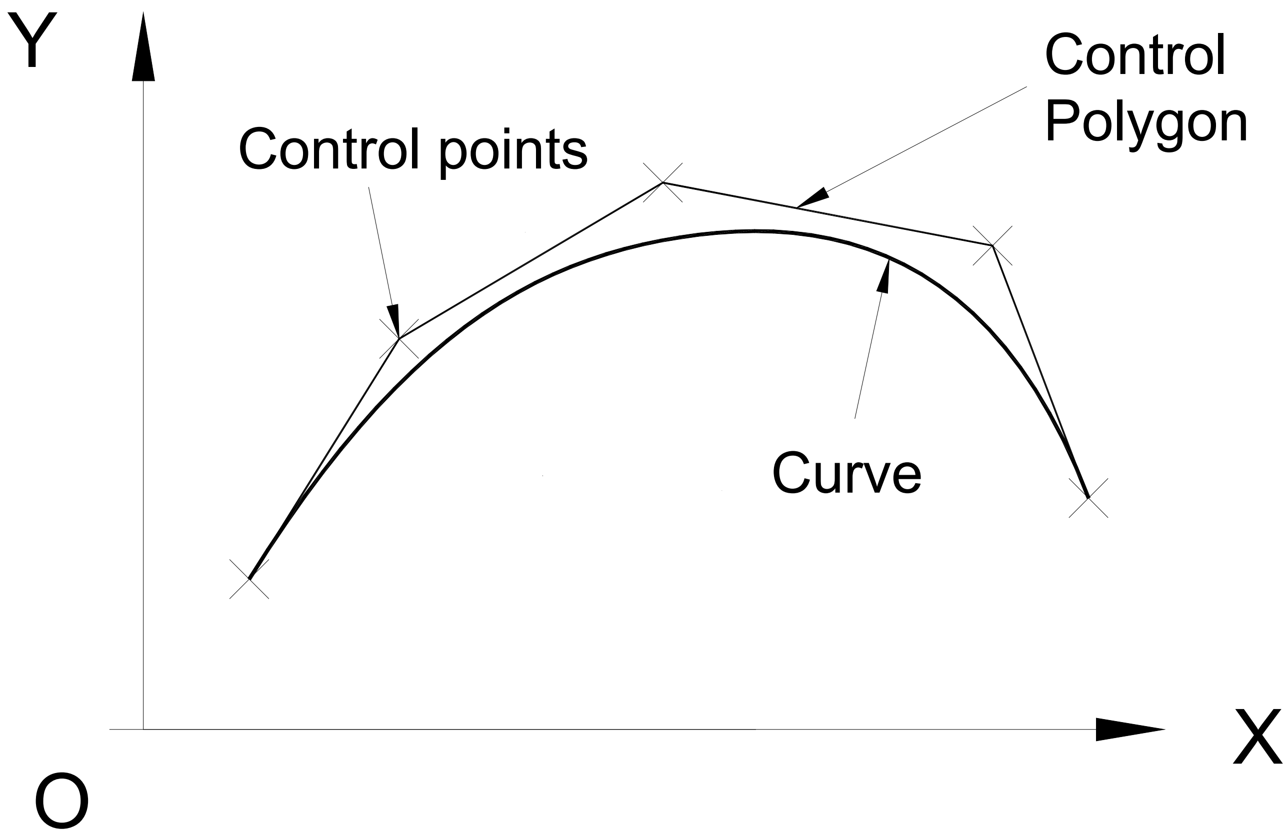


Fig. 4.22 The various examples of Bézier curves depending on the associated control polygons

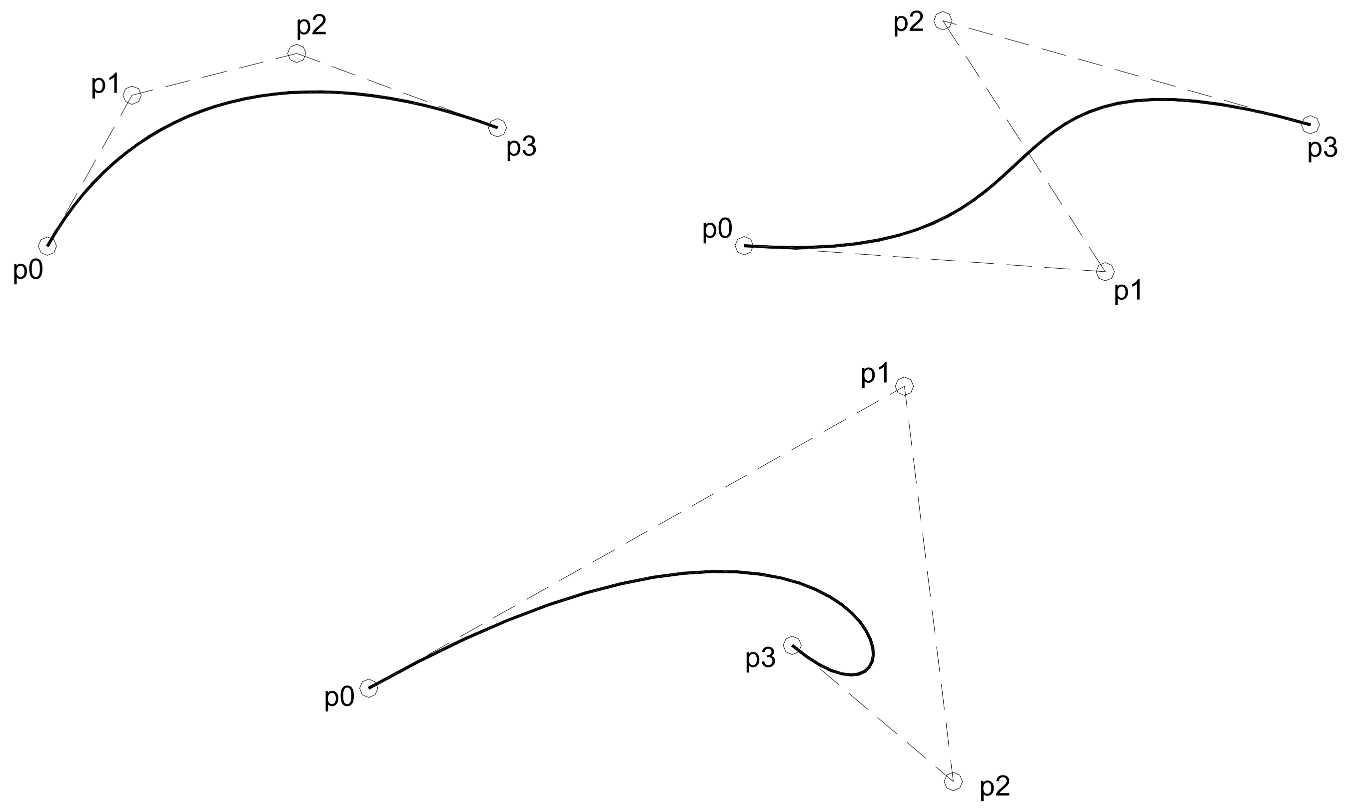


Fig. 4.23 The modification of Bezier curve by tweaking the control points

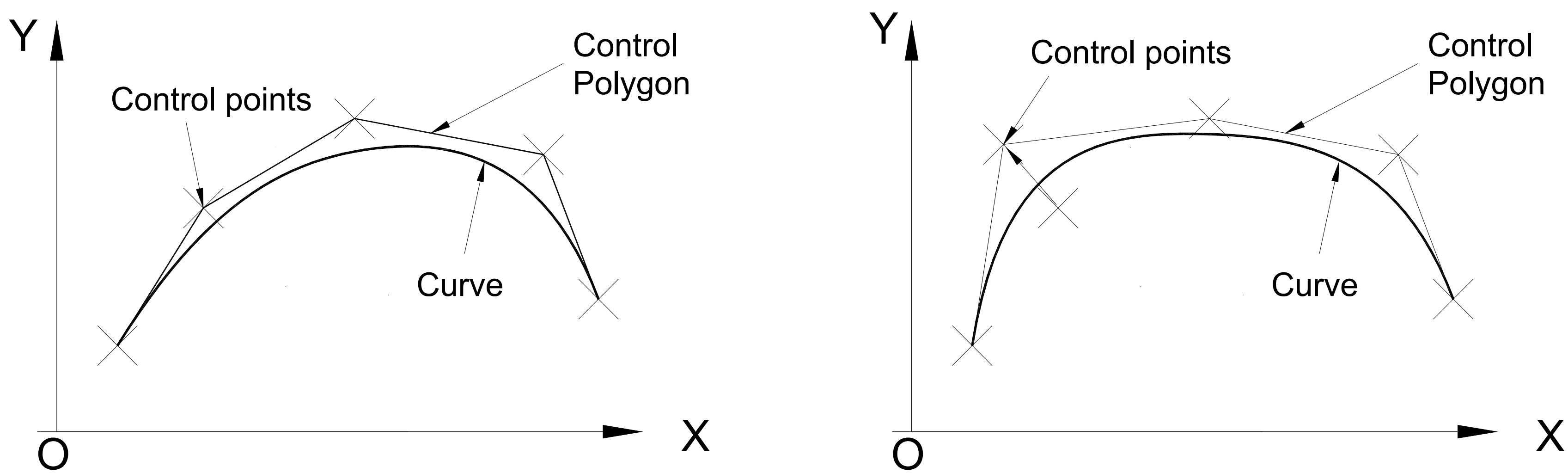


Fig. 4.24 The spline curve

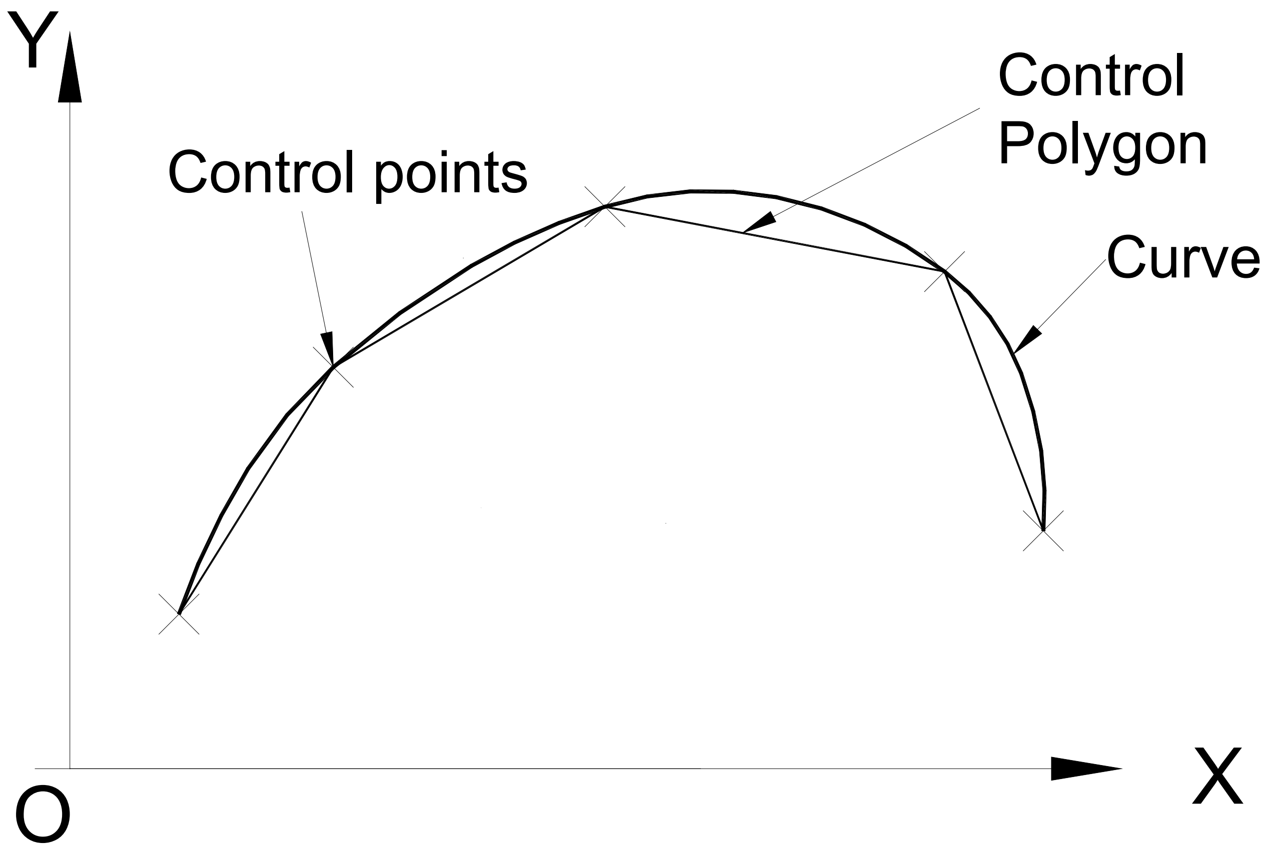


Fig. 4.25 The lofted surface

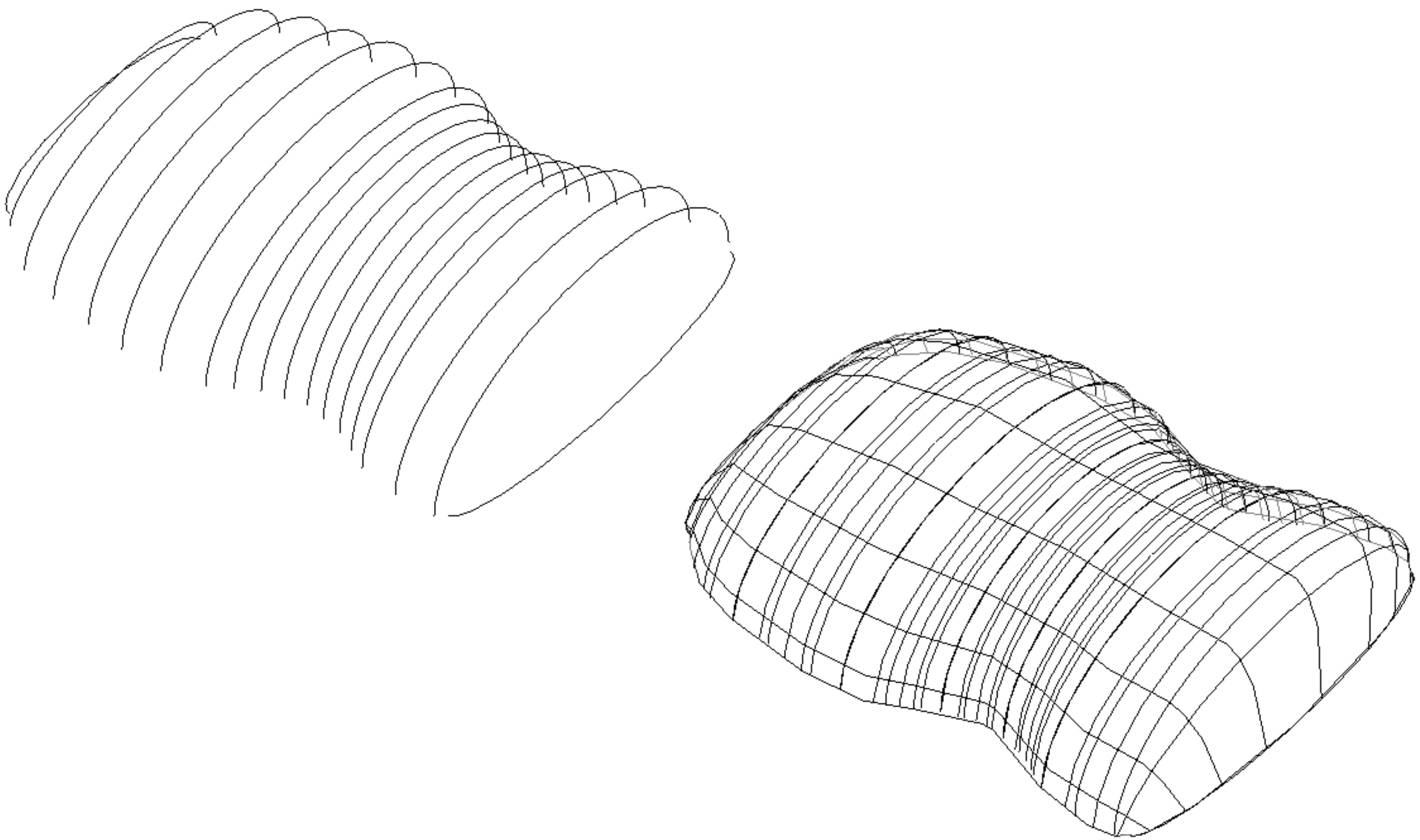


Fig. 4.26 Example of filleting or blend method for model generation

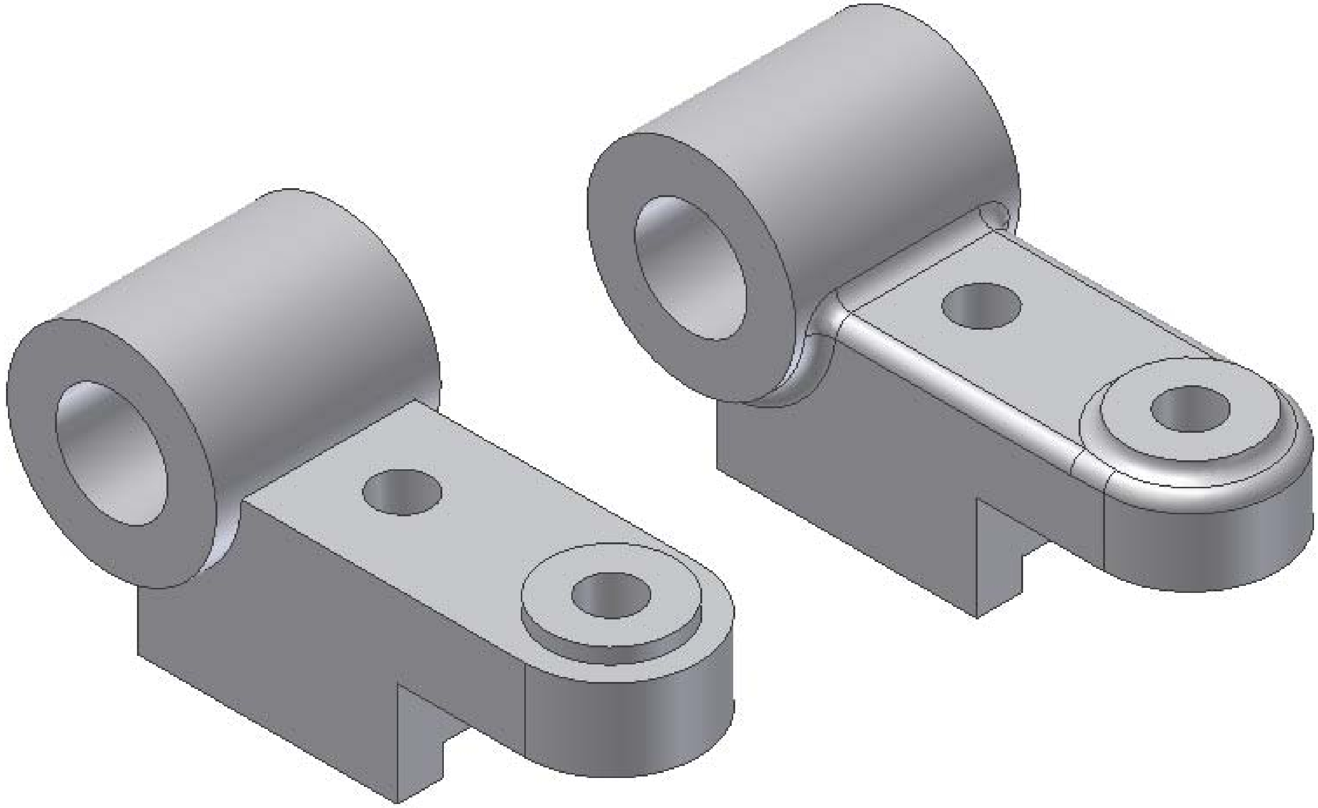
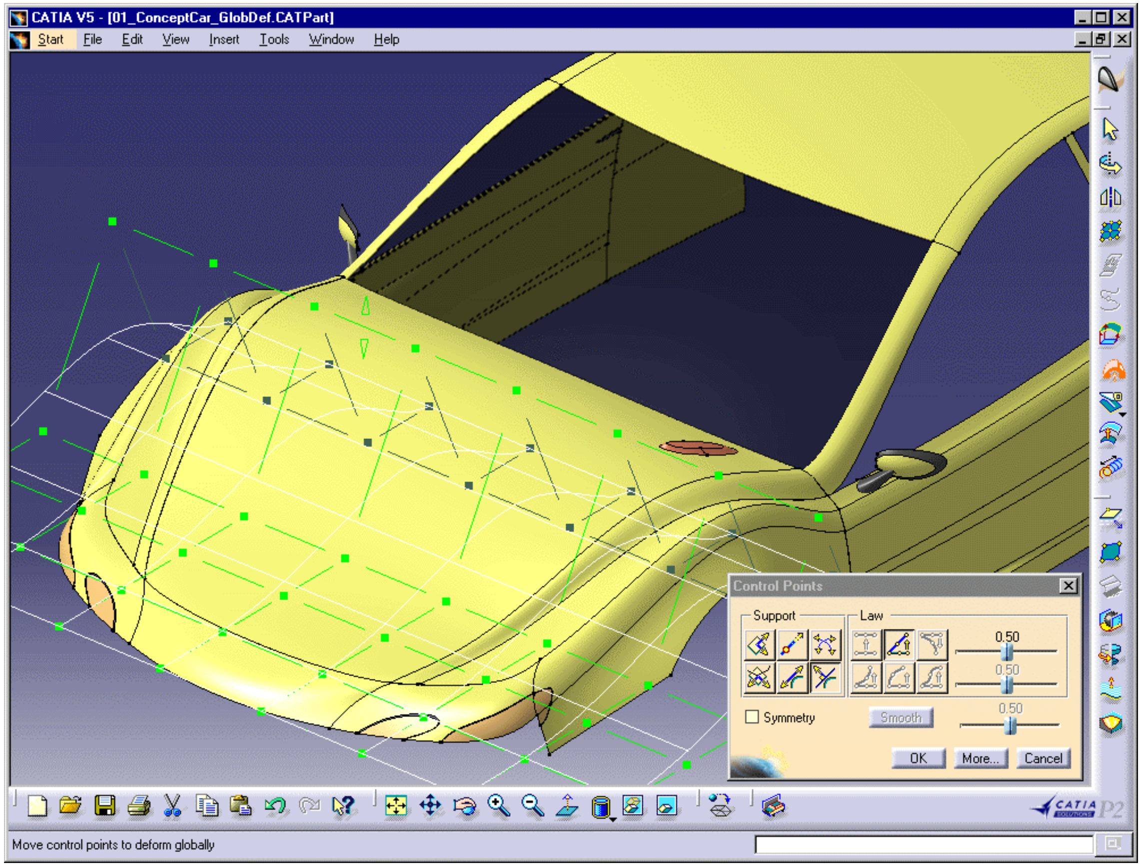


Fig. 4.27 Example of tweaking method for surface modification ((Image appears with the permission of IBM World Trade

Corporation/Dassault Systems - Model generated using CATIA))



4.4 Constraint Based Modelling

Fig. 4.28 Example of initial sketch without any dimensions

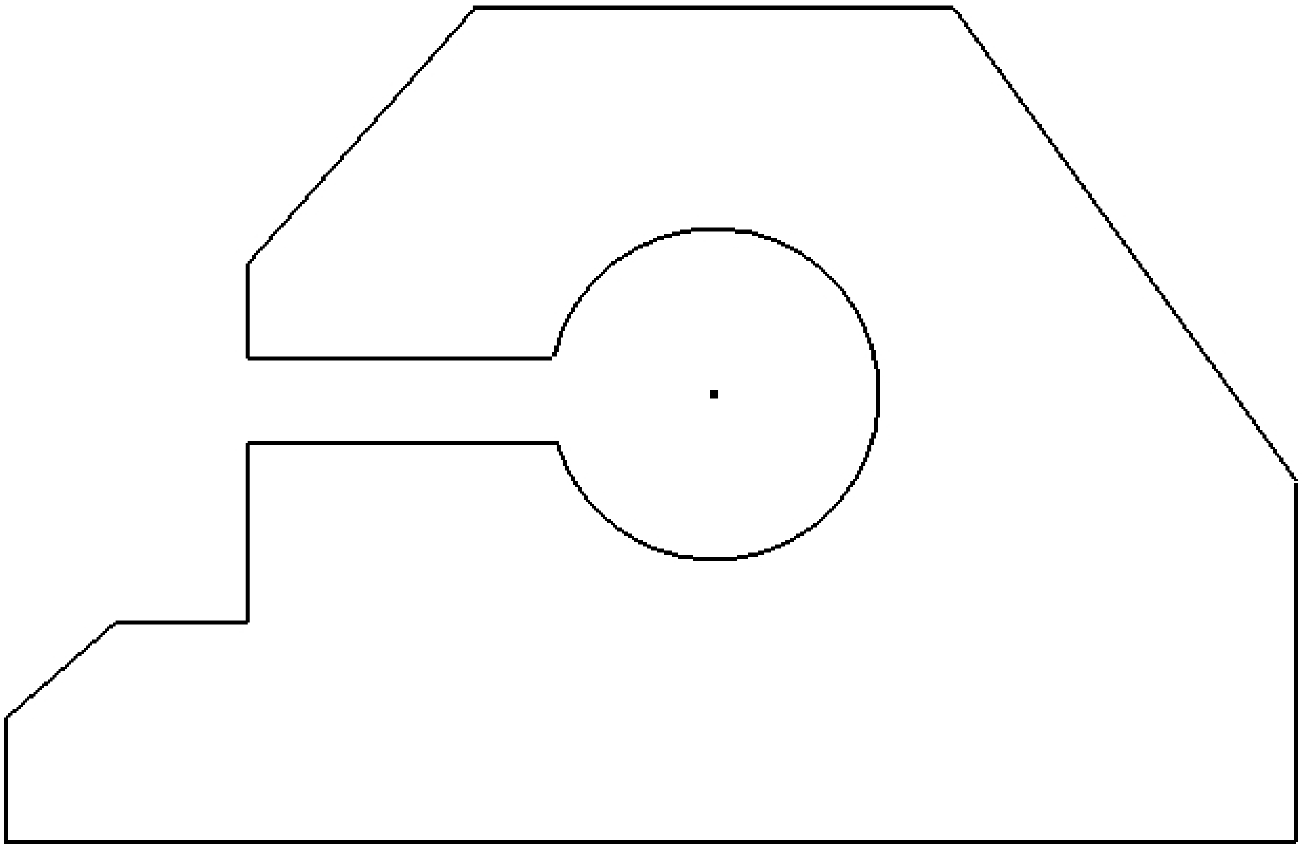


Fig. 4.29 The sketch shown above which is fully constrained and dimensioned

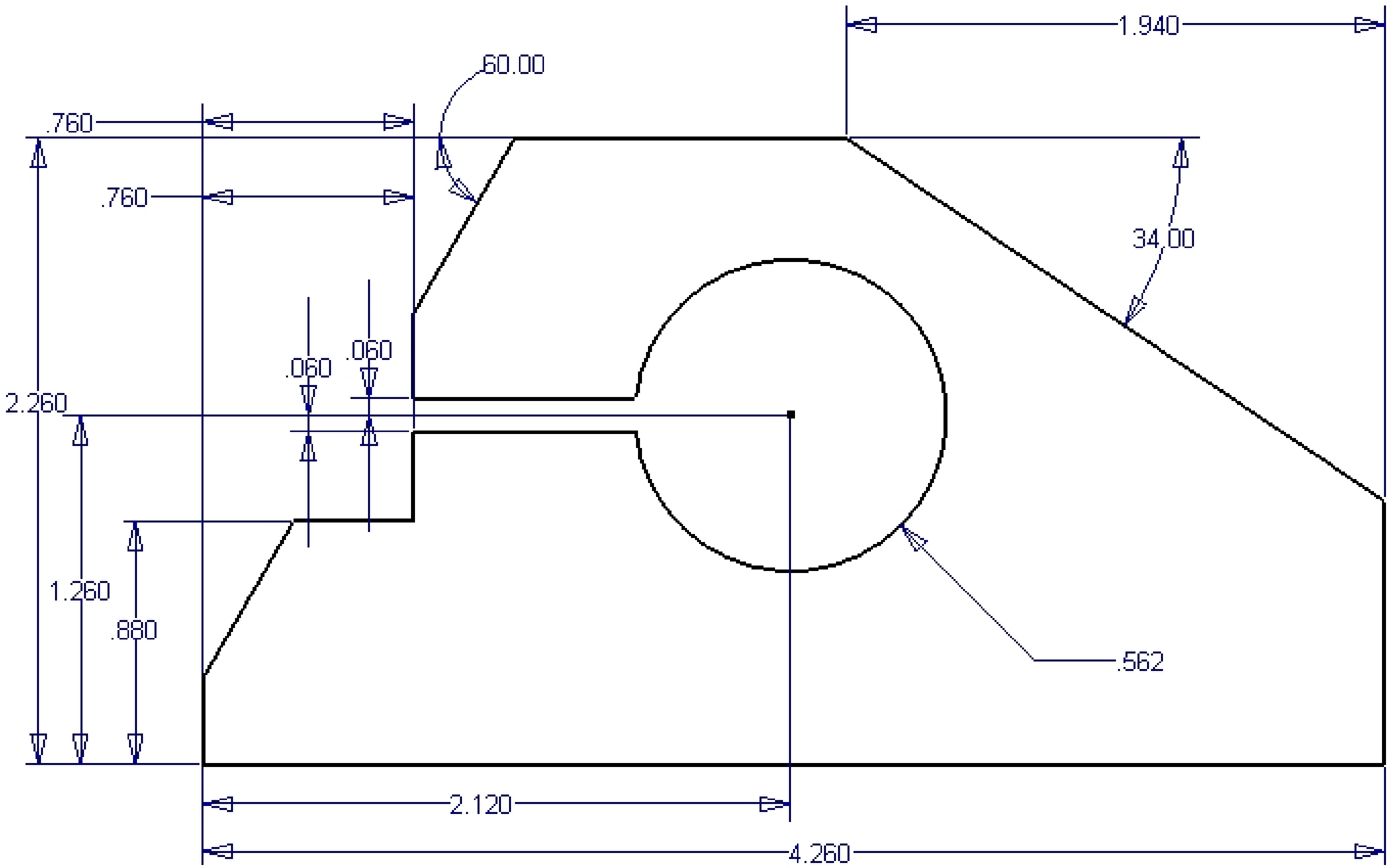


Fig. 4.30 The sketch in Fig. 4.29 when swept along a linear path produces the solid

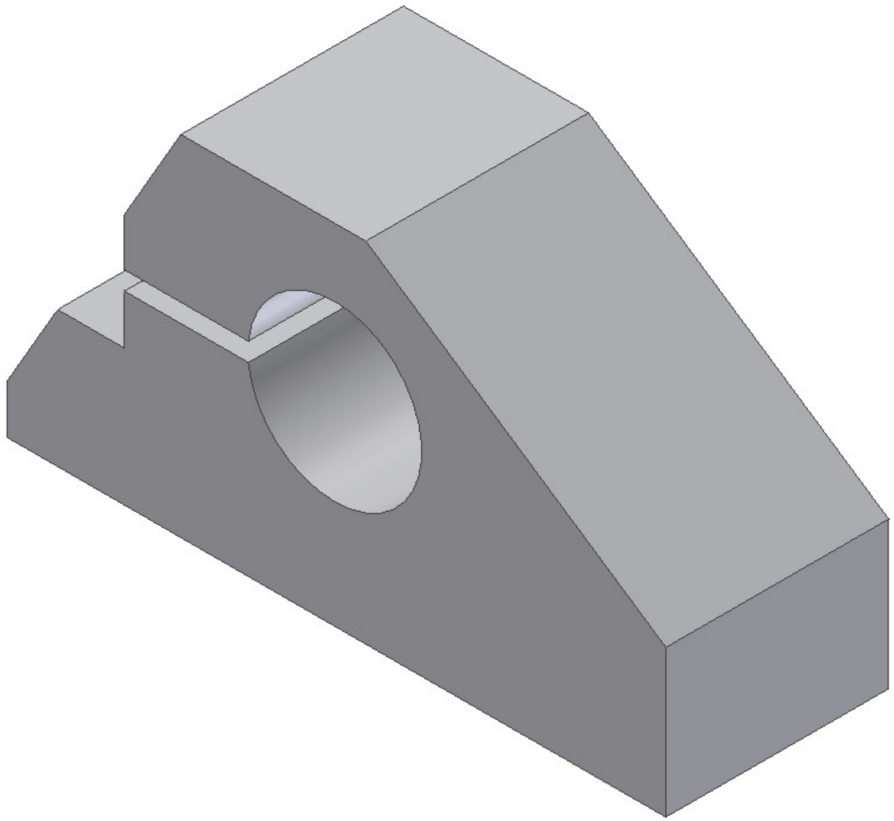


Fig. 4.31 The sketch for the new feature (a cut)

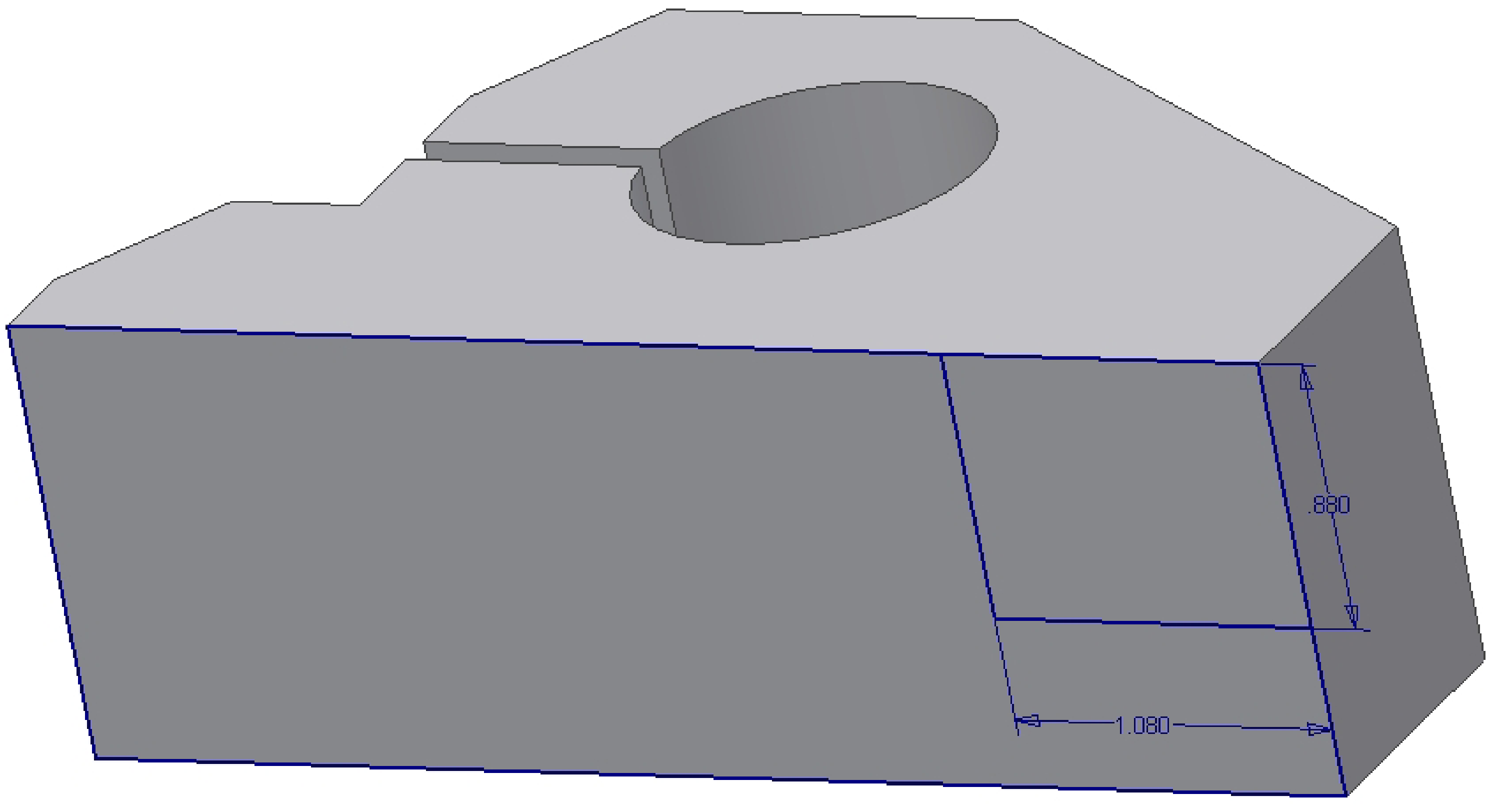


Fig. 4.32 The solid after executing an extruded cut of the geometry in Fig. 4.31

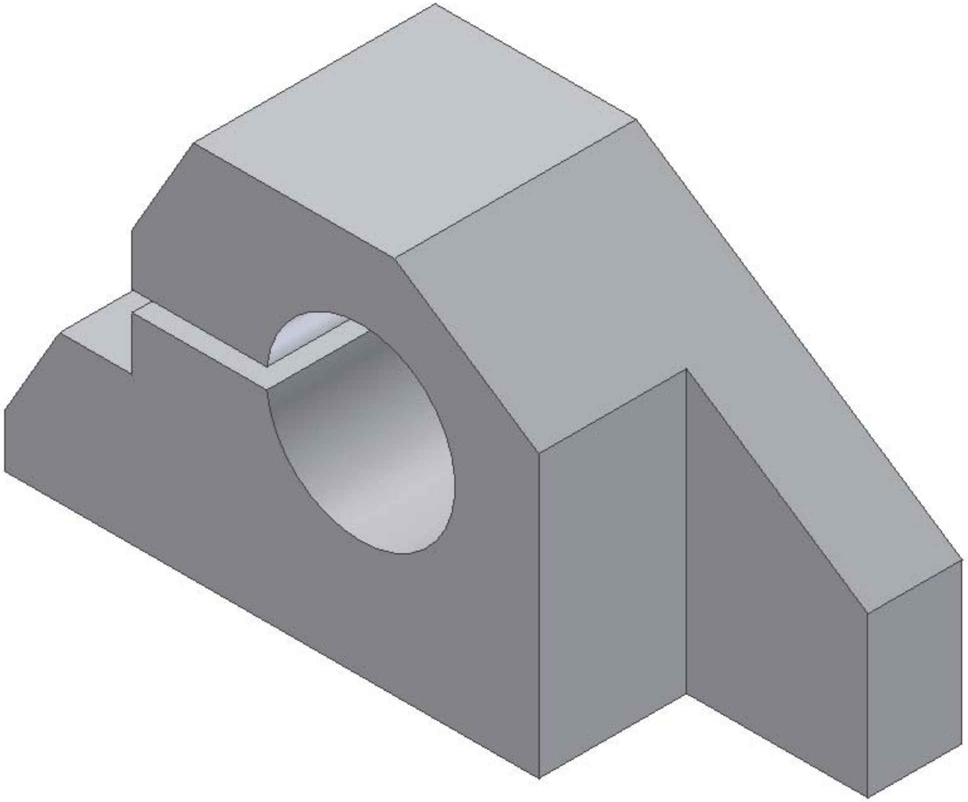


Fig. 4.33 The final solid

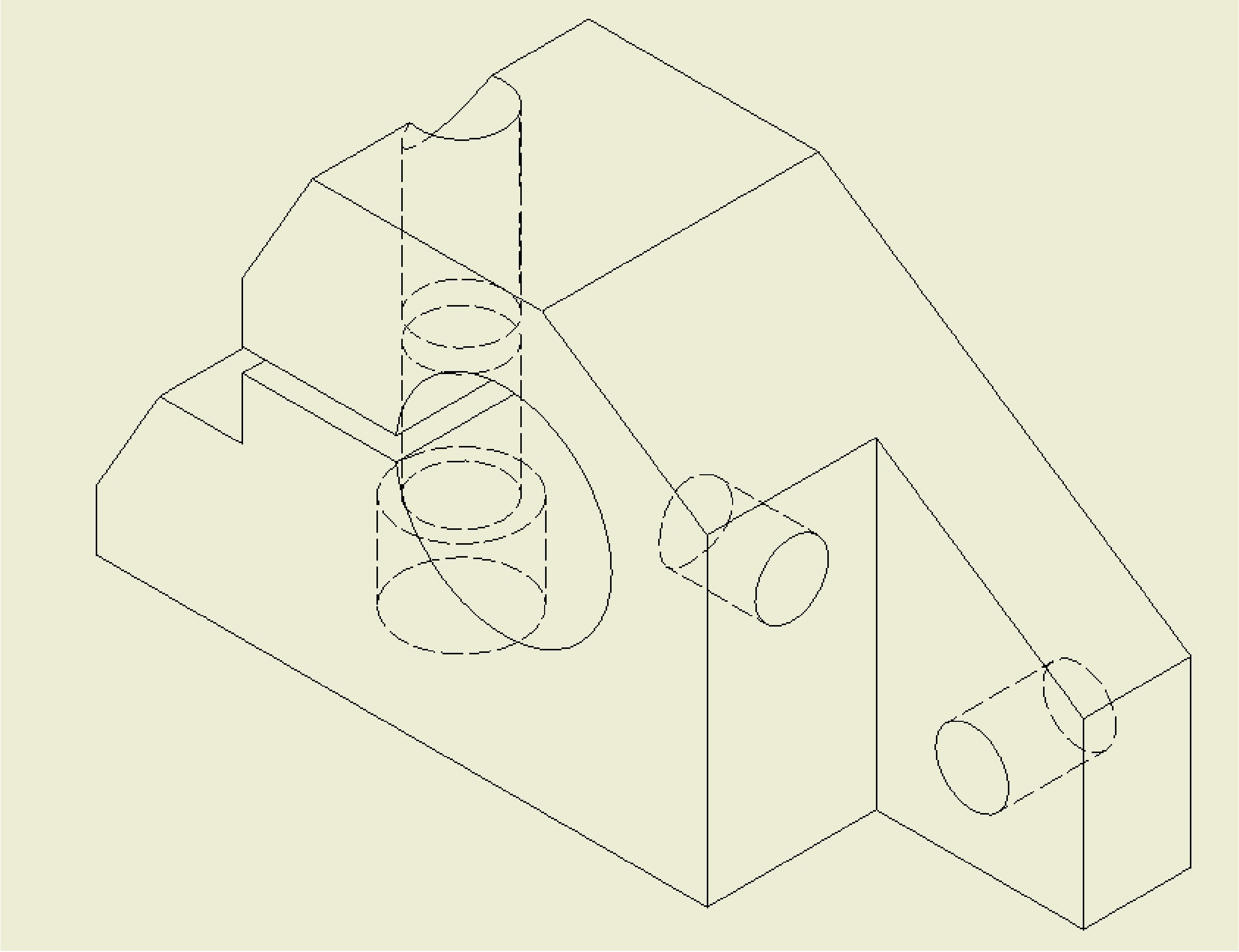


Fig. 4.34 The model tree of the part showing the modelling process

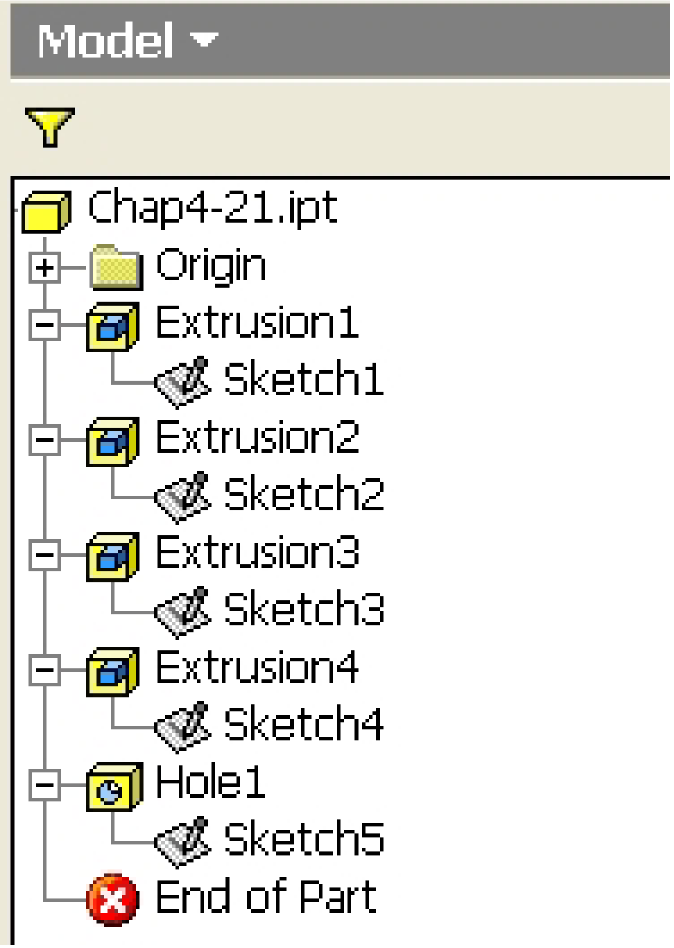


Fig. 4.35 A geometric model created following the sequence of features as

Box → Hole → Shell

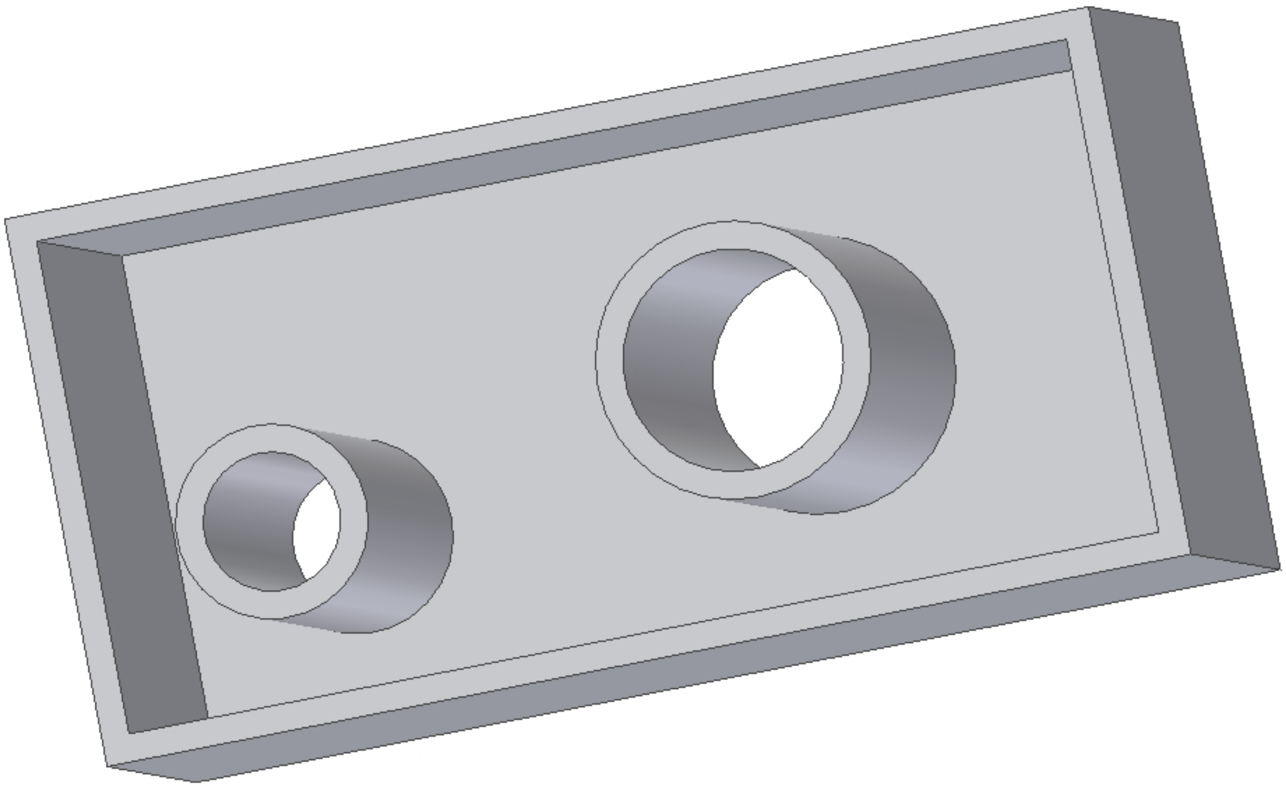


Fig. 4.36 A geometric model created following the sequence of features as

Box → Shell → Hole

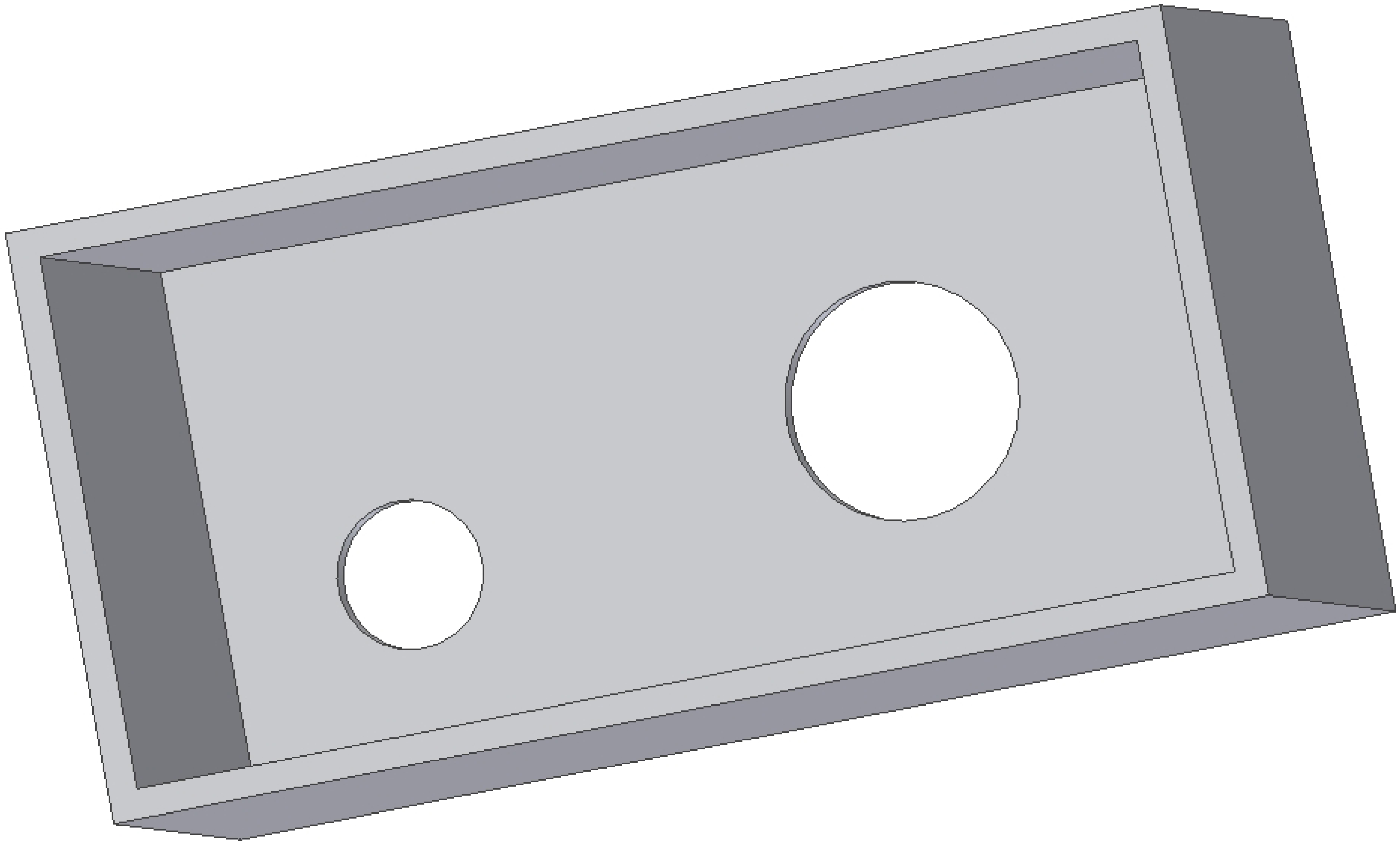
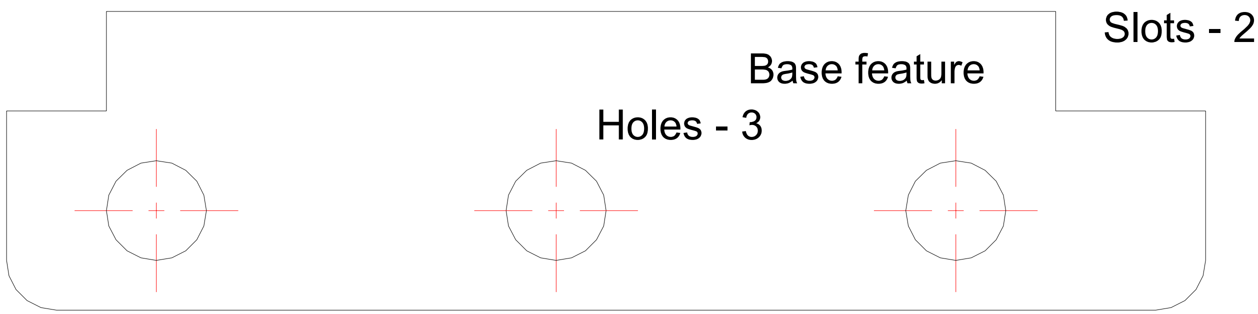
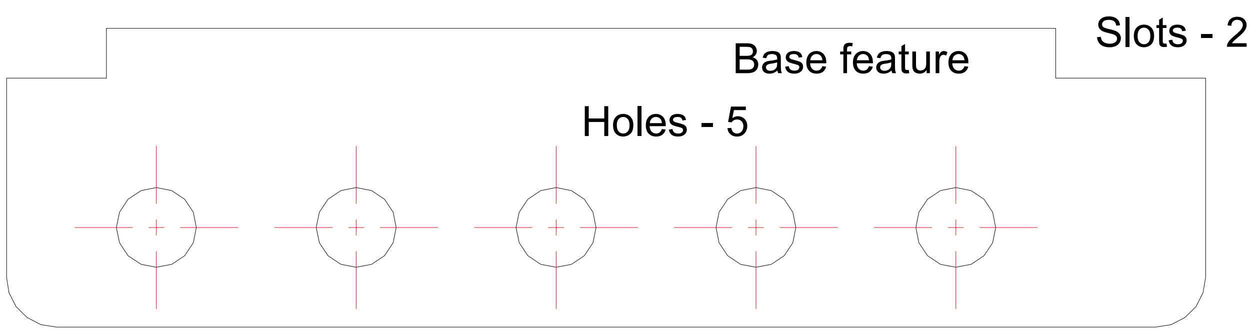


Fig. 4.37 Feature based model and its modified form



(A) Original model



(B) Modified model

Fig. 4.38 Typical drawing for the variant method of modelling

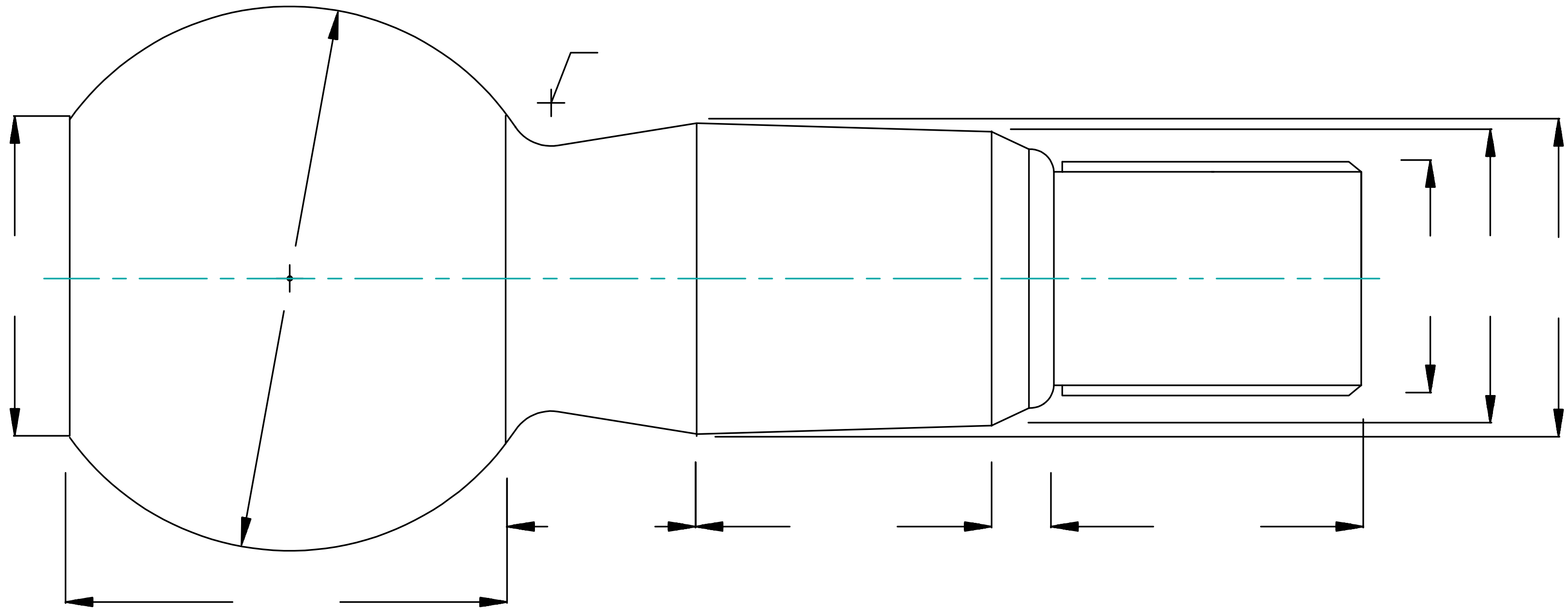


Fig. 4.39 Part model produced using the symbolic programming

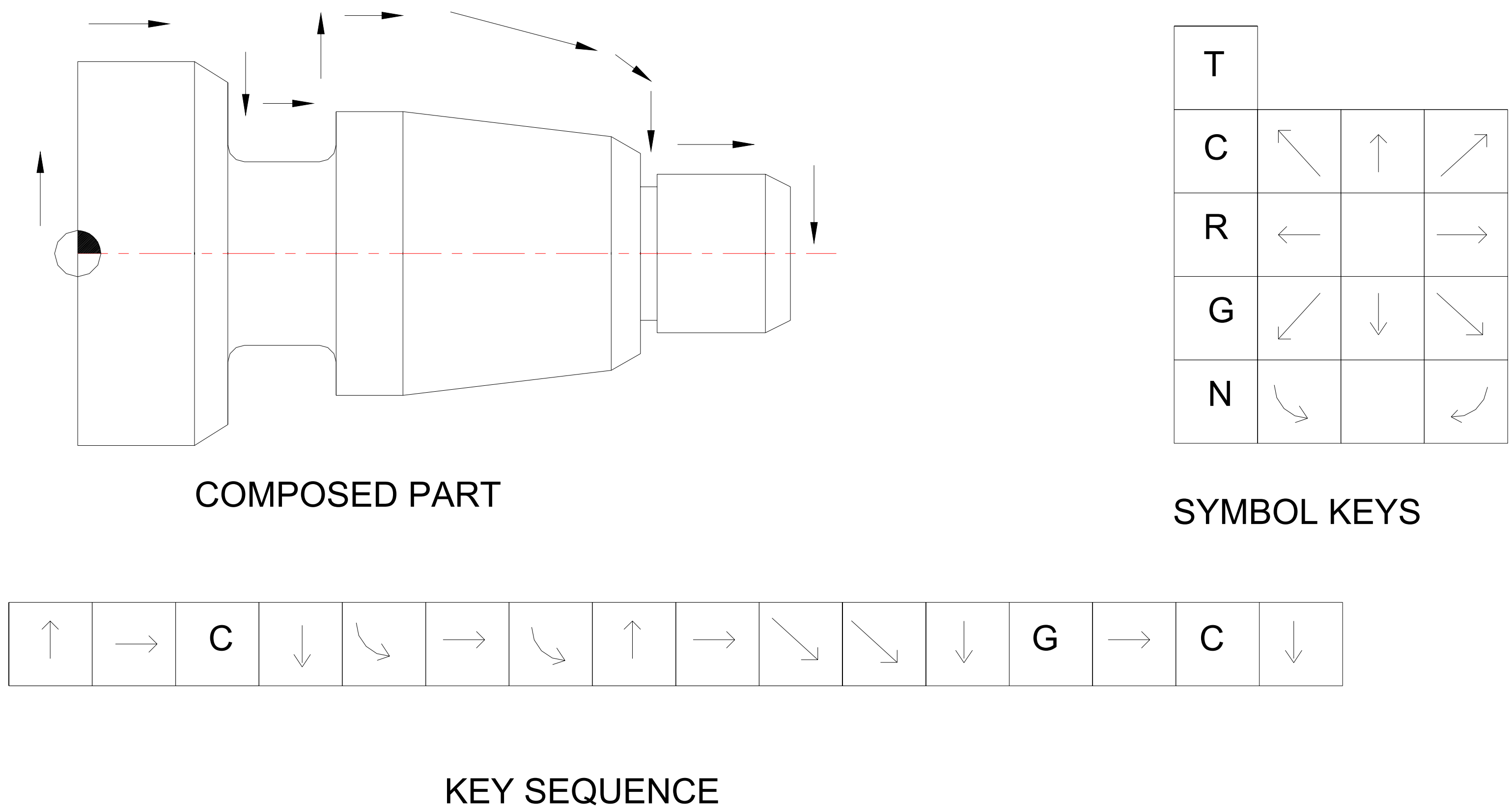


Fig. 4.40 Examples of form elements used for model generation in the case of axi-symmetric components

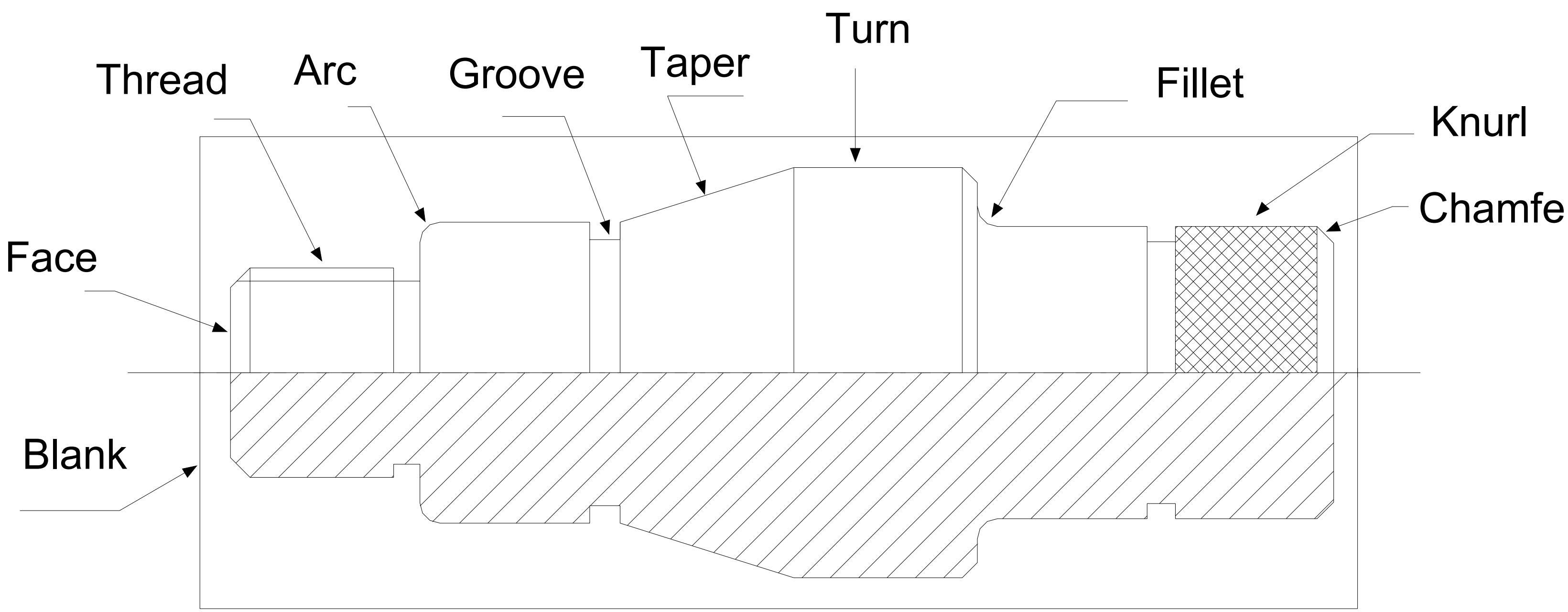


Fig. 4.41 Examples of form features for modelling axi-symmetric components with milled features

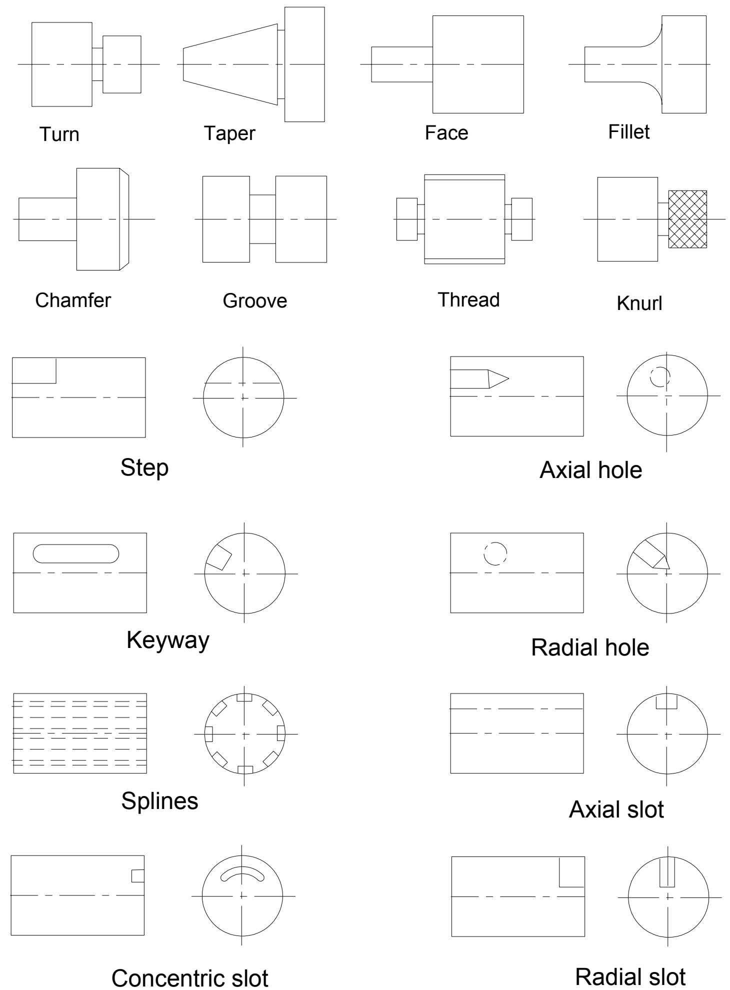


Fig. 4.42 Example component modelled using the features shown in Fig. 4.41

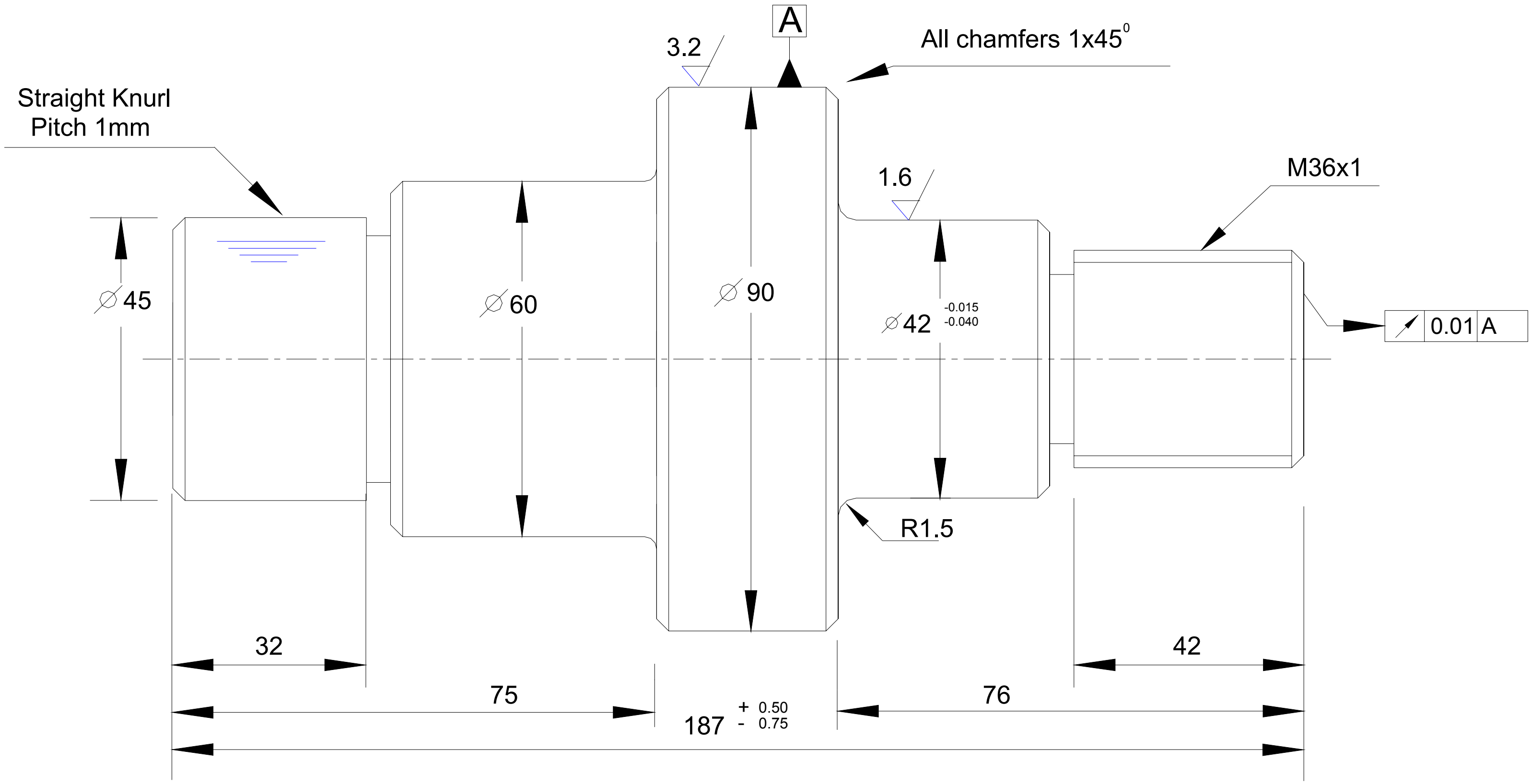
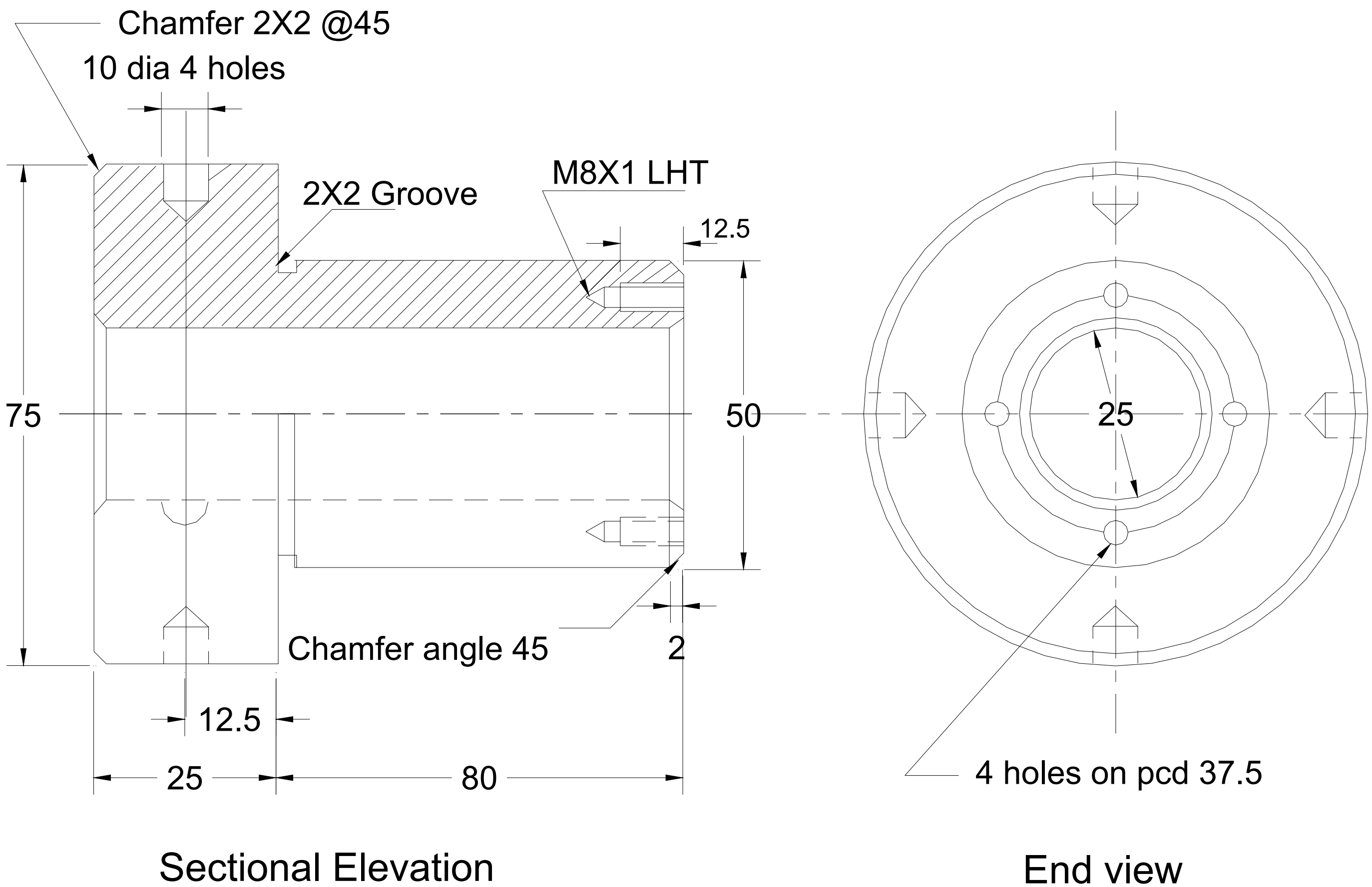


Fig. 4.43 Example component modelled using the features shown in Fig. 4.41



4.6 Curve representation

- Implicit form, and
- Parametric form.
- In parametric form, the curve is represented as
- $X = x(t)$
- $Y = y(t)$
- $Z = z(t)$

Fig. 4.44 Circle

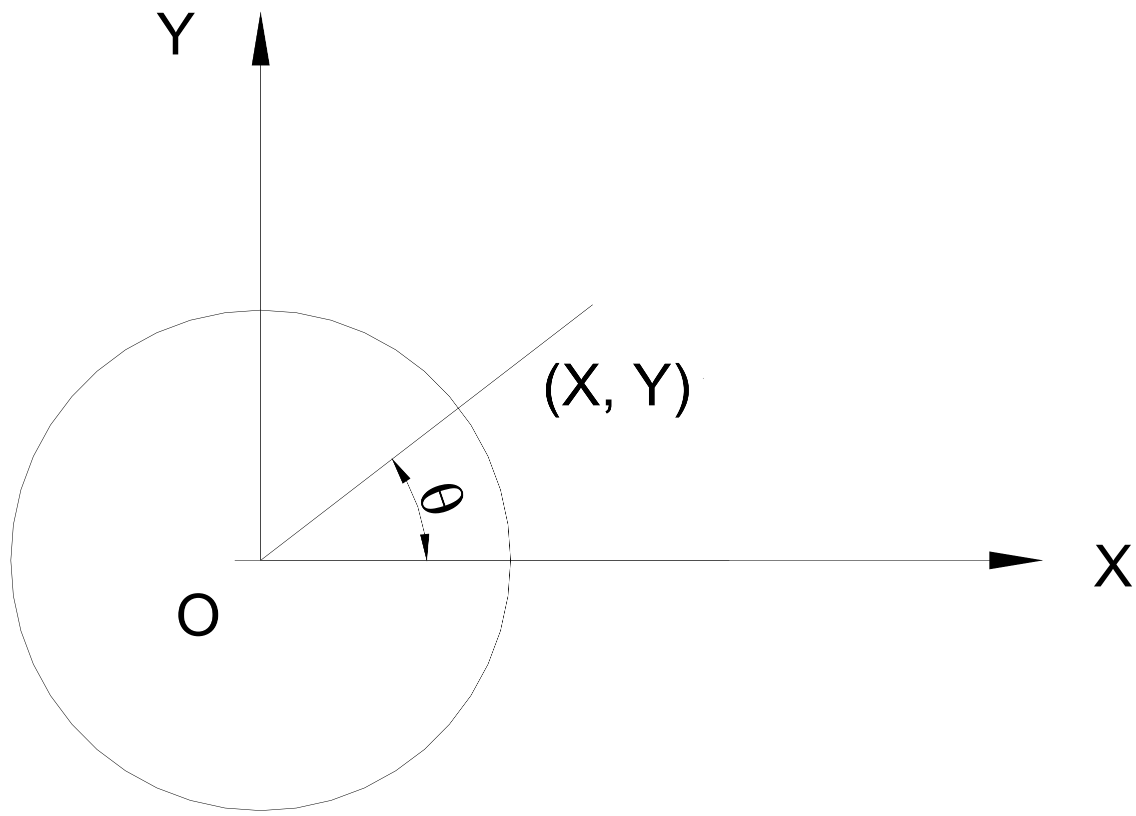
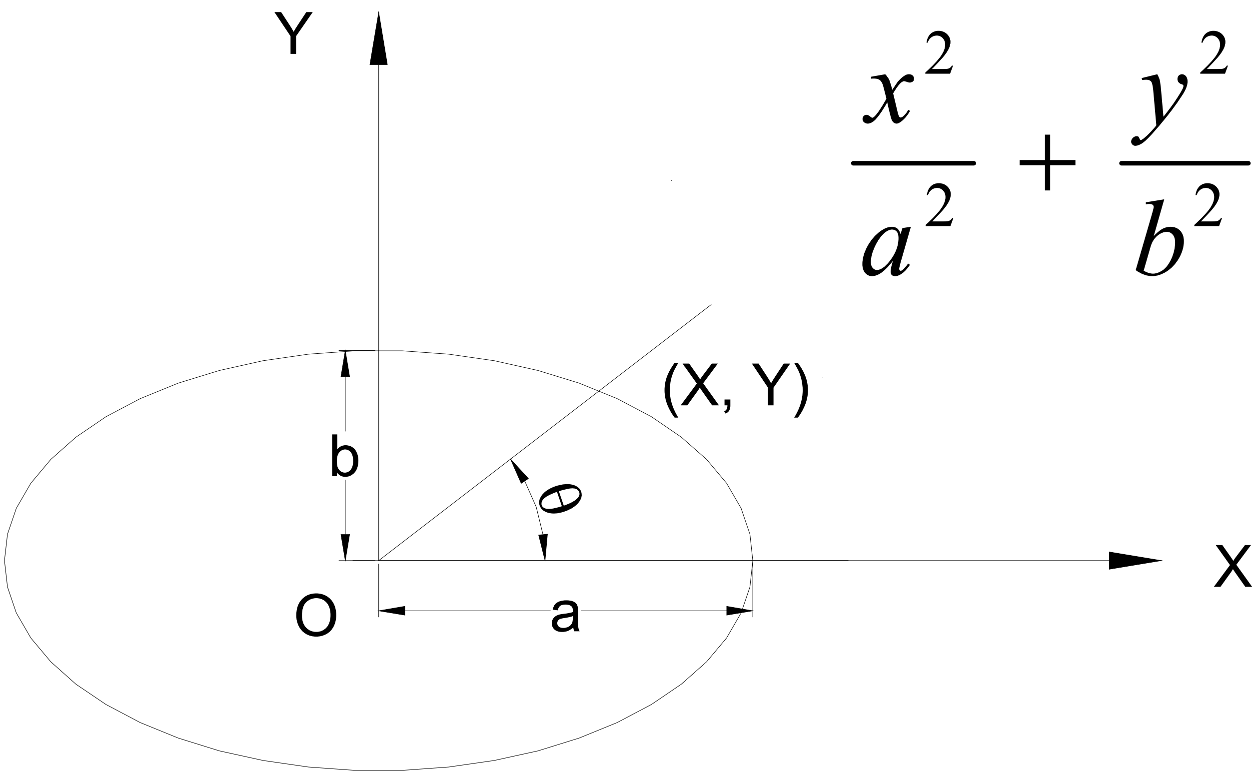


Fig. 4.45 Ellipse



$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

Fig. 4.46 Parametric curve representation in Cartesian space

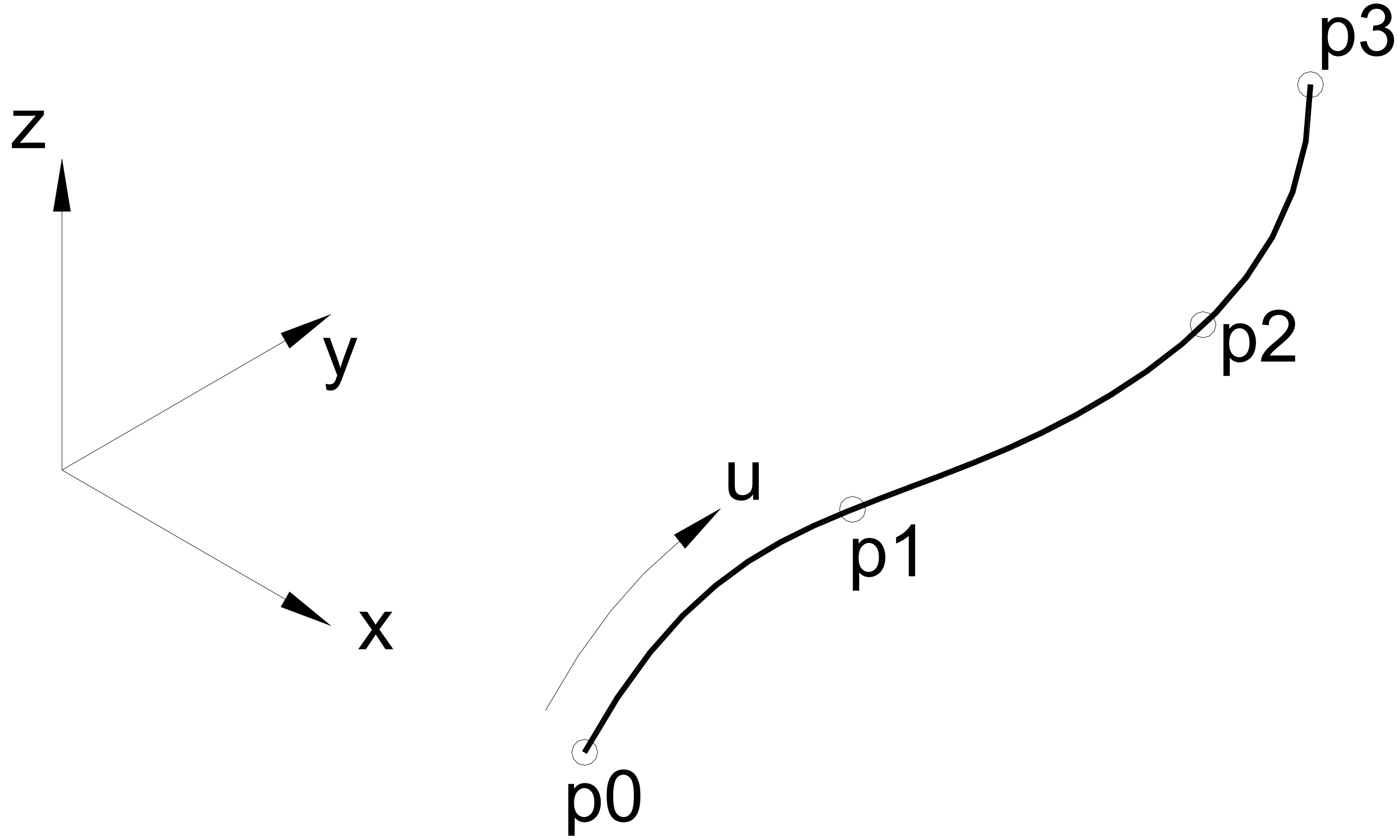
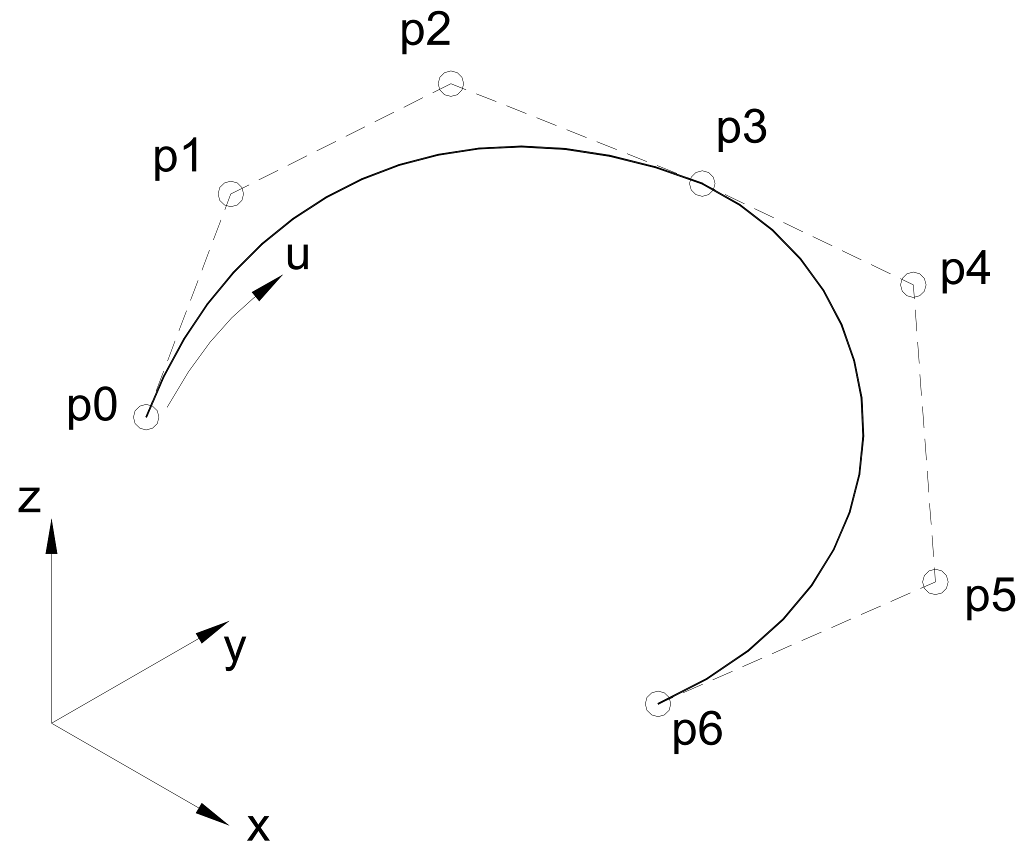


Fig. 4.47 Two cubic Bézier curves joined at p3



4.7 Surface Representation Methods

Fig. 4.48 Typical surface display with the parametric variables u and v

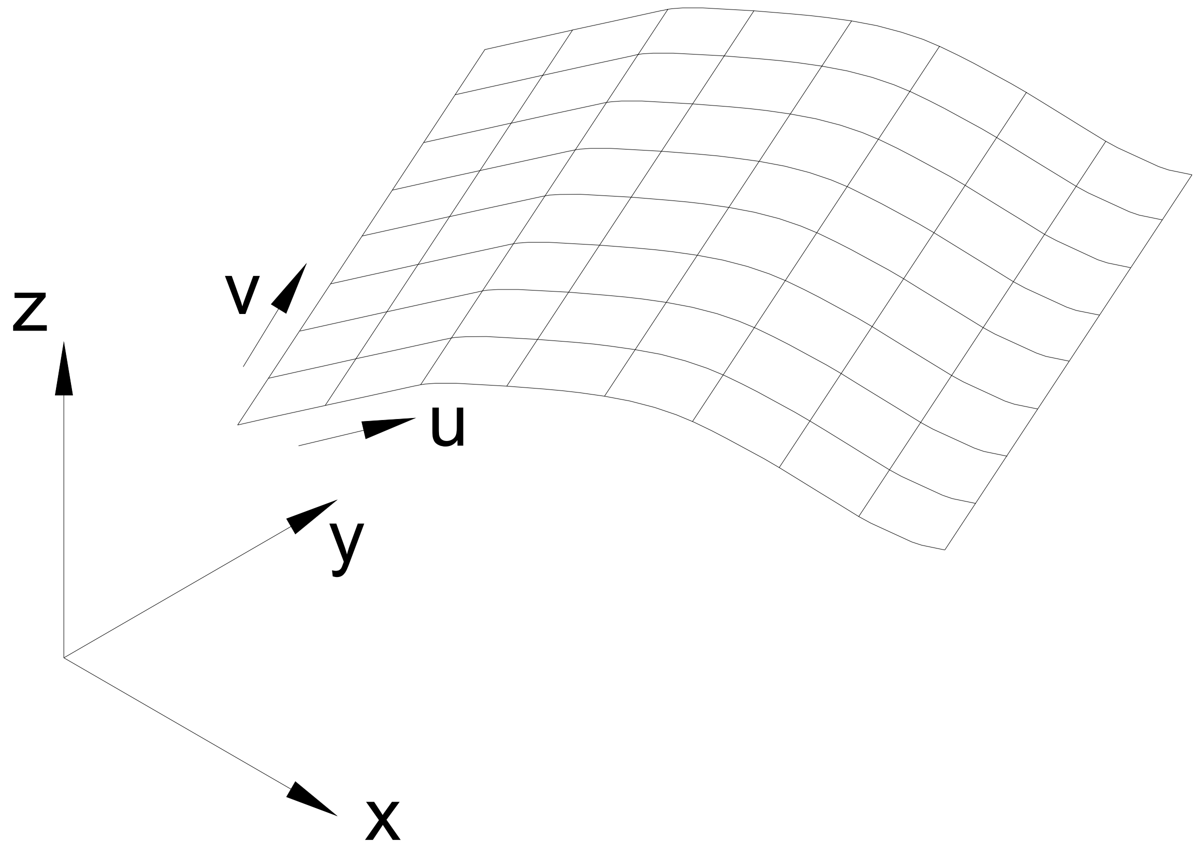
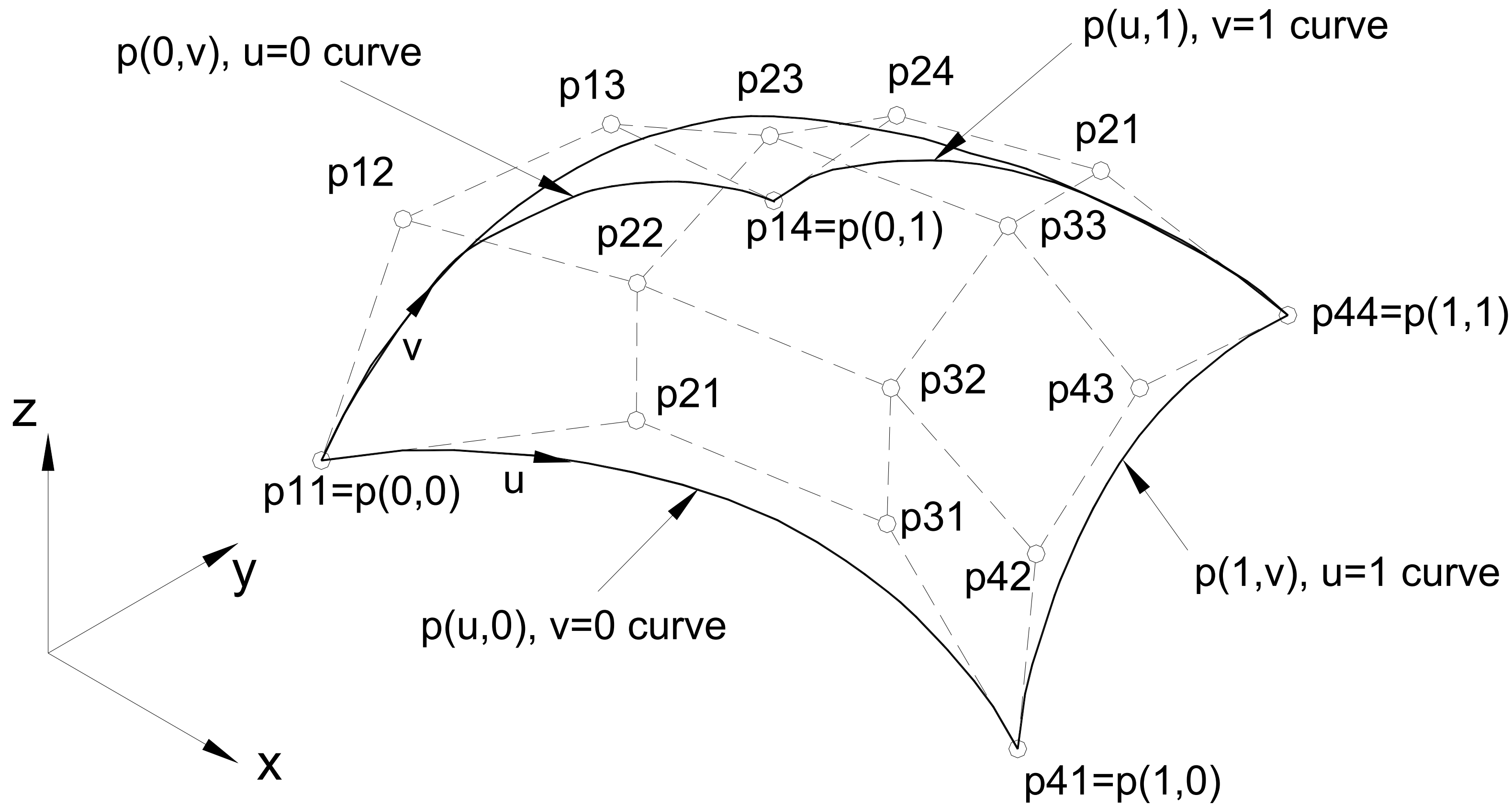


Fig. 4.49 A bi-cubic Bézier surface patch



4.8 Modelling Facilities Desired

- The geometric modelling features.
- The editing or manipulation features.
- The display control facilities.
- The drafting features.
- The programming facility.
- The analysis features.
- The connecting features.

Fig. 4.50 Elimination of hidden lines in display

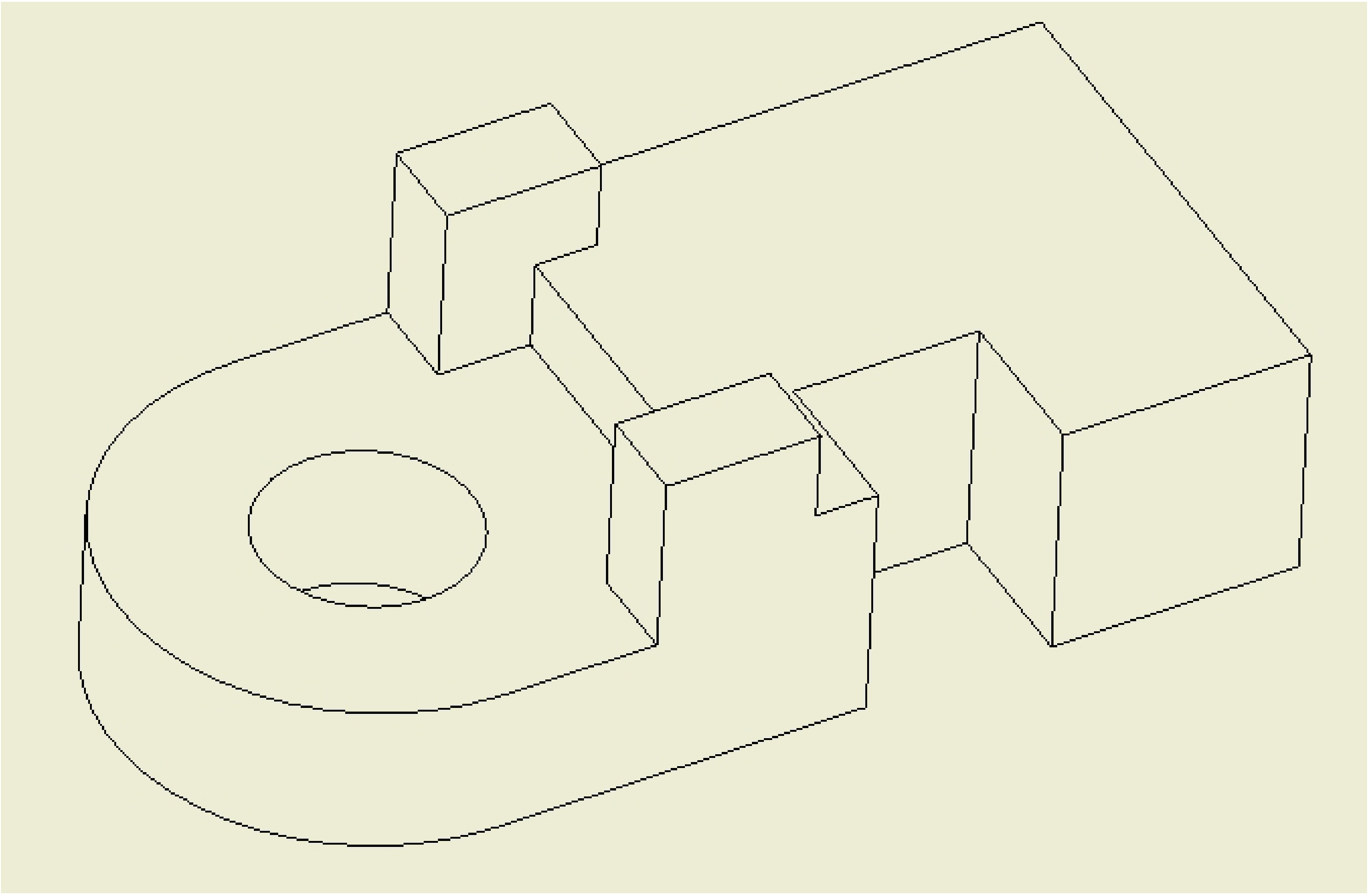


Fig. 4.51 Shaded image of a CAD geometric model ((Image appears with the permission of IBM World Trade Corporation/Dassault Systems - Model generated using CATIA))

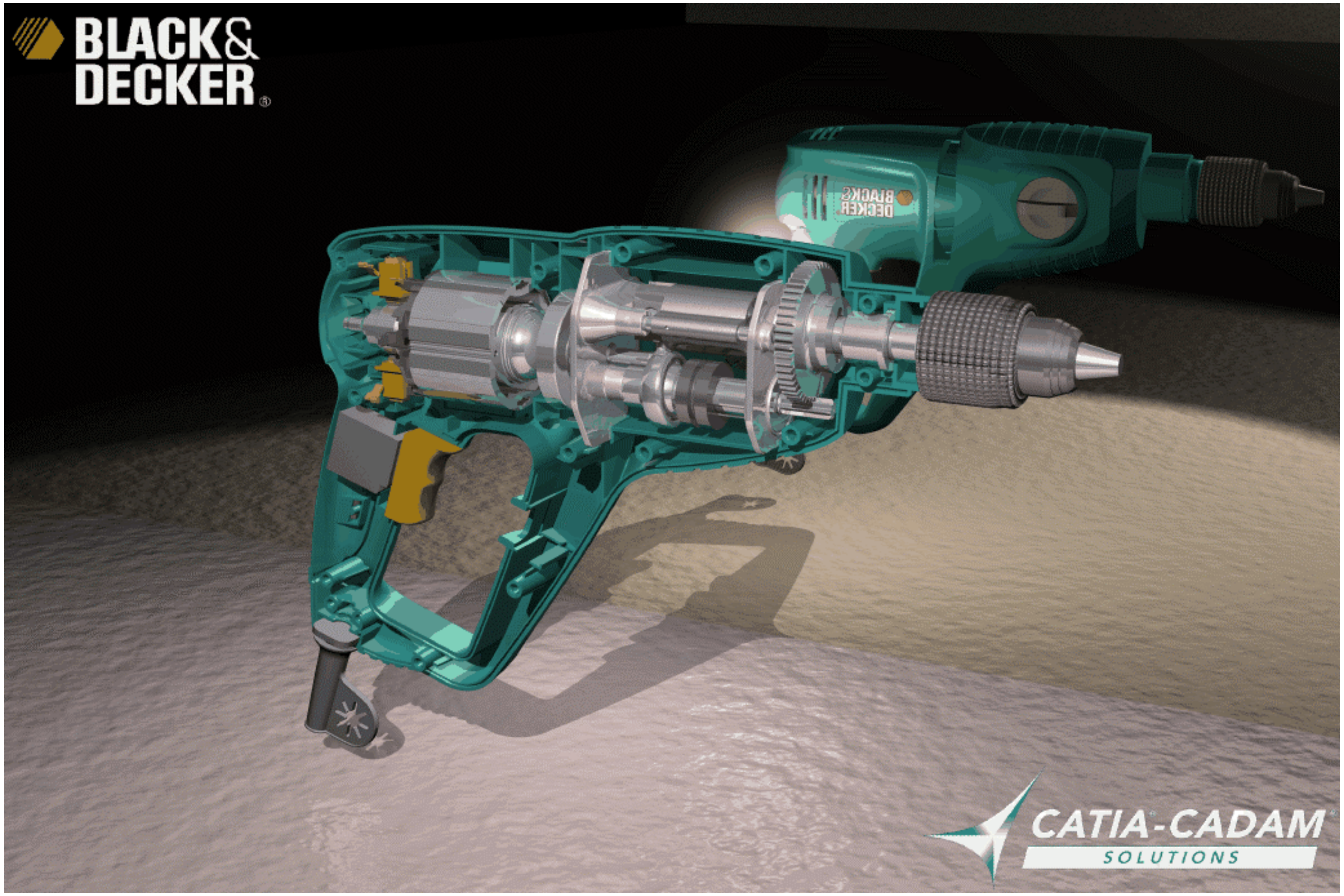


Fig. 4.52 Orthographic views from a geometric model (Image appears with the permission of IBM World Trade Corporation/Dassault Systems - Model generated using CATIA)

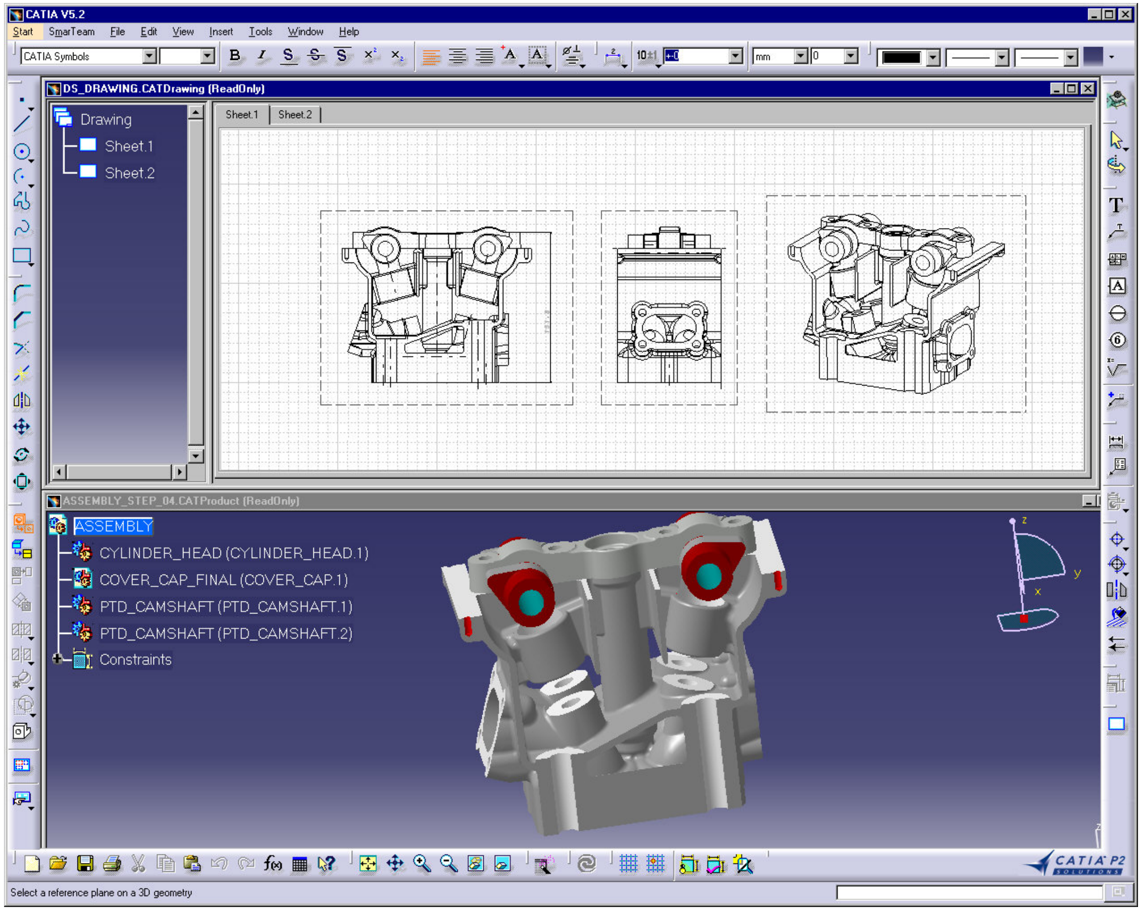


Fig. 4.53 Section view generation from a geometric model

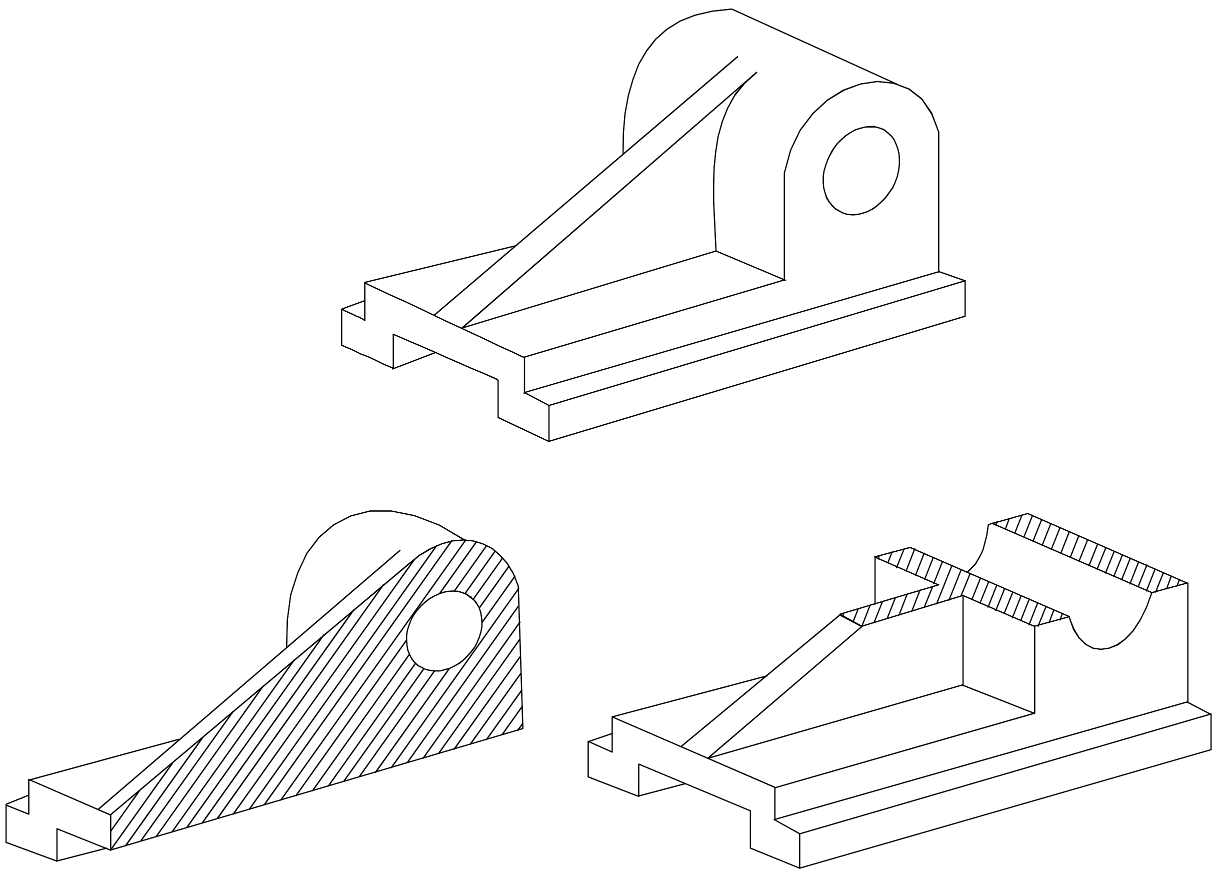
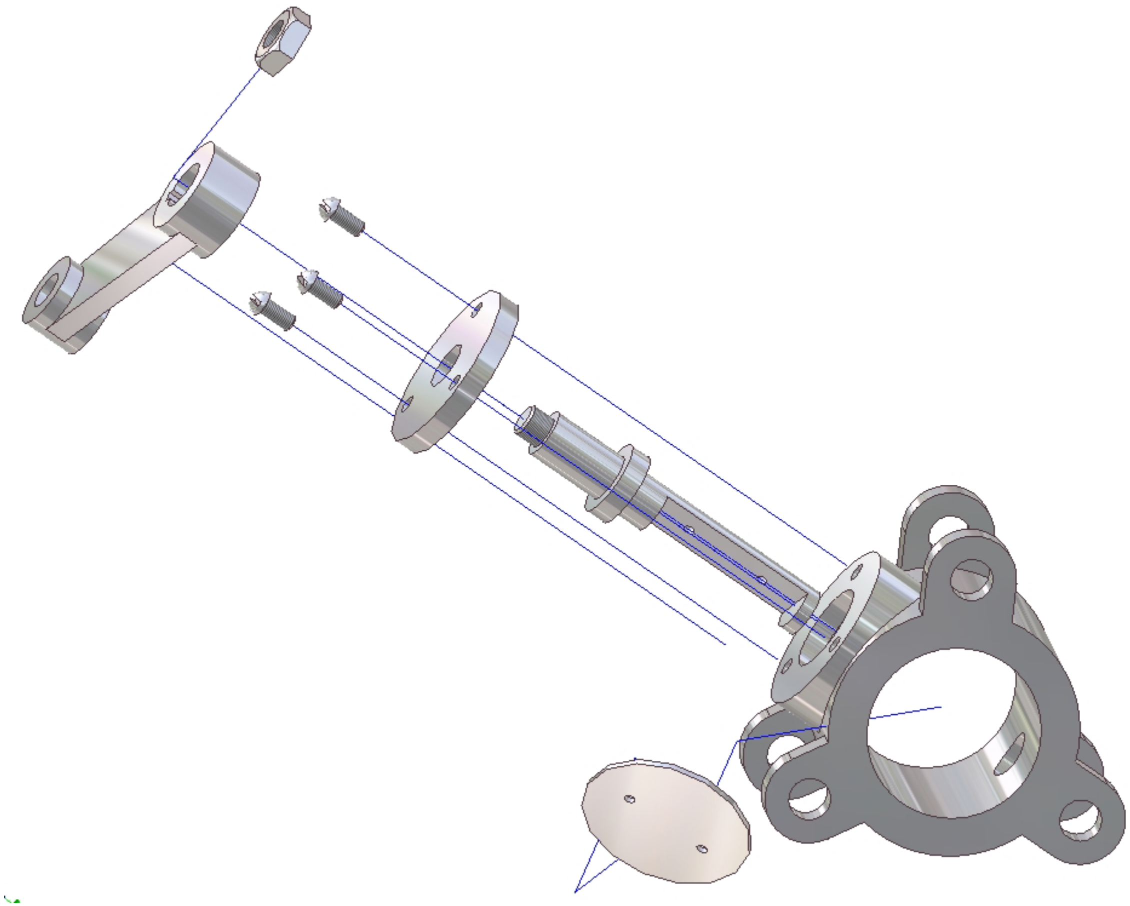


Fig. 4.54 Exploded view and bill of materials



4.9 Rapid Prototyping (RP)

Figure 4.55 Schematic of Stereolithography device

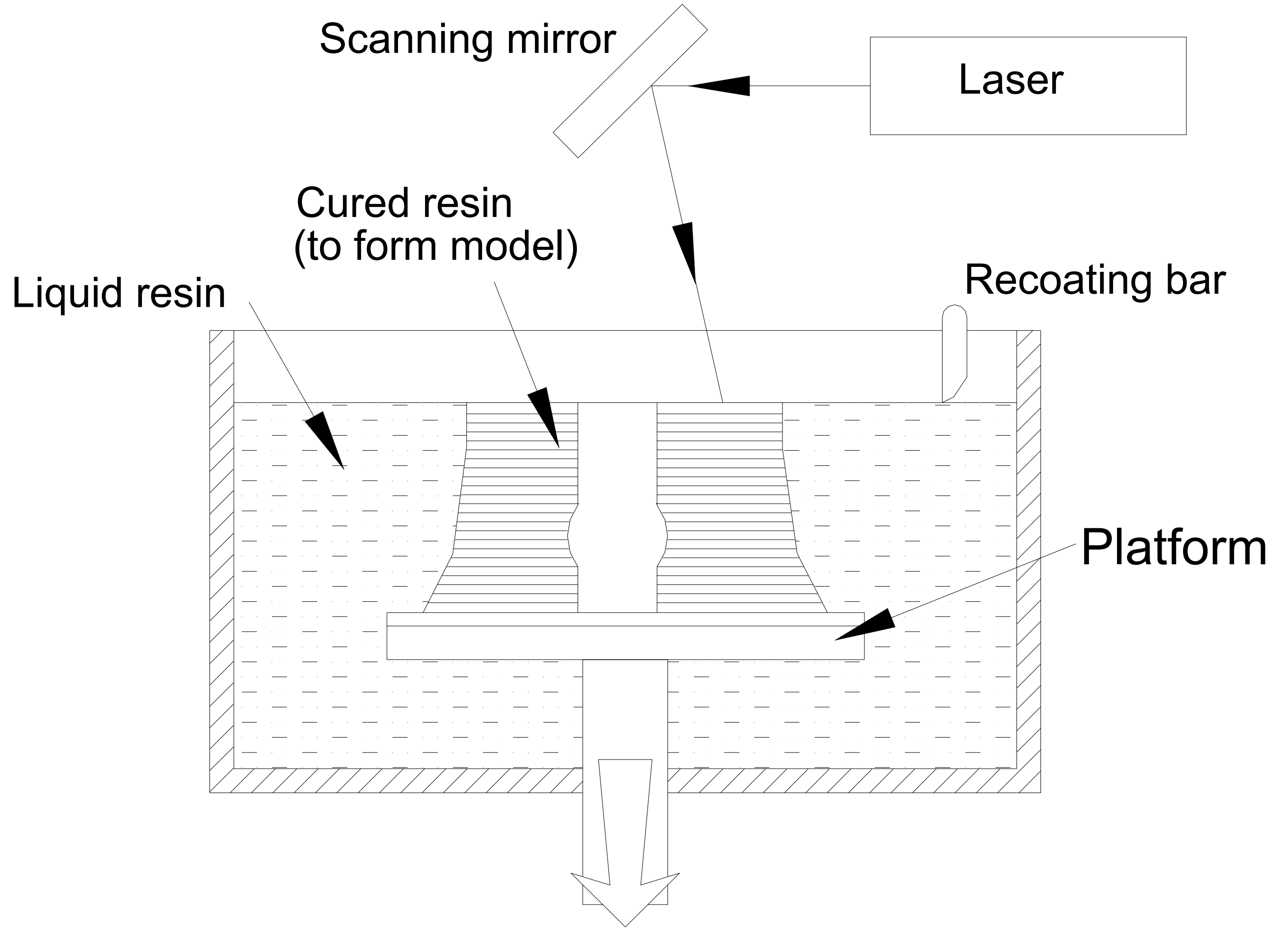


Figure 4.56 Schematic of selective laser sintering device

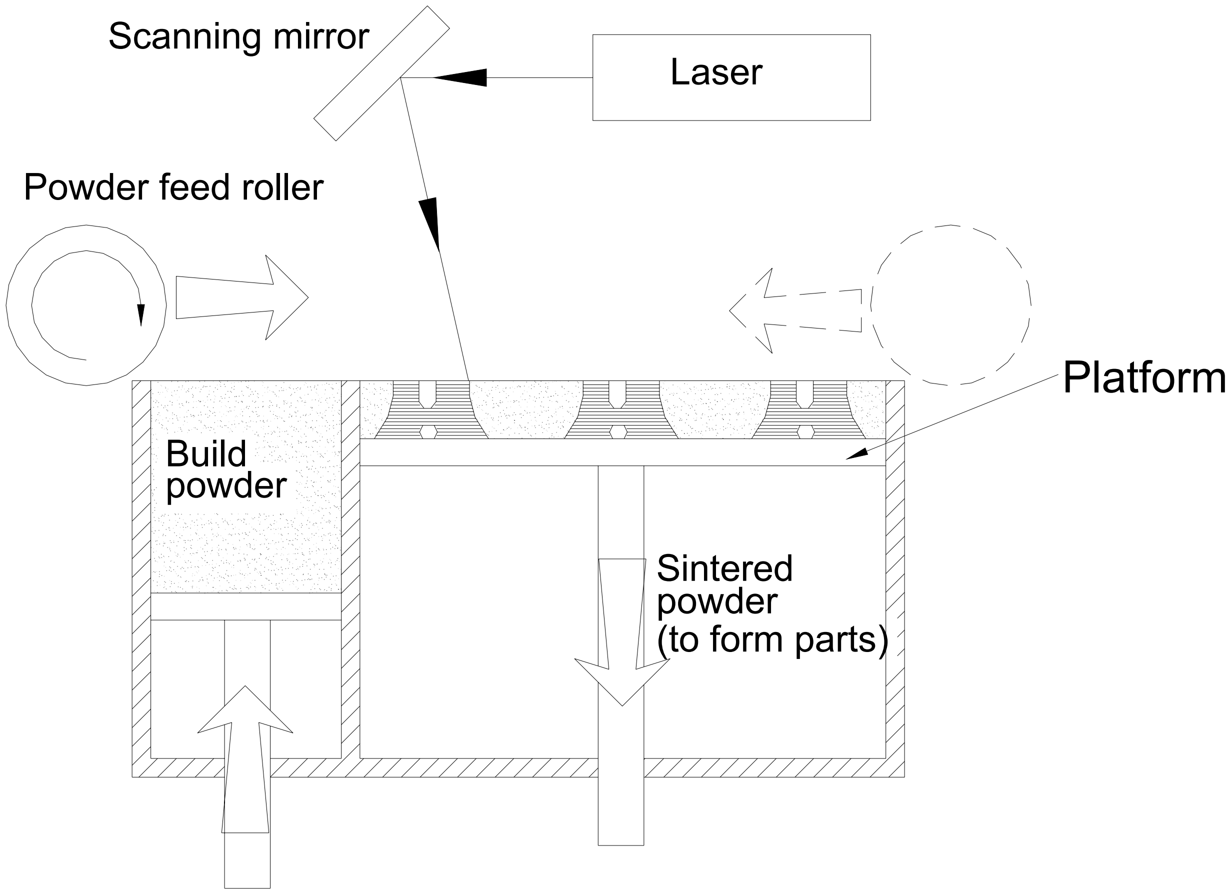


Figure 4.57 Schematic of Three-dimensional printing device

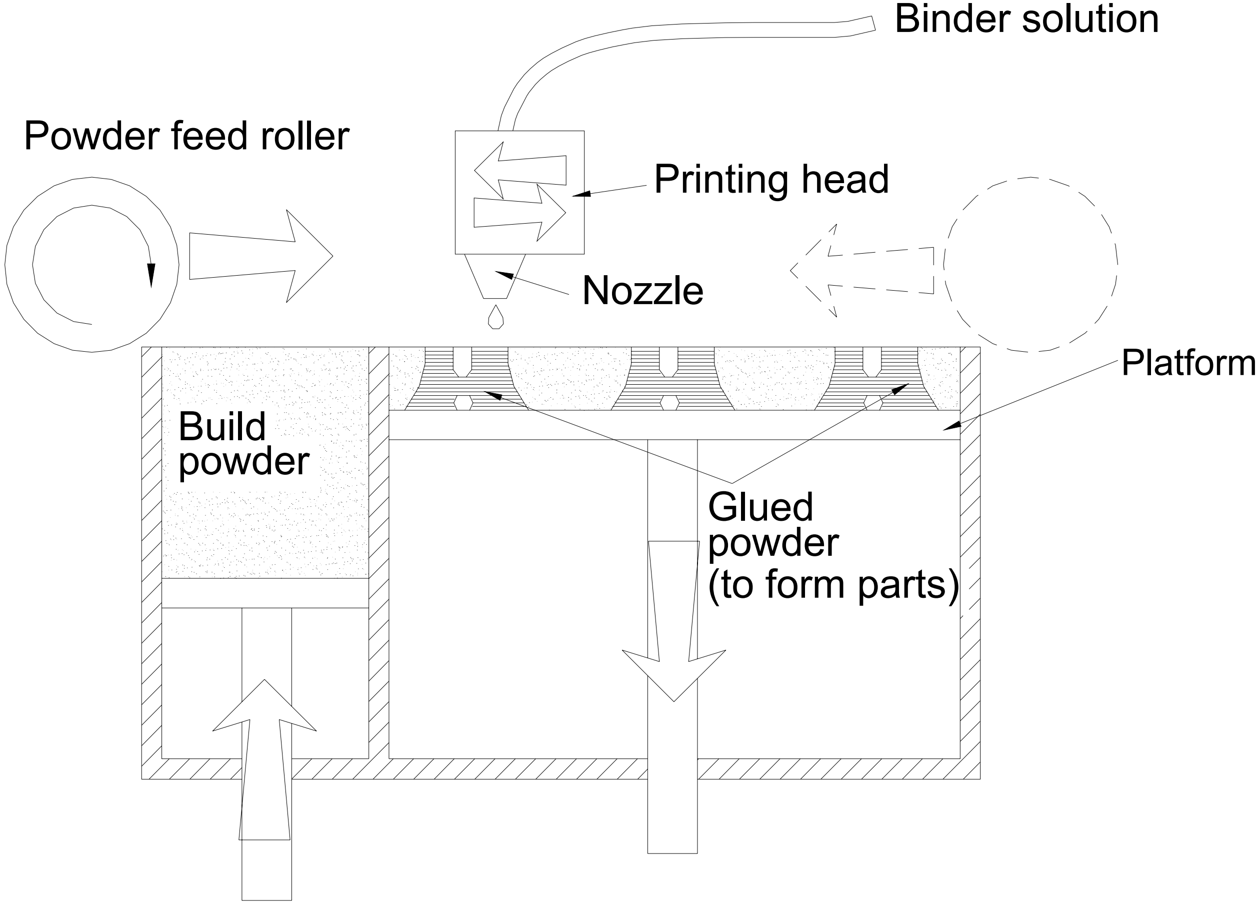


Fig. 4.58 Schematic of Fused deposition modelling device

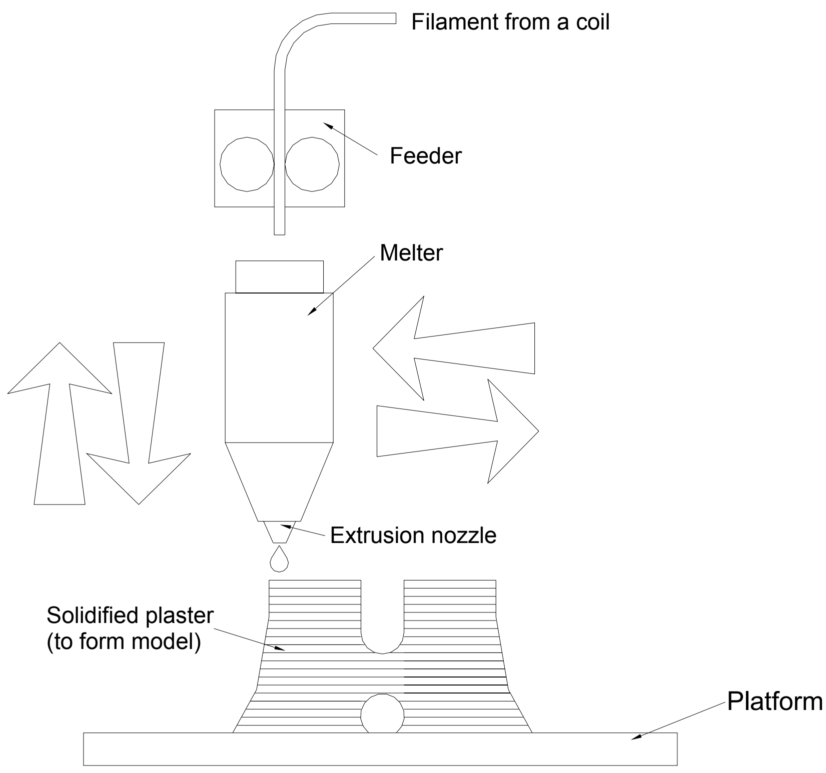
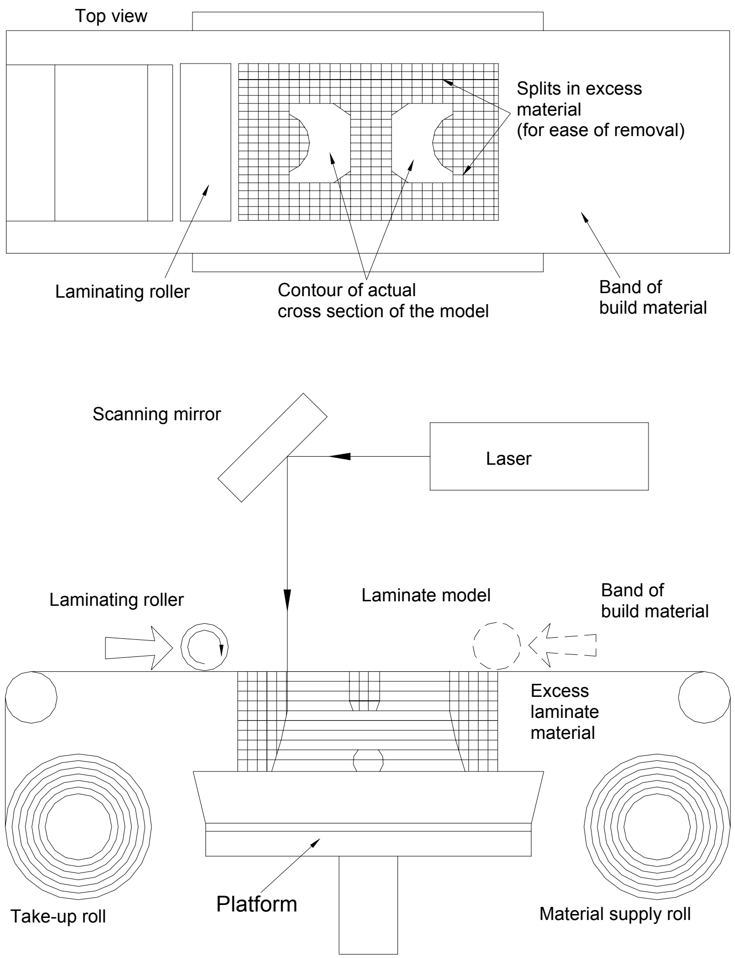


Fig. 4.59 Schematic of Laminated Object Manufacturing device



Summary

- Information entered through geometric modeling is utilized in a number of downstream applications such as drafting, manufacturing, inspection and planning.
- Geometric models are three types, viz line model, surface model and solid model. Line model though simple is rarely used because of the ambiguity present. Surface and solid models are extensively used in industrial applications.
- Among the geometric construction methods sweep or extrusion is most widely used, because of its simplicity and elegance in developing 3D models.
- Solid modeling provides the most unambiguous representation of the solid model, but is more computing intensive. However to get the correct geometric model, it is essential to utilize solid modeling approach.

Summary

- Surfaces are more widely used and it is necessary to use different types of surfaces such as b-splines, Bezier, NURB, lofted, to get the user requirements fulfilled.
- Constraint or parametric based modeling is the main methodology used by most of the 3D CAD systems. This system helps in grasping the designer’s intent and would greatly facilitate the modification and reuse of the existing designs.
- Some variant modeling systems are used based on tabular data for specific applications.
- Form features is another form of modeling system that helps in designing CAD systems with more intelligence built into the geometric entities that is possible by purely geometric systems discussed thus far.

Summary

- The mathematical representation of the geometric entities can be in implicit or parametric form, the latter being the preferred method used in CAD systems because of its easier adaptation in software development.
- The curve representation methods can be extended for surface representations such as used in free form surfaces.
- A number of modeling facilities need to be considered while selecting a CAD/CAM system for any given application.
- Rapid prototyping is used to generate the product directly from the 3D CAD model data. A number of different processes such as stereo lithography, selective laser sintering, 3D printing, fused deposition modeling, laminated object manufacturing, are used for this purpose.