A Laboratory Manual for

RAPID PROTOTYPING (3171926)

B.E. Semester 7 (Mechanical)

Directorate of Technical Education, Gandhinagar, Gujarat

Vision of the DTE

- To provide globally competitive technical education;
- Remove geographical imbalances and inconsistencies;
- Develop student friendly resources with a special focus on girls' education and support to weaker sections;
- Develop programs relevant to industry and create a vibrant pool of technical professionals.

Vision of the Institute

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MECHANICAL ENGINEERING DEPARTMENT

Vision of the Department

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Lukhdhirji Engineering College, Morbi

Certificate

This is to certify that Mr./Ms. ____ _________ Enrollment No. _________________ of B.E. Semester _____Mechanical Engineering of this Institute (GTU Code: _____) has satisfactorily completed the Practical / Tutorial work for the subject **Rapid Prototyping (3171926)** for the academic year 2022-23.

Place: ___________

Date: ___________

Name and Sign of Faculty member

Head of the Department

Preface

Main motto of any laboratory/practical/field work is for enhancing required skills as well as creating ability amongst students to solve real time problem by developing relevant competencies in psychomotor domain. By keeping in view, GTU has designed competency focused outcome-based curriculum for engineering degree programs where sufficient weightage is given to practical work. It shows importance of enhancement of skills amongst the students and it pays attention to utilize every second of time allotted for practical amongst students, instructors and faculty members to achieve relevant outcomes by performing the experiments rather than having merely study type experiments. It is must for effective implementation of competency focused outcome-based curriculum that every practical is keenly designed to serve as a tool to develop and enhance relevant competency required by the various industry among every student. These psychomotor skills are very difficult to develop through traditional chalk and board content delivery method in the classroom. Accordingly, this lab manual is designed to focus on the industry defined relevant outcomes, rather than old practice of conducting practical to prove concept and theory.

By using this lab manual students can go through the relevant theory and procedure in advance before the actual performance which creates an interest and students can have basic idea prior to performance. This in turn enhances pre-determined outcomes amongst students. Each experiment in this manual begins with competency, industry relevant skills, course outcomes as well as practical outcomes (objectives). The students will also achieve safety and necessary precautions to be taken while performing practical.

This manual also provides guidelines to faculty members to facilitate student centric lab activities through each experiment by arranging and managing necessary resources in order that the students follow the procedures with required safety and necessary precautions to achieve the outcomes. It also gives an idea that how students will be assessed by providing rubrics.

Rapid Prototyping is a dynamic and innovative subject that revolutionizes the traditional product development process. It involves the swift creation of tangible prototypes using advanced technologies like 3D printing and computer-aided design (CAD). This iterative approach allows designers and engineers to quickly visualize, test, and refine their ideas, accelerating innovation and driving advancements across various industries. Through this subject, students will explore the methods, tools, and applications of Rapid Prototyping, gaining the skills to bring their creative visions to life in a faster, more cost-effective manner.

Utmost care has been taken while preparing this lab manual however always there is chances of improvement. Therefore, we welcome constructive suggestions for improvement and removal of errors if any.

Rapid Prototyping (3171926)

Practical – Course Outcome matrix

Course Outcomes (COs):

Sr. No.	CO statement
CO-1	Distinguish RP and other related technology.
CO-2	Understand and use techniques for processing of CAD models for rapid Prototyping.
CO-3	Apply fundamentals of rapid prototyping techniques.
CO-4	Use appropriate tooling for rapid prototyping process.
CO-5	Create component with RP applications.

Sr. No.	Objective(s) of Experiment	CO 1	CO 2	CO 3	CO 4	CO 5
1.	Review of CAD modeling technique and Introduction to Rapid prototyping	√				
2.	Generating STL files from the CAD models & Working on STL files.		√			
3.	Processing the CAD data in Catalyst software (Selection of Orientation, Supports generation, Slicing, Tool path generation)		√			
4.	Simulation in Catalyst Software			√		
5.	Fabrication the physical part on a RP machine			√		
6.	Learning techniques for fabricating an assembly.				√	
7.	Prepare a CAD model with complex geometry and Study effect of slicing parameters on final product manufactured through RP.					√
8.	Assignments					

Industry Relevant Skills

The following industry relevant competencies are expected to be developed in the student by undertaking the practical work of this laboratory.

1. To aware about CAD software
2. To aware about graphics standard

Guidelines for Faculty members

1. Teacher should provide the guideline with demonstration of practical to the students with all features.
2. Teacher shall explain basic concepts/theory related to the experiment to the students before starting of each practical
3. Involve all the students in performance of each experiment.
4. Teacher is expected to share the skills and competencies to be developed in the students and ensure that the respective skills and competencies are developed in the students after the completion of the experimentation.
5. Teachers should give opportunity to students for hands-on experience after the demonstration.
6. Teacher may provide additional knowledge and skills to the students even though not covered in the manual but are expected from the students by concerned industry.
7. Give practical assignment and assess the performance of students based on task assigned to check whether it is as per the instructions or not.
8. Teacher is expected to refer complete curriculum of the course and follow the guidelines for implementation.

Instructions for Students

1. Students are expected to carefully listen to all the theory classes delivered by the faculty members and understand the COs, content of the course, teaching and examination scheme, skill set to be developed etc.
2. Students shall organize the work in the group and make record of all observations.
3. Students shall develop maintenance skill as expected by industries.
4. Student shall attempt to develop related hand-on skills and build confidence.
5. Student shall develop the habits of evolving more ideas, innovations, skills etc. apart from those included in scope of manual.
6. Student shall refer technical magazines and data books.
7. Student should develop a habit of submitting the experimentation work as per the schedule and s/he should be well prepared for the same.

Common Safety Instructions

In a Rapid Prototyping Lab, safety is of importance to ensure the well-being of individuals and the proper functioning of equipment. By adhering to these safety instructions and exercising caution, individuals can create a safer environment for working with rapid prototyping equipment, minimizing risks and ensuring successful outcomes in the lab.

Index
(Progressive Assessment Sheet)
Mechanical Engineering Department

Sr. No.	Objective(s) of Experiment	Page No.	Date of performance	Date of submission	Assessment Marks	Sign. of Teacher with date	Remarks
1.	Review of CAD modeling technique and Introduction to Rapid prototyping						
2.	Generating STL files from the CAD models & Working on STL files.						
3.	Processing the CAD data in Catalyst software (Selection of Orientation, Supports generation, Slicing, Tool path generation)						
4.	Simulation in Catalyst Software						
5.	Fabrication the physical part on a RP machine						
6.	Learning techniques for fabricating an assembly.						
7.	Prepare a CAD model with complex geometry and Study effect of slicing parameters on final product manufactured through RP.						
8.	Assignments						

BE SEM VII (MECHANICAL)

Subject: Rapid Prototyping (3171926)

Sr. No.	Title	CO
1	Review of CAD modeling technique and Introduction to Rapid prototyping	1
2	Generating STL files from the CAD models & Working on STL files.	2
3	Processing the CAD data in Catalyst software (Selection of Orientation, Supports generation, Slicing, Tool path generation)	2
4	Simulation in Catalyst Software	3
5	Fabrication the physical part on a RP machine	3
6	Learning techniques for fabricating an assembly.	4
7	Prepare a CAD model with complex geometry and Study effect of slicing parameters on final product manufactured through RP.	5
8	Assignments	

Experiment -1

Review of CAD modeling technique and Introduction to Rapid prototyping

Objective: (a) To understand the basic of Rapid prototyping

(b) To differentiate rapid prototyping technique

Relevant CO: Distinguish RP and other related technology

1.1 CAD Modeling

A CAD Model is a computer representation of an object or part. It contains all of the design information including geometry, tolerances, materials and manufacturing information. A 3D Model is the most general model used in CAD software. There are many geometric models such as wireframe; surface and solid model are available. Modeling techniques are decided based on the expected utilization of the resulting database later in the design and manufacturing process.

There are three types of 3D techniques methods.

a) Wireframe Modeling b) Surface Modeling c) Solid Modeling

a) Wireframe Modeling

It is the simplest geometrical model an object and used to represent mathematically in the computer. It is also called edge representation. Wireframe model consists of points, lines, arcs and circles, conics and curves. It doesn't require much computer time and memory and hence is considered to be the simplest. The major disadvantage is the ambiguous representation of real object and purely depends on human interpretation. In fact, the interpretation of the correct object becomes difficult in the case of complex model. This limits the application of wireframe models from engineering viewpoint.

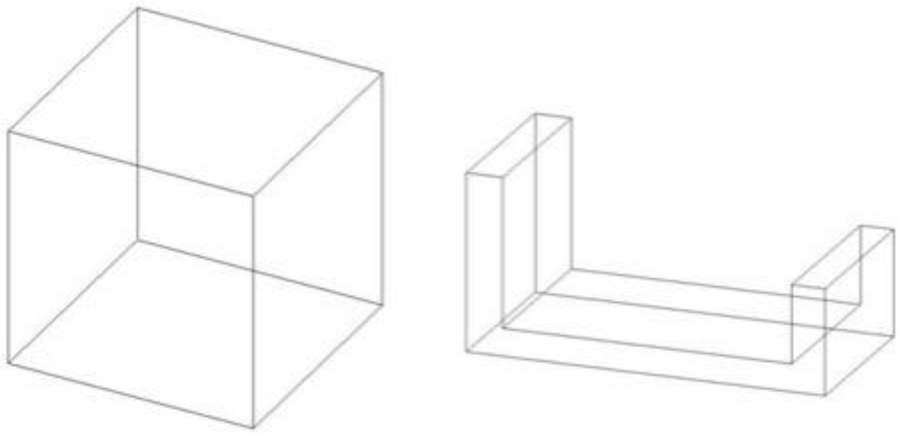


Fig. 1.1 Wire frame model

b) Surface Modelling

Shape design and representation of complex object such as bodies of car, ship, airplane etc can't be represented by wireframe model. In such cases surface models are to be used for precise and accurately representation. In comparison to wireframe model, surface models of an object provide more complete and less ambiguous representation. In the surface model, the geometry of the object is defined without storing any information about topology. For example if two surfaces are joined, they share one wireframe entities edge. But neither the surface nor the entities store such information. Surface representation can be done in both parametric and nonparametric form. In order to use surface for both computation and programming purpose, it is required to develop proper equation and algorithms.

Types of surface available in CAD/CAM systems are, Plane surface, Ruled surface, Surface of revolution, Tabulated cylinder, Bezier surface, B-spline surface, Coons patch, Fillet surface, and Offset surface.

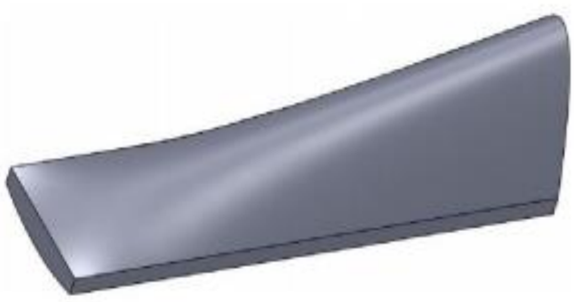


Fig. 1.2 Surface Model

c) Solid Model

A solid model of an object provides more complete representation than its surface model. The database of the solid model stores geometric data and topological information of the corresponding object. Geometry is the actual dimension that defines entities of the object whereas topology on the other hand is the connectivity and associativity of the object

For creating solid models of objects various representation schemes have been designed and developed. Such scheme are, Half space model, Boundary representation, Constructive solid geometry, Sweeping, Analytic Solid modeling, Cell decomposition, Spatial enumeration, Octree Encoding, Primitive Instancing. Boundary representation, Constructive solid geometry, Sweeping are the most commonly used schemes

Boundary Representation

Boundary representation is one of the most popular representation schemes widely used to create solid model. A boundary model is based on the topological notion that a physical object is bounded by a set of faces. These faces are regions or subsets of closed and orientable surfaces. An orientable surface is one in which it is possible to distinguish two sides by using the direction of surface normal to point to the inside or outside of the solid model under construction. Each face is bounded by edges and each edge is bounded by vertices. The data base of boundary model contains both geometry and topology**.**

Constructive solid geometry (CSG)

According to CSG model a physical object can be divided in two set of primitives (basic element or shapes) that can be combined in certain order following a set of rules (Boolean operation) to form the object as shown in Fig.1.3. Primitives are also valid CSG model. Each primitive is bounded by a set of surfaces usually close and orientable. Through boundary evaluation process, the primitive surfaces are combined and the boundary of the object is formed in turn, the faces edges and vertices are obtained.

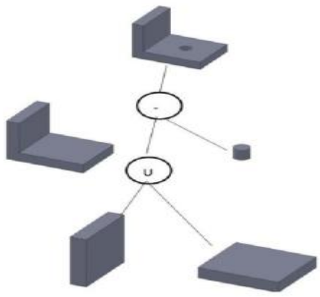


Fig. 1.3 Constructive Solid Geometry

1.2 Introduction to Rapid Prototyping

Rapid prototyping technologies are able to produce physical model in a layer by layer manner directly from their CAD models without any tools, dies and fixtures and also with little human intervention. RP is capable to fabricate parts quickly with too complex shape easily as compared to traditional manufacturing technology.

RP is capable to fabricate parts quickly with too complex shape easily as compared to traditional manufacturing technology. RP helps in earlier detection and reduction of design errors.

1.3 Principle of Rapid Prototyping

The principal of RP is illustrated in fig. 1(a). The CAD model of the object shown in fig.1 (a) is sliced by parallel planes. The edges of the slices thus obtained 1(b) are squared 1(b). Thus a complex 3D object is decomposed into several 2D objects or slices. In other words, a complex 3D manufacturing problem is converted into several simple 2D manufacturing problems. These slices are physically realized in one of several ways, stacked and pasted together as shown in fig. 1(D), to obtain the physical prototype 1(e). The accuracy of these prototypes, due to the staircase effect, can be improved by decreasing the slice thickness. For even better finish, polishing can be applied1 (f). Each physical layer will be placed over the previous one. If the previous layer is smaller than the current one, then it will not be able to fully support the current layer. For this purpose, a complementary shaped sacrificial layer of a different material is deposited and fused to the previous layer using one of several available deposition and fusion technologies. The sacrificial material has two primary roles: first, it holds the part, analogous to a fixture in traditional fabrication techniques: second, it serves as a substrate upon which unconnected regions and overhanging features can be deposited.

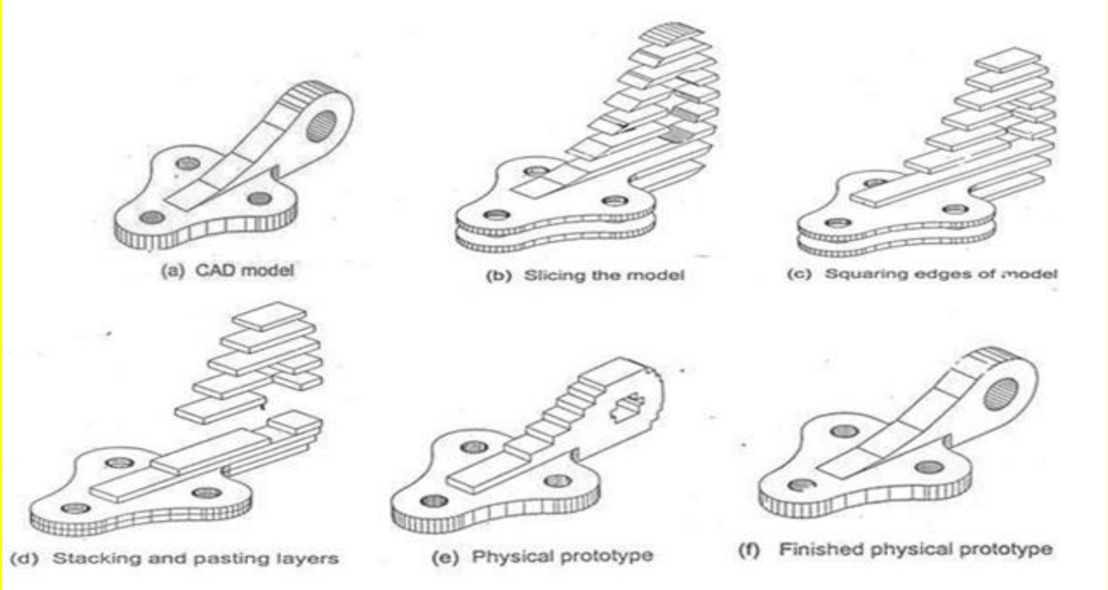


Fig. 1.4 Different models

The unconnected regions require this support since they are not joined with the main body until subsequent layer are deposited. Another use of sacrificial material is to form blind cavities in the part. The collection of this sacrificial layer is called support structure.

1.4 Rapid Prototyping Steps

There are many different RP processes, but the basic operating principles are very similar. Figure shows the data-flow diagram of the basic process. It includes the following steps:

1. Construct the CAD model
2. Convert the CAD model to STL format
3. Check and fix STL file
4. Generate support structures if needed
5. Slice the STL file to form layers
6. Produce physical model
7. Remove support structures

8. Post-process the physical model

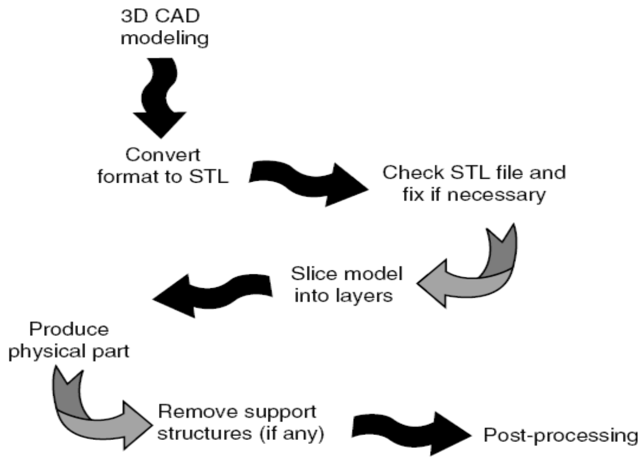


Fig. 1.5 Data Flow of the Basic RP Process

1.5 Classification of Rapid Prototyping Systems:

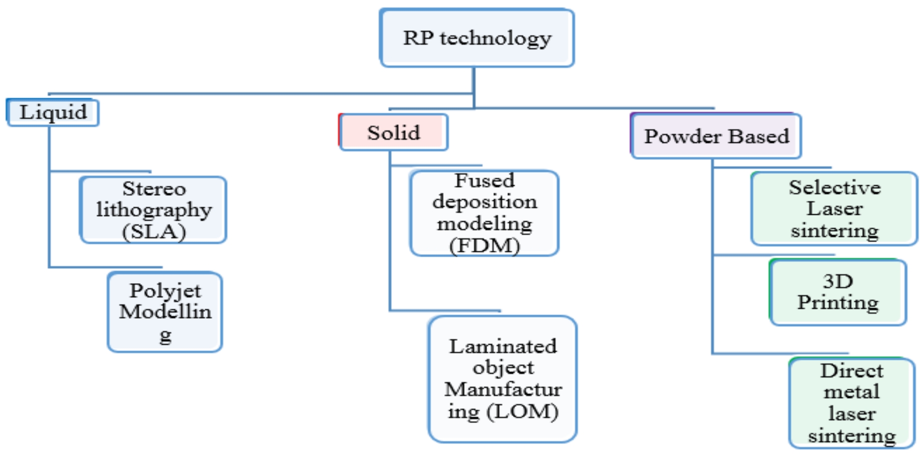


Fig. 1.6 Classification of Rapid Prototyping Systems

1.6 Liquid Based Rapid Prototyping System

Liquid based rapid prototyping systems have the initial form of its material in liquid state. The base material can include a resin or a polymer. Liquid based rapid prototyping systems works on the principle of ‘Photo curing’ under which three methods are possible

i. Single laser beam method ii. Masked lamp method iii. Two laser beam method

Most of these systems build parts in a vat of photo-curable resin, an organic resin that solidifies under the exposure to laser radiation, in UV range. The laser cures the resin near the surface, forming a hardened layer. The formed layer is lowered by an elevation control system to allow the next layer of resin to be similarly formed over it. This continues until the entire part is completed. Under liquid based rapid Prototyping system, stereo lithography is very unique and patented process which combines CAD, CAM, CAE, Laser Scanning, Optical Scanning technologies including chemistry to fabricate 3D solid models from 3D CAD data.

1.7 Solid Based Rapid Prototyping System

Solid based rapid prototyping systems are meant to encompass all the forms of materials in solid state. The solid form can include the shape in the form of a wire, laminate, pellets or a roll. Solid-based rapid prototyping systems works on the following principles:

i. Cutting and Gluing / Joining method.

ii. Melting and solidifying / fusing method.

These processes are different from one another, though some of them use the laser in the process of fabricating prototypes. They all utilize solid in one form or the other, as the primary medium to create a prototype.

1.8 Powder Based Rapid Prototyping System

Powder particles are by-and-large to the particles of solid state in a strict context. However, intentionally it is categorized outside the solid-based rapid prototyping systems to refer powder in grain form. All the powder based rapid prototyping systems works on the principle of Joining/Binding.

The method of joining / binding differs for all the systems, in that some employ a laser while others use a binder/glue to achieve the joining effect. Binder material is deposited on to selected regions of layer of powder particles to produce a layer of powder particles that are completely bonded at the selected regions. Iterations would fabricate the desired part. Post-processing is highly required to remove the unbounded powder particles.

1.9 Comparison and selection of Rapid Prototyping Systems

Optimization of an artifact for characterization of the form using the procedure of computed tomography (CT) with geometric dimensioning and tolerances and internal channels and the structures those are comparable to that of the cooling channels in heat exchangers. Investigation has been done to determine the accuracy and capability of computed tomography measurements and is compared with the reference measurements, determined by co-ordinate measuring machine (CMM).

The layer height for stereo lithography apparatus (SLA) and selective laser sintering (SLS) are same, but the layer height differs for fused deposition modeling (FDM). Thus, SLA and SLS can be compared like for like, whereas FDM has to be considered when comparing results.

Process parameters influence the accuracy of the part fabricated. Also the interactions of process parameters influence the dimensional accuracy of the fabricated component. Parameters such as raster width, path speed, slice height and tip dimension at two different levels must be taken into consideration to determine the influence of these process parameters and their interactions on the dimensional accuracy of the part fabricated. Rapid prototyping systems may involve large number of contradictory factors that majorly influence the accuracy during the fabrication of the component. A standardized methodology of optimization is used to determine the optimum level settings for the part fabrication. Thus, experimental and numerical analysis reveals that the control of the process parameters of the machine at appropriate levels, improve the dimensional accuracy of the fabricated component or part.

With the availability of growing number of rapid prototyping technologies and their capabilities, it has created a problem of selecting the appropriate method to suit the requirement. Thus, IRIS intelligent rapid prototyping system selector, an interactive program guides the potential purchaser to select the rapid prototyping system which suits the specific requirements. The program’s database includes complete specifications of all systems. Thus, the program is used to compare specifications and applications of rapid prototyping system in making the final selection of the suitable method. The selection of appropriate rapid prototyping system can also be done on the basis of a quantitative analysis.

The selection of a suitable rapid prototyping process for the required application is facilitated by the parameters, orientation for building the component, building cost, manufacturing time, dimensional accuracy, and surface finish. The building cost is the primary optimization objective. Volumes of building inaccuracy, surface finish, manufacturing time are the secondary optimization objectives to resolve the tie-breaks for orientations, for building the model.

Part orientation for the part fabrication depends on the surface finish, support structure, shrinkage, build time, curing and part cost. A support system is developed to facilitate the selection of appropriate build direction as well as best suitable rapid prototyping process. The three major factors in determining best part orientation are the build time, surface roughness and part cost. A multi-criterion decision making method is taken into consideration in order to choose the best part orientation.

1.10 RAPID TOOLING

A much-anticipated application of rapid prototyping is rapid tooling, the automatic fabrication of production quality machine tools. Tooling is one of the slowest and most expensive steps in the manufacturing process, because of the extremely high quality required. Tools often have a complex geometry, yet must be dimensionally accurate to within a hundredth of a millimeter.

In addition, tools must be hard, wear-resistant, and have very low surface roughness (about 0.5 micrometers root mean square). To meet these requirements, moulds and dies are traditionally made by CNC-machining, electro-discharge machining, or by hand. All are expensive and time consuming, so manufacturers would like to incorporate rapid prototyping techniques to speed the process. Peter Hilton, president of Technology Strategy Consulting in Concord, MA, believes that “tooling costs and development times can be reduced by 75 percent or more” by using rapid tooling and related technologies.

1.11Classification of Rapid Tooling

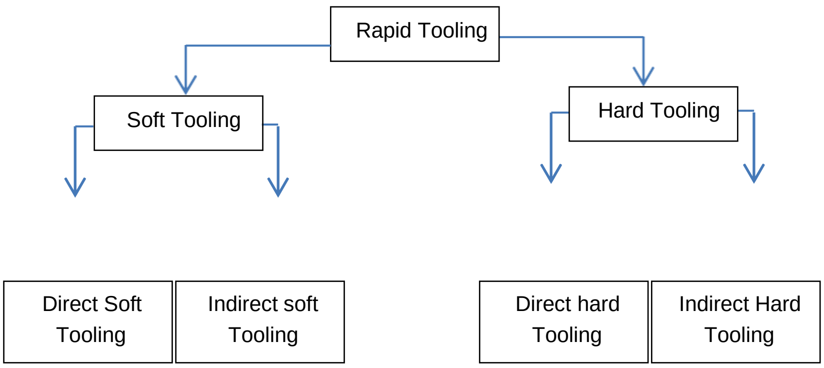


Fig.1.7 Classification of Rapid Tooling

1.12 Types of Rapid Tooling

1.12.1 Indirect Tooling

Most rapid tooling today is indirect: RP parts are used as patterns for making moulds and dies. RP models can be indirectly used in a number of manufacturing processes:

Vacuum Casting: In the simplest and oldest rapid tooling technique, a RP positive pattern is suspended in a vat of liquid silicone or room temperature vulcanizing (RTV) rubber. When the rubber hardens, it is cut into two halves and the RP pattern is removed. The resulting rubber mould can be used to cast up to 20 polyurethane replicas of the original RP pattern.

A more useful variant, known as the Keltool powder metal sintering process, uses the rubber moulds to produce metal tools. Developed by 3M and now owned by 3D Systems, the Keltool process involves filling the rubber moulds with powdered tool steel and epoxy binder. When the binder cures, the “green” metal tool is removed from the rubber mould and then sintered. At this stage the metal is only 70% dense, so it is infiltrated with copper to bring it close to its theoretical maximum density. The tools have fairly good accuracy, but are limited to less than 25 centimeters in size.

1.12.2 Direct tooling:-

To directly make hard tooling from CAD data is the Holy Grail of rapid tooling. Realization of this objective is still several years away, but some strong strides are being made. Rapid Tool: A DTM process that selectively sinters polymer-coated steel pellets together to produce a metal mould. The mould is then placed in a furnace where the polymer binder is burned off and the part is infiltrated with copper (as in the Keltool process). The resulting mould can produce up to 50,000 injection moldings. In 1996 Rubbermaid produced 30,000 plastic desk organizers from a SLS-built mould. This was the first widely sold consumer product to be produced from direct rapid tooling. Extrude Hone, in Irwin PA, will soon sell a machine, based on MIT’s 3D Printing process, which produces bronze-infiltrated PM tools and products.

Quiz

1. Explain the working principle of rapid prototyping with neat sketch.
2. Enlist the various prototyping methods.
3. Define terms of direct tooling and indirect tooling.

Criteria	%	10	9-8	7-6	5
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70-89%.	Student give the correct answers between 50-69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *______		
Quality of report	35		0.35*______		
Participation	20		0.2*______		
Punctuality	15		0.15*_______		
Total Marks					

Teacher Sign

Experiment -2

Generating STL files from the CAD models & Working on STL files.

Objective: (a) to understand the importance of STL format

(b) To make STL format from CAD file

Relevant CO: Understand and use techniques for processing of CAD models for rapid prototyping.

2.1 Introduction to STL file format

STL (an abbreviation of "stereo lithography") is a file format native to the stereo lithography CAD software created by 3D Systems. STL has several after-the-fact acronyms such as "Standard Triangle Language" and "Standard Tessellation Language". This file format is supported by many other software packages; it is widely used for rapid prototyping, 3D printing and computer-aided manufacturing. STL files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common, since they are more compact.

An STL file describes a raw, unstructured triangulated surface by the nit normal and vertices (ordered by the right-hand rule) of the triangles using a three-dimensional Cartesian coordinate system. In the original specification, all STL coordinates were required to be positive numbers, but this restriction is no longer enforced and negative coordinates are commonly encountered in STL files today. STL files contain no scale information, and the units are arbitrary.

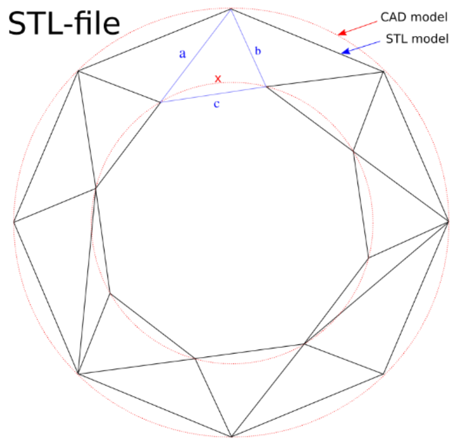


Fig. 2.1 - CAD Representation of a torus

Figure 2.1 shows two concentric circles, representing a CAD model of a doughnut shape, and a series of triangles approximating the doughnut, representing how STL modeling works.

2.2 STL file formats

The STL file format provides two different ways of storing information about the triangular facets that tile the object surface. These are called the *ASCII encoding* and the *binary encoding*. In both formats, the following information of each triangle is stored:

1. The coordinates of the vertices.
2. The components of the unit normal vector to the triangle. The normal vector should point outwards with respect to the 3D model.

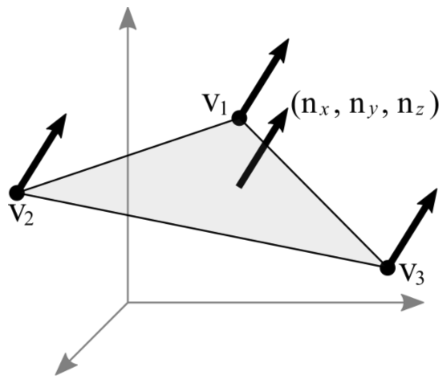


Fig. 2.2- A facet object with three faces and three vertices

2.3 The ASCII STL file format

The ASCII STL file starts with the mandatory line:

solid <*name*>

where <*name*> is the name of the 3D model. Name can be left blank, but there must be a space after the word solid in that case. The file continues with information about the covering triangles. Information about the vertices and the normal vector is represented as follows:

facet normal n_x n_y n_z

outer loop

vertex $v1_x$ $v1_y$ $v1_z$

vertex $v2_x$ $v2_y$ $v2_z$

vertex $v3_x$ $v3_y$ $v3_z$

endloop

endfacet

Here, *n* is the normal to the triangle and *v1*, v2 and *v3* are the vertices of the triangle. Co-ordinate values are represented as a floating point number with sign-mantissa-e-sign-exponent format, e.g., “3.245000e-002”.

The file ends with the mandatory line:

endsolid<*name*>

2.4 The binary STL file format

If the tessellation involves many small triangles, the ASCII STL file can become huge. This is why a more compact binary version exists. The binary STL file starts with an80-character header. This is generally ignored by most STL file readers, with some notable exceptions that we will talk about later. After the header, the total number of triangles is indicated using a 4-byte unsigned integer.

UINT8[80] – Header

UINT32 – Number of triangles

The information about the triangles follows subsequently. The file simply ends after the last triangle.

Each triangle is represented by twelve 32-bit floating point numbers. Just like the ASCII STL file, 3 numbers are for the 3D Cartesian co-ordinates of the normal to the triangle. The remaining 9 numbers are for the coordinates of the vertices (three each). Here's how this looks like:

for each triangle

REAL32[3] – Normal vector

REAL32[3] – Vertex 1

REAL32[3] – Vertex 2

REAL32[3] – Vertex 3

UINT16 – Attribute byte count

end

Note that after each triangle, there is a 2-byte sequence called the "attribute byte count". In most cases, this is set to zero and acts a space between two triangles. But some software also uses these 2 bytes to encode additional information about the triangle. We will see such an example later, where these bytes will be used to store colour information.

2.5 Working with STL file on CAD program

Virtually all 3D Rapid Prototyping machines and 3D Printers use the STL file format for input. Almost all CAD programs have a way to save or export to the STL file format. Following is the list of programs that supports exporting the CAD model as STL file format.

• Alibre • AutoCAD • Autodesk 3ds Max (3D Studio MAX) • Autodesk Inventor • Autodesk Mechanical Desktop • Bentley Microstation V8 • Blender • Cadkey / KeyCreator • Catia • CoCreate • Creo Direct • Creo Elements/Pro	• Ironcad Pro/ENGINEER • Revit Rhino • Siemens PLM NX • Google Sketchup • Solid Edge • SolidDesigner • SolidWorks • Unigraphics • Vectorworks • Creo Parametric • I-DEAS • Inventor

2.6 Generating STL files from the CAD models in various CAD software

3D solid model can be exported to STL file in most of the CAD software. Following are the procedures to export 3D CAD file as STL file in some of the famous 3D CAD software packages.

2.6.1 AutoCAD

In AutoCAD one can only export 3D solid objects to STL. Following are the steps to generate STL file from 3D CAD model in AutoCAD.

1. At the command prompt type "FACETRES"

2. Set FACETRES to 10

3. Type "STLOUT"

4. Select the objects

5. Enter Y or hit Enter for Create a binary STL file? [Yes/No] <Yes>

6. Enter Filename

7. Save

2.6.2 Autodesk 3ds Max (3D Studio MAX)

1.File > Export

2.Select type StereoLitho *.stl

3.Enter Filename

4.Save

5.Select Binary

6.OK

2.6.3 Catia

The export to the STL format is only possible in the Part Design environment. If you want to export a complete assembly (CAT Product) as a single STL file, you will have to convert the assembly in the Assembly Design environment to a CAT Part as follows:

1. Select the entire product tree
2. Tools > Generate CAT Part from Product
3. Enter New Part number
4. do NOT check: Merge all bodies of each part in one body
5. OK

Now you can export the CAT Part in the Part Design environment. The accuracy of the STL file depends on the Display accuracy. First set the display accuracy.

1.Tools > Options...

    1.In the tree select General > Display

    2.select the Performance tab

    3.Under 3D Accuracy select Fixed

    4.Set to 0.02 mm (0.0008 in)

    5.Adjust Curves' accuracy ratio to 0.2

    6.OK

2.File > Save As

3.Enter Filename

4.Select type stl

5.Save

2.6.4 Creo Direct (Creo Elements/Direct, CoCreate, OneSpace, SolidDesigner)

1.File > Save

2.Press Select > select the objects (or click All Objects)

3.Select File Type STL (*.stl)

4.Click Options

  1.Check Binary

  2.Max Deviation Distance: enter 0.025 mm (0.001 in)

  3.Angle: enter 30°

5.Enter Filename

6.Save

2.6.5 Creo Parametric (Creo Elements/Pro, Pro/ENGINEER)

1.File > Save a Copy

2.Select type STL > OK

3.Select Coordinate System Standard

4.Check Binary

5.Set Chord Height to 0 (Pro/E changes it to the smallest allowable value)

6.Leave Angle Control at the default

7.Enter Filename > OK

2.6.7 Autodesk Inventor / Mechanical Desktop

One can export individual parts or whole assemblies.

1.Manage tab > Update panel > Rebuild All

2.File > Save as > Save Copy As

3.Select STL

4.Enter Filename

5.Select Options

  1.Format > Binary

  2.Units > mm or inches

  3.Resolution > High

6.Save

2.6.8 Siemens PLM NX (Unigraphics)

1.File > Export > STL

2.Select Output Type Binary

3.Set Triangle Tol to 0.025 mm (0.001 in)

4.Set Adjacency Tol to 0.1 mm (0.04 in)

5.Set Auto Normal Gen to **On**

6.Set Normal Display to **Off**

7.Set Triangle Display to **On**

8.OK

9.Enter Filename > OK

2.6.9 SolidWorks

1.File > Save As...

2.Set type to STL(*.stl)

3.Click Options...

1.Output as: check Binary

2.Unit: >Millimetres or Inches

3.Resolution > Fine

4.OK

4.Enter Filename

5.Save

2.7 Optimizing an STL file for best 3D printing performance

The STL file format approximates the surface of a CAD model with triangles. The approximation is never perfect, and the facets introduce coarseness to the model.

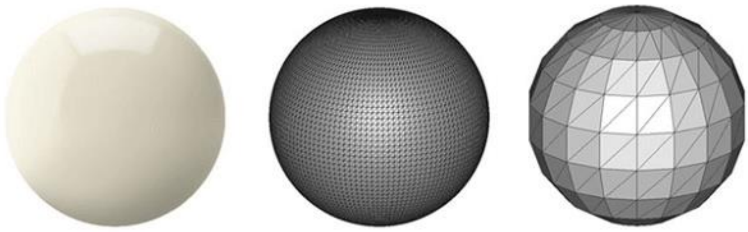


Fig 2.3 - Effect of degree of approximation in tessellation on Solid geometry

Figure 2.3 shows the Effect of degree of approximation in tessellation on Solid geometry. The perfect spherical surface on the left is approximated by tessellations. The figure on the right uses big triangles, resulting in a coarse model. The figure on the centre uses smaller triangles and achieves a smoother approximation.

The 3D printer will print the object with the same coarseness as specified by the STL file. Of course, by making the triangles smaller and smaller, the approximation can be made better and better, resulting in good quality prints. However, as you decrease the size of the triangle, the number of triangles needed to cover the surface also increases. This leads to gigantic STL file which 3D printers cannot handle. It’s also a pain to share or upload huge files like that. It is therefore very important to find the right balance between file size and print quality. It does not make sense to reduce the size of the triangles ad infinitum because at some point your eye is not going to be able to distinguish between the print qualities.

Most CAD software offer a couple of settings when exporting STL files. These settings control the size of the facets, and hence print quality and file size. Let's dig into the most important settings and find out their optimum values.

2.7.1 Chord height or tolerance

Most CAD software will let you choose a parameter called chord height or tolerance. The chord height is the maximum distance from the surface of the original design and the STL mesh. If you choose the right tolerance, your prints will look smooth and not pixelated. It's quite obvious that the smaller the chord height, the more accurately the facets represent the actual surface of the model.

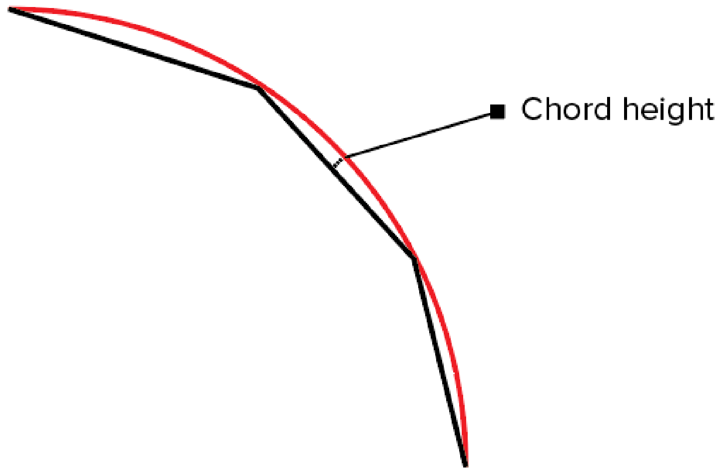


Fig 2. 4 - The chord height (height between the STL mesh and the actual surface)

It is recommended to set the tolerance between 0.01 millimeters to 0.001 millimeters. This usually results in good quality prints. There is no point in reducing this any further, as 3D printers cannot print with that level of detail.

2.7.2 Angular deviation or angular tolerance

Angular tolerance limits the angle between the normals of adjacent triangles. The default angle is usually set at 15 degrees. Decreasing the tolerance (which can range to 0 to 1) improves print resolution. The recommended setting for this parameter is 0.

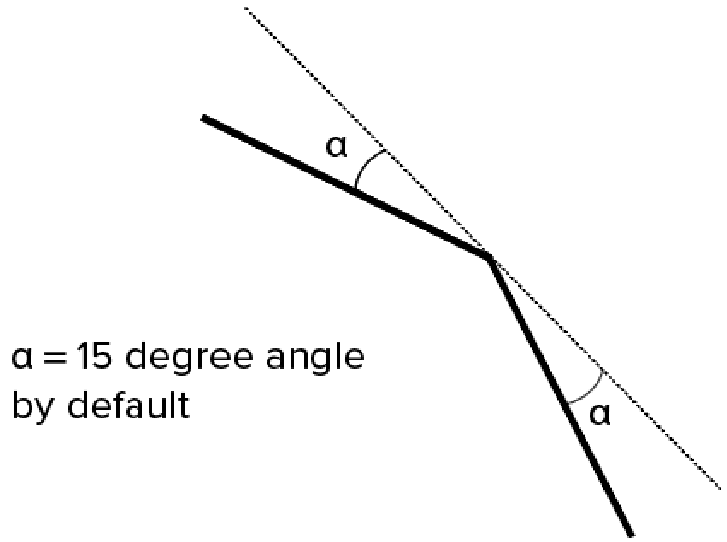


Fig 2.5- Angular tolerance (Angle between the normal of adjacent triangles)

8.7.3 Selection between Binary and ASCII

Finally, we have a choice of exporting the STL file in binary or ASCII format. The binary format is always recommended for 3D printing since it results in smaller file sizes. However, if we want to manually inspect the STL file for debugging, then ASCII is preferable because it is easier to read.

2.8 STL File Manipulation

Once a part has been converted into STL there are only a few operations that can be performed. This is because the triangle-based definition does not permit radical changes to the data. Associations between individual triangles are through the shared points and vertices only. A point or vertex can be moved, which will affect the connected triangles, but creating a regional effect on larger groups of points would be more difficult. Consider the modeling of a simple geometry, like the cut cylinder in Fig. 2.6a Making a minor change in one of the measurements may result in a very radical change in distribution of the triangles. While it is possible to simplify the model by reducing the number of triangles, it is quite easy to see that defining boundaries in most models cannot be easily done. The addition of a fillet in Fig. 2.6b shows an even more radical change in the STL file. Furthermore, if one were to attempt to move the oval that represents the cut surface, the triangles representing the filet would no longer show a constant-radius curve.

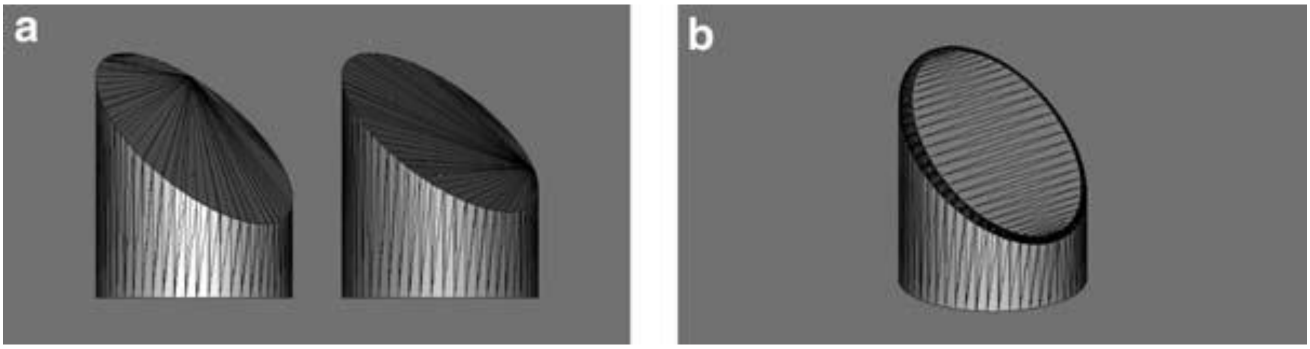


Fig 2. 6- STL files of a cut cylinder.

Here it is to be noted that Note that although the two models in (a) are very similar, the location of the triangles is very different. Addition of a simple filet in (b) shows even greater change in the STL file.

Quiz

1. Explain the importance of graphics standard.
2. What is .STL file format? Explain the importance of conversation of CAD file into stl format.
3. Define the terms: Chordal height.

Criteria	**%**	**10**	**9-8**	**7-6**	**5**
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70-89%.	Student give the correct answers between 50-69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *______		
Quality of report	35		0.35*______		
Participation	20		0.2*______		
Punctuality	15		0.15*______		
Total Marks					

Teacher Sign

Experiment -3

Processing the CAD data in Catalyst software (Selection of Orientation, Supports generation, Slicing, Tool path generation)

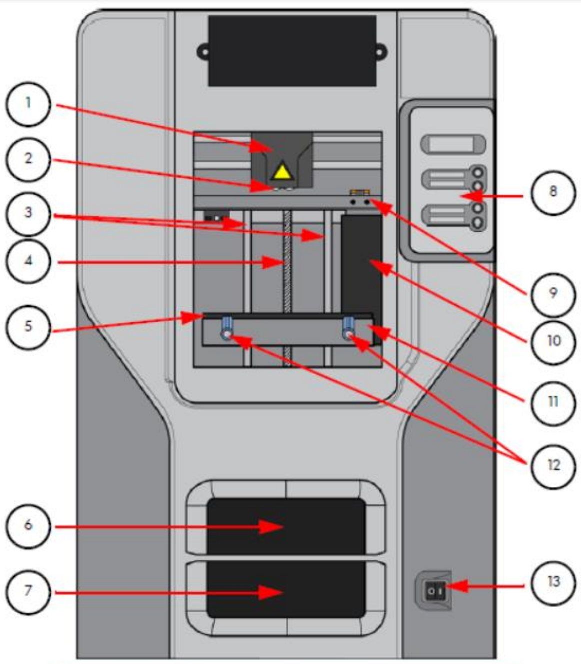
Objective: **(a) to understand about set the process parameter of RP**

(b) To discuss the effect of process parameter on build quality

Relevant CO: (a) Understand and use techniques for processing of CAD models for rapid prototyping. (b) Apply fundamentals of rapid prototyping techniques.

3.1 Introduction

Dimension 1200es printers build models, including internal features, from CAD STL files. Three dimensional parts are built by extruding a bead of ABS plastic through a computer-controlled extrusion head, producing high quality parts that are ready to use immediately after completion. With two-layer resolution settings, you can choose to build a part quickly for design verification, or you can choose a finer setting for higher quality surface detail. The Dimension 1200es systems consist of two primary components — the Dimension 1200es 3Dprinter and CatalystEX. CatalystEX is the preprocessing software that runs on a Windows Vista or Windows 7 platform. The build envelope measures 254 x 254 x 305 mm (10 x 10 x 12 in). Each material cartridge contains 922 cc (56.3 cu. in.) of usable material.



1	Extrusion Head	8	Display Panel
2	Extrusion Tips	9	Tip Cleaning Assembly
3	Guide Rods	10	Purge Container
4	Lead Screw	11	Z stage platen
5	Modeling Base	12	Modeling Base Retainers (2)
6	Model Material Cartridge	13	Power Switch
7	Support Material Cartridge		

Figure 3.1 stratasys 1200es

3.2 CatalystEX overview

- **General tab:**

  This section is where you can select the model fill style, support style, change the STL units and STL scale.

- **Orientation tab:**

  This section allows you to rotate, resize and auto-orient your parts. You can also change the view and insert a pause.

- **Pack tab:**

  This section shows you which parts are in the pack for printing. You can add parts, arrange the parts for a better fit or clear the pack from this section.

- **Printer Status tab:**

  This section shows you the amount of material remaining (both model and support) as well as which parts are in the Build Queue.

- **Printer Services tab:**

From this section you can check the printer history, set the printer time, set the printer password, update printer software, get printer info and export configuration files(files containing specific operating information regarding the printer).

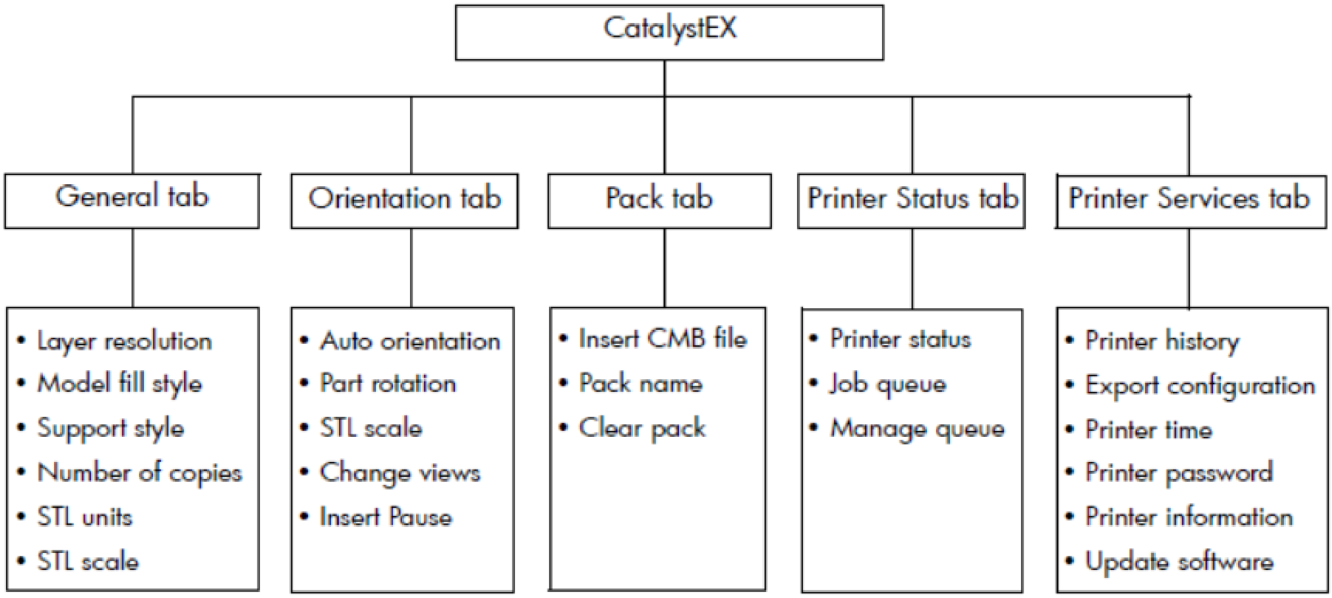


Fig. 3.2 CatalystEX overview

3.3 Processing your STL file for printing

Opening your STL file with CatalystEX:

1. Create an STL file using your CAD software. Refer to your CAD software help section for more information about converting your CAD drawings into STL files.
2. Open the Catalyst EX.
3. From the **File** menu select **Open STL.**
4. Navigate to and select the STL file that you have created.

3.4 Selecting layer resolution:

Layer resolution can be changed on the printer. Changing layer resolution will affect surface finish and build times. Selecting a smaller layer resolution creates a smoother surface finish, but takes longer to build. Layer resolution also affects the minimum wall thickness. Minimum wall thickness applies to the horizontal (XY) plane of your part. If a feature in an STL is smaller than the limit, the modeler will increase the size of the feature to the minimum wall thickness.

Available layer resolutions	Minimum Wall thickness
.010 inch (.254 mm)	.036 inch (.914 mm)
.013 inch (.330 mm)	.047 inch (1.194 mm)

3.4.1 Slicing methods

1. STL-based Slicing

- Uniform slicing generates constant layer thickness slices. Adaptive slicing is a variant of the uniform slicing, where the spacing between the slices is not constant but determined by the geometry and machine capability.
- However, there are still not 3D printers that fully support or able to take full advantages of adaptive slicing. Therefore, uniform slicing seems more versatile.

2. Direct Slicing

- Direct slicing can generate precise slice contours from original 3D models and discard the error-detection and repairing process of STL files.
- it can only be used for a specific set of software and machine, and is not applicable to any other 3D CAD combinations. So , STL-based slicing is still the commonly used method in processing the problem of layered 3D printing.

Slice

A single, horizontal, cross-sectional cut of a 3D model. Each slice will have support (if necessary) and model tool path information for the printer. See Slice Height.

Slice-Height

The thickness (magnitude) of each slice. The height will be equal to the amount of material extruded to produce each layer of the model. Selection is available from the Resolution Property on the General Tab. (Syn: Layer Resolution)

Slicing

The action of cutting the 3D STL model into a stack of 2D horizontal part boundary contours (slices). The slicing operation begins at the bottom of the model and progresses sequentially to the top at a constant interval.

3.5 Selecting model interior fill style:

This establishes the type of fill used for the interior areas of the part. There are three types of model interior that you can choose from.

1. **SOLID:** Used when a stronger, more durable part is desired. Build times will be longer and more material will be used.
2. **SPARSE HIGH DENSITY:** This is the default model interior style and is highly recommended. Build times will be shorter, less material will be used and the possibility of part curl for geometries with large mass will be greatly reduced.
3. **SPARSE LOW DENSITY:** The interior will be “honeycombed” or “hatched”. This style allows for the shortest build times and lowest material usage but will decrease the strength of the part.

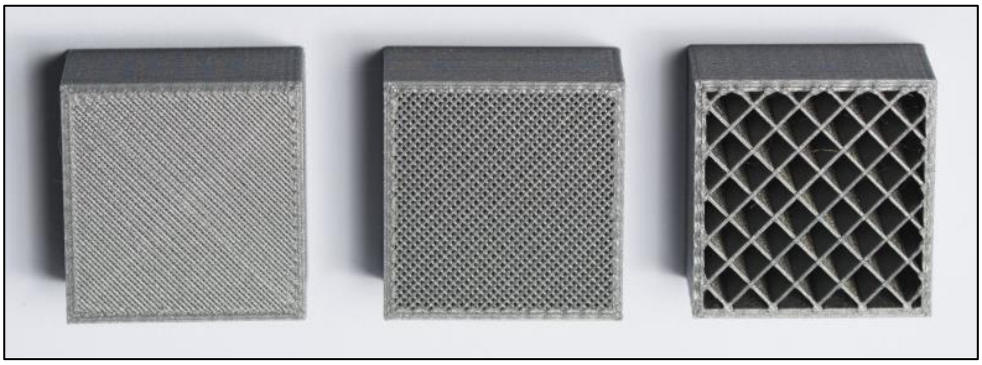


Fig. 3.3 (A) solid (B) sparse high density (C) sparse low density

3.6 Selecting support style (Support generation):

Support material is used to support the model during the build process. It is removed when the part is complete. Support styles will affect the support strength and build time of the print. SMART support is the default support setting.

1. **BASIC**- May be used for most parts. Basic support uses a consistent spacing between support tool paths.
2. **SMART** - minimizes the amount of support material used, reduces the build time, and improves support removal for many parts. SMART supports use a wide spacing between tool path raster and change the shape of the support region. As the supports descend from the underside of the part feature to the base of the supports, the support region shrinks and transforms to a simpler shape to reduce the amount of material used and the build time. SMART supports are suitable for all parts, especially those with large support regions, and are the default style for builds using soluble supports

3. **SURROUND**- The entire model is surrounded by support material. Typically used for tall, thin models.

3.7 Selecting the scale of your STL files

Before you process a part for printing, you can change the size of the part within the build

Envelope. Every part has a pre-defined size within the STL file. After you have opened the file you

can change the size of the part produced from the STL file by changing the scale. The scale always

relates to the original STL file size definition. For example: a cube that is defined as 2 X 2 X 2 can be built to be 4 X 4 X 4 by simply changing the scale to 2.0. If after changing the scale to 2.0, you decide that a size of 3 X 3 X 3 would be preferred, change the scale to 1.5 - the scale relates to the original size of 2.0, NOT the resulting4.0 from the first scale change. Click within the scale input box to type a scale of your choice.

3.8 Selecting the orientation of your STL file:

It refers to the inclination of the part in a build platform with respect to the X-Y-Z axis. The X & Y axis are considered in parallel direction to build platform & Z axis is considered along the direction of built part.

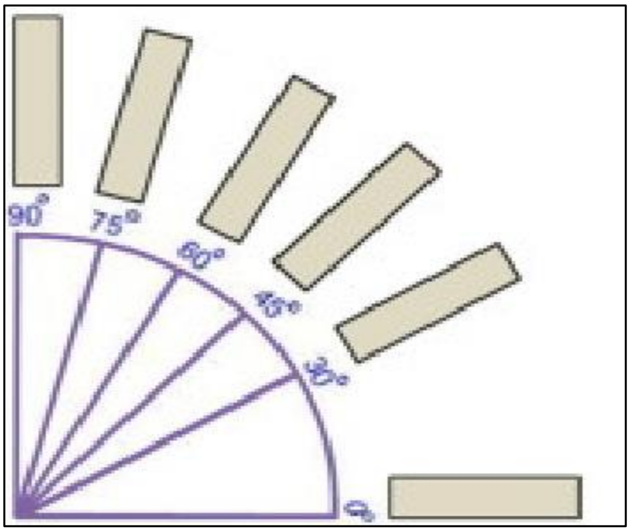
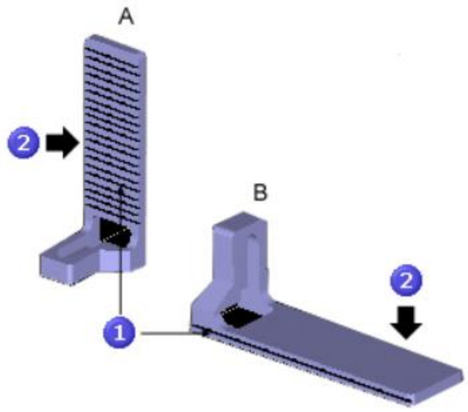


Figure 3.2 orientation

The Orientation tab has an expanded preview window. It provides options for viewing a part, measuring a part, orienting a part, processing a part and viewing the layers of a part. How parts oriented in the preview window will determine how the part is oriented when it prints. Orientation impacts build speed, part strength, surface finish and material consumption. Orientation can also affect the ability of CatalystEX to repair any problems with the STL file. You can choose to auto orient your part, which allows Catalyst EX to determine the best orientation for the part for the fastest build time and least material usage, or you can manually change the orientation of your part.

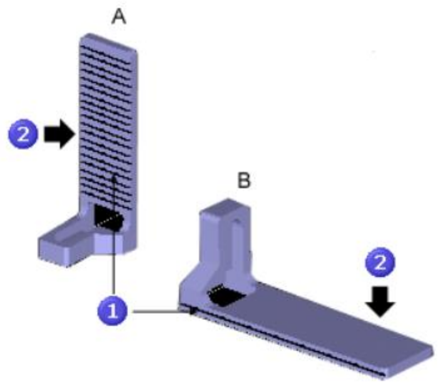
3.9 Orientation Considerations:

1. **Build Speed** - Closely related to material use. A lesser amount of supports will allow for a faster build speed. Another factor affecting build speed is the axis orientation. The printer can build faster across the X-Y plane than it can along the Z axis. Orienting a part so that it is shorter within the modeling envelope will produce a quicker build.
2. **Part Strength** - A model is stronger within a layer than it is across layers. Depending upon what features you want your part to demonstrate, you may need to orient your part to have its greatest strength across a specific area. For example, a tab that needs to be pressed would be weakest if you are applying pressure across layers.



1	Layer direction
2	Force applied to the part. Orientation B produces the strongest part against the indicated force.

3. **Surface Finish** - Much like orienting for strength, how the part is oriented will determine how the surface finish will look and allow the printer to provide the smoothest finish for a specific area. For example, if building a cylinder, orienting the cylinder upright will have a smoother surface finish than building it on its side.



1	Layer direction
2	Appearance of long surface. The long surface of orientation B will be smoother than the long surface created by orientation A.

4. **STL File Repair** - It is possible for an STL file to have errors while appearing to be trouble free. If the STL file contains errors, Catalyst EX may have problems processing the file. Catalyst EX has the ability to automatically correct some STL file errors. How the part is oriented can impact this automated repair function.

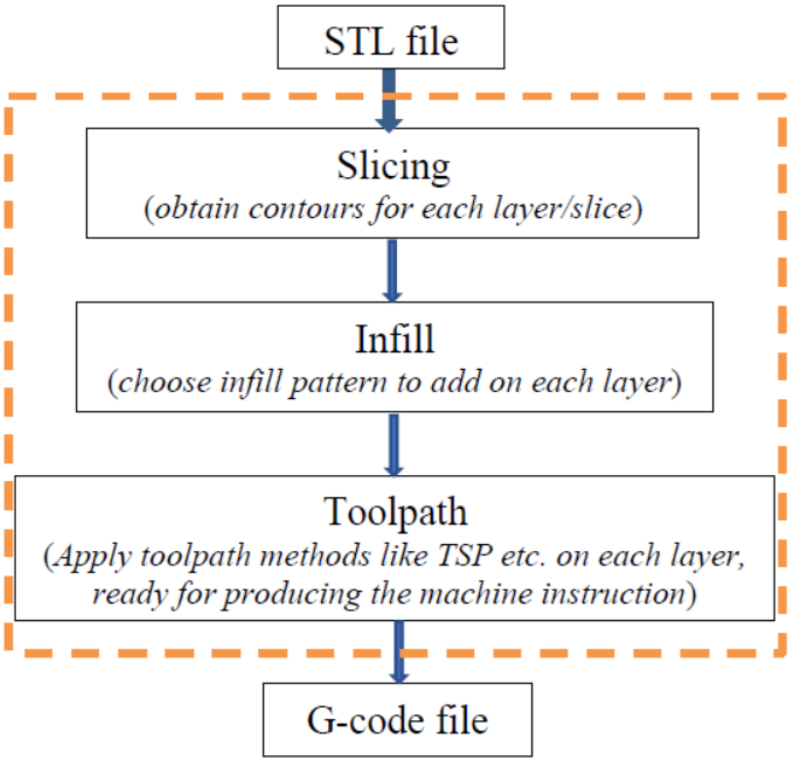
3.10 Adding your STL file to the pack:

The **Add to Pack** button is found on the General, Orientation and Pack tabs. When you click on the **Add to Pack** button, Catalyst EX will add the file that is currently in the preview window (General tab or Orientation tab) to the pack preview window (Pack tab).If the file in the preview window has not been processed for printing, processing will occur before the file is added to the pack. Each additional click of the **Add to Pack** button will add another copy of the file to the pack.

3.11 Printing your STL file:

The **Print** button is found on the General, Orientation and Pack tabs. CatalystEX will now process all parts in the pack and create a CMB file from which the printer will print the parts.

Plotting and path control:



Quiz

1. Enlist the various process parameter of selective laser sintering process.
2. Define the terms: Hatch Distance, Layer Thickness, and Scanning Speed.
3. Discuss the effect of layer thickness on mechanical properties.

Criteria	**%**	**10**	**9-8**	**7-6**	**5**
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70-89%.	Student give the correct answers between 50-69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *______		
Quality of report	35		0.35*______		
Participation	20		0.2*______		
Punctuality	15		0.15*_______		
Total Marks					

Teacher Sign

Experiment – 4

Simulation in Catalyst Software

Objective: (a) To simulate the entire process from STL to Physical part

Relevant CO: (a) Understand and use techniques for processing of CAD models for rapid prototyping. (b) Apply fundamentals of rapid prototyping techniques. (c) Use appropriate tooling for rapid prototyping process.

The simulation was carried out CatalystEX 4.4 software which is used for producing part directly from CAD model in Fused Deposition Modeling, which is one of the widely used rapid prototyping process. First the CAD model of part to be produced in any high-end modeling software like Nx, Solidworks, Creo, Inventor, etc. is converted to STL (Standard Triangulation Language) file format.

Step 1: open the CatalystEX 4.4 software and import STL file of the part to be produced.

Step 2: After importing file general properties like layer thickness, model interior, support fill, etc should be given. In this software depending on the machine capabilities there are two fixed value of layer thickness 0.01 inch and 0.013 inch available. According to the complexity of the part two of this value entered.

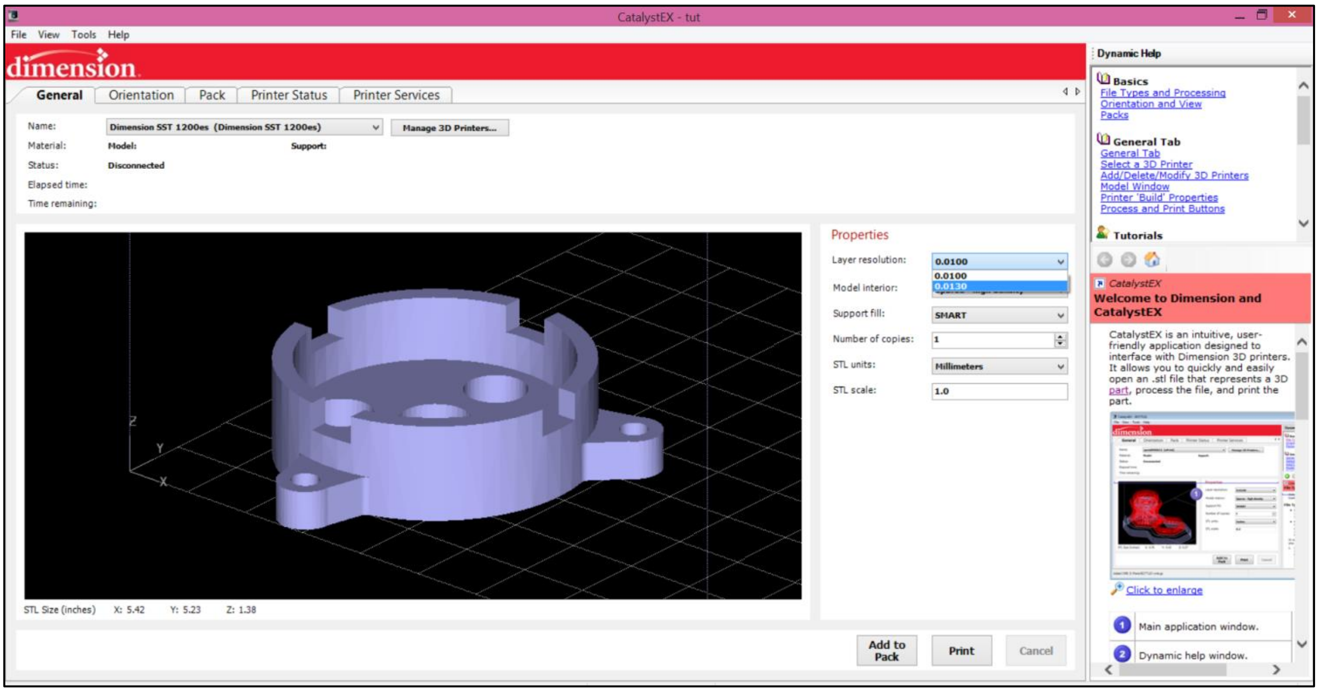


Figure 4.1 selection of layer thickness

Step 3: After selecting layer thickness model interior should be selected. There are three option is available: (1) Sparse-low density, (2) Solid (3) Sparse-High density. The effect of this factor is directly on the production time and material usage and strength of the part achieved. If Sparse-low density is selected then there is less material usage, time of production and strength of part achieved. For Sparse-High density is selected then there is higher material usage, time of production and strength of part achieved and solid option gibe intermediate result of these two options. According to feasibility of the part this model interior option should be wisely chosen.

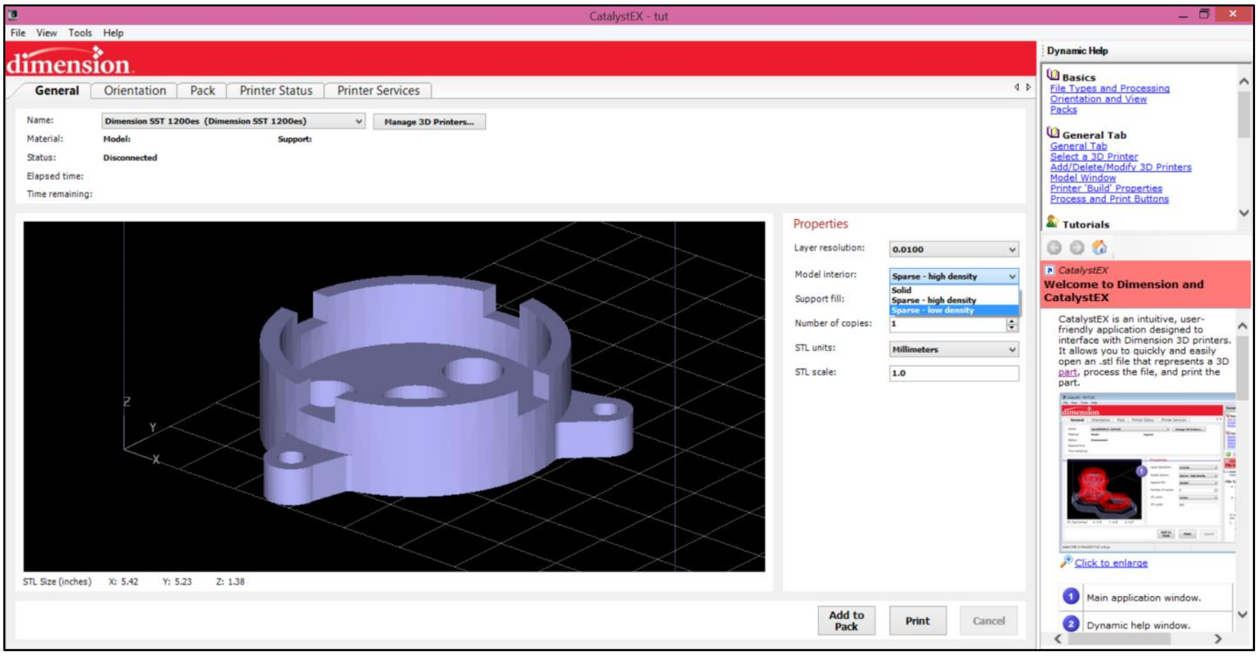


Figure 4.2 selection of model interior

Step 4: After selection of model interior support fill should be selected. There are four options available for support fill: (1) Sparse (2) Basic (3) Smart (4) Surround. This option takes more time of production and support material in ascending order. According to part to be produced support fill option should be wisely chosen.

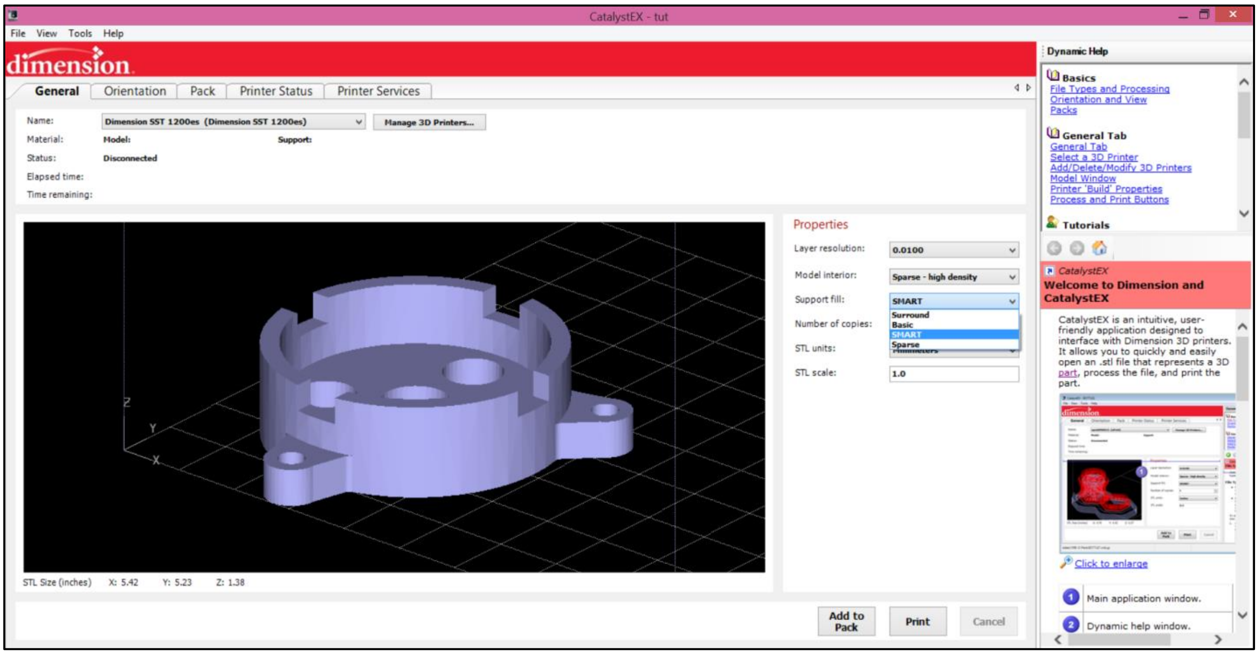


Figure 4.3 selection of support fills

Step 5: This option allows to select number of copies pf same part to be produced and STL scale is also provided in the software so that scaling of the part can be possible without modifying original geometry. As per requirement this option can be used.

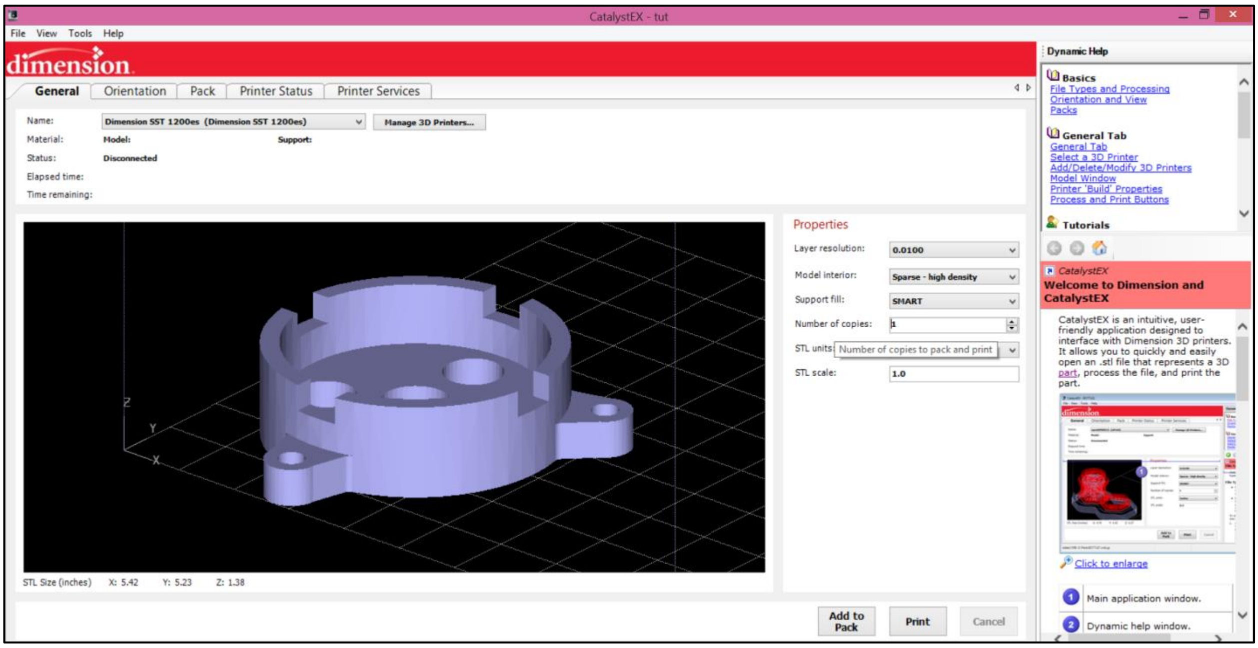


Figure 4.4 selection of number of copies to be produced and STL scale

Step 6: This software allows to change the unit of that STL file without changing the original CAD model.

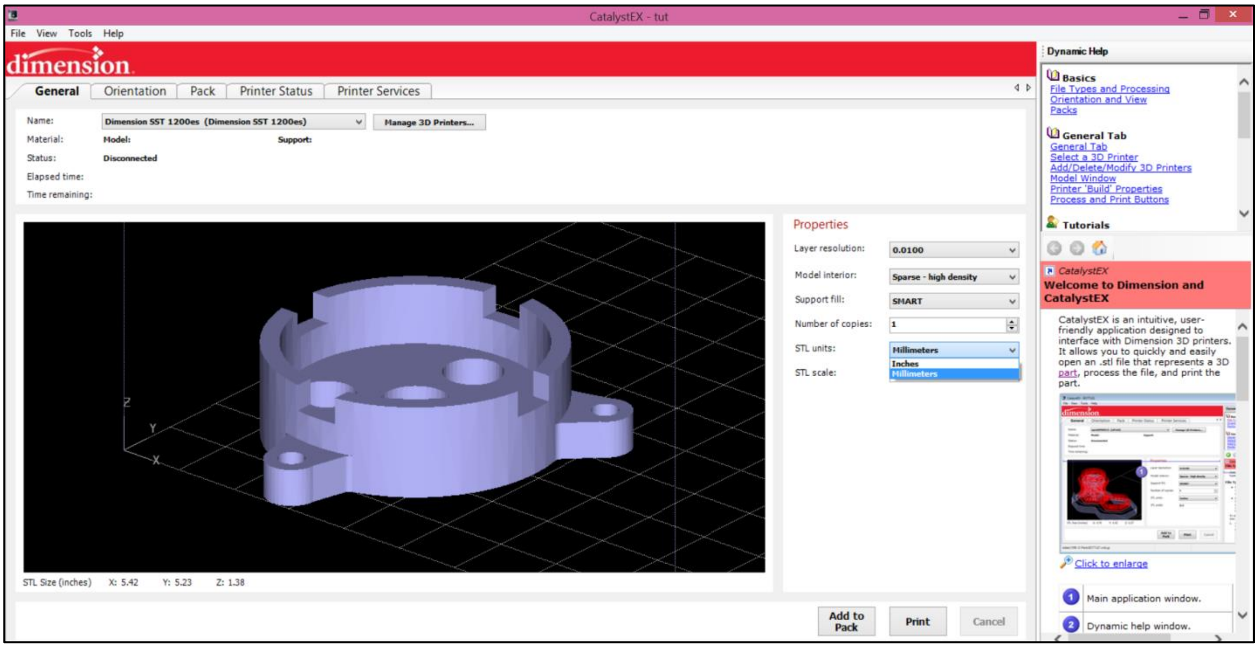


Figure 4.5 selections of STL units

Step 7: Part can be oriented under the orientation option provided by this software. Part orientation plays important role to provide proper strength to the part and it saves the support material effectively. There are two option available (1) Auto orient (2) Manual orient. By selecting auto orient option software automatically set orientation of the part and in manual orientation part can be rotate at available degrees about X, Y and Z axis. According to the part to be built proper orientation should be selected.

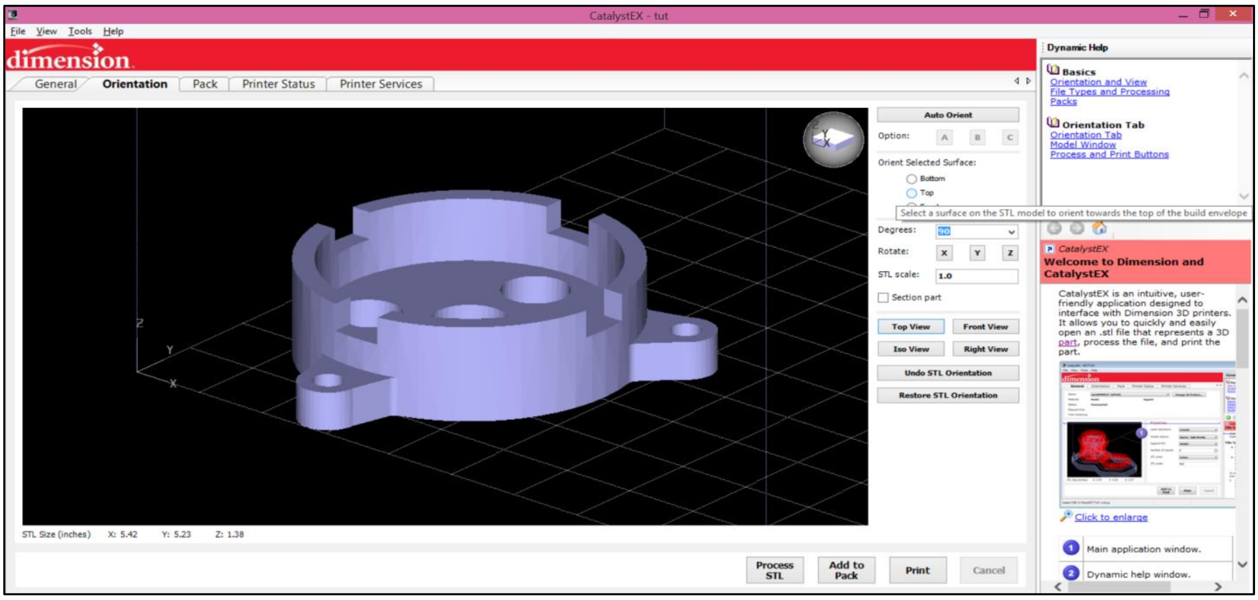


Figure 4.6 selection of part orientation

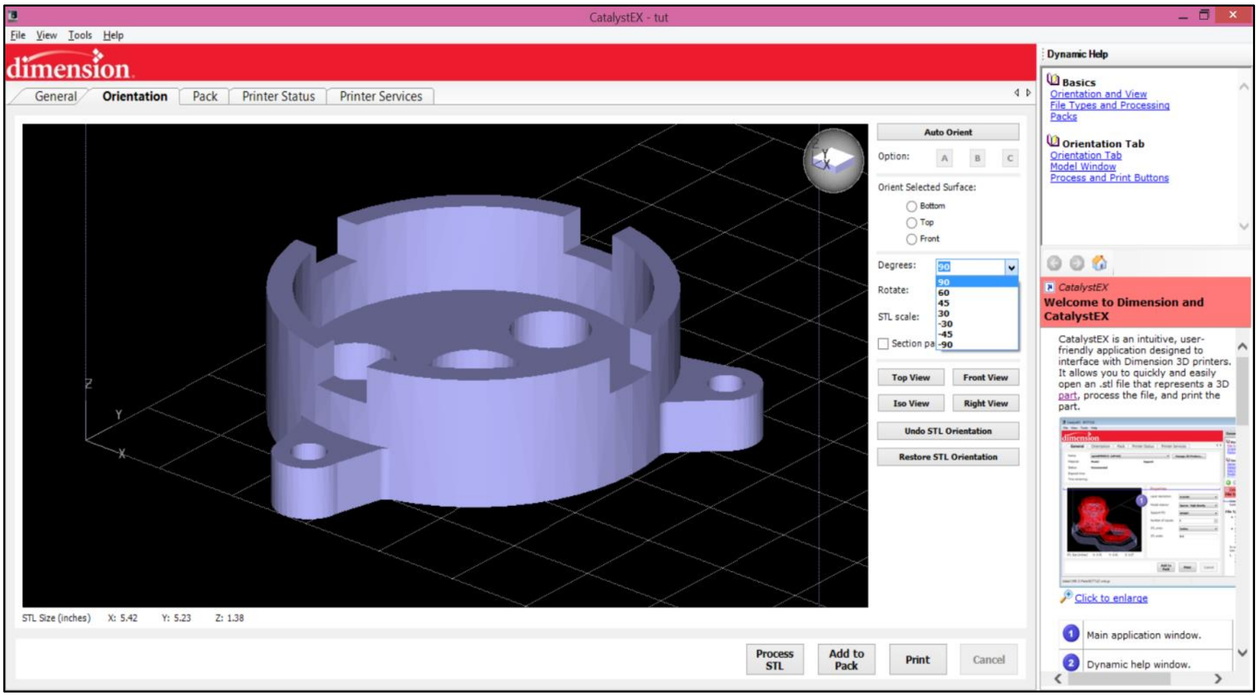


Figure 4.7 selection of manual orientation at diff. degree

Step 8: After selecting proper orientation add to pack option is to be selected which slice the object according to selected value. The below fig shows 0.01-inch layer thickness throughout the part. The white color shows the support material and red color shows the model material. This software also provides different views of the product by selecting that option.

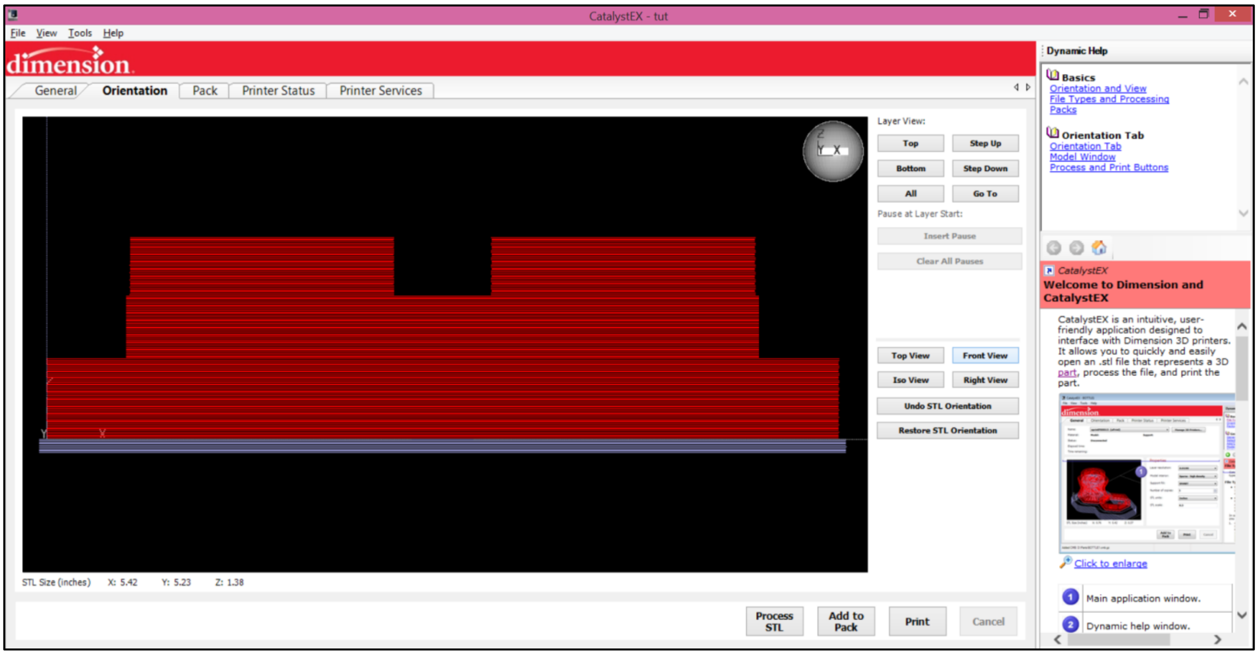


Figure 4.8 Layer thickness of 0.01 inch throughout the part

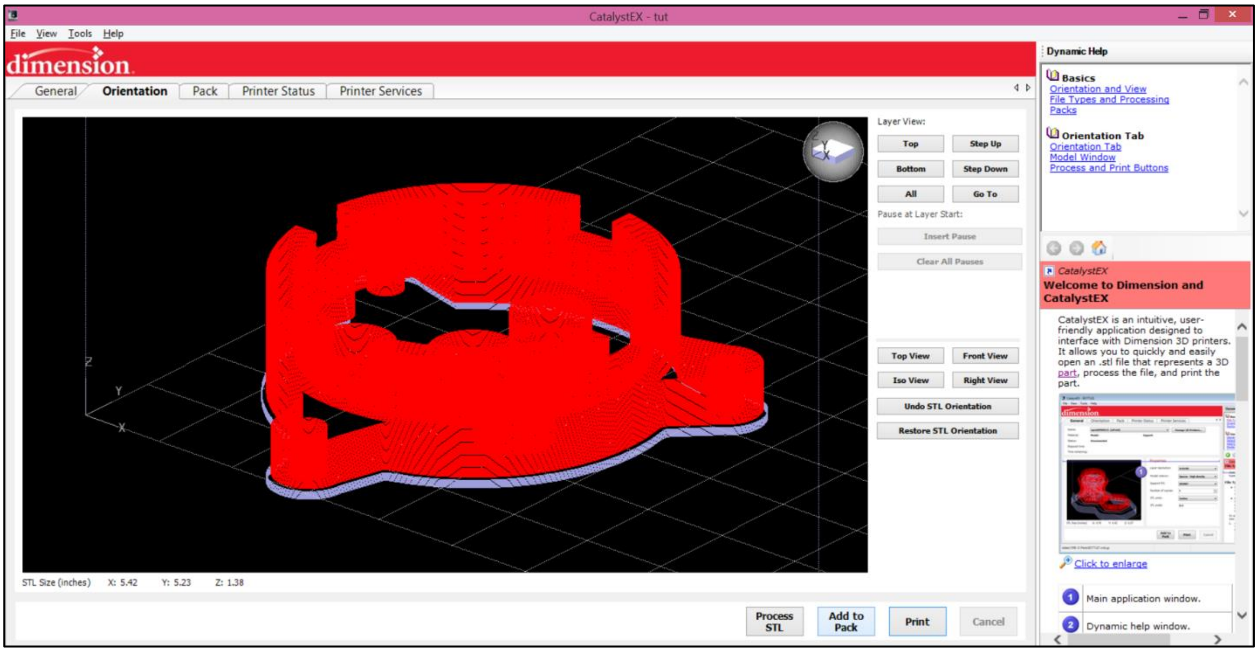


Figure 4.9 ISO view of the part to be produced

Step 9: After adding to the pack the pack detail of the part is available under the pack option. Under this option main focus is to locate the part where it should be built on palate. This option allows to produce number of same part by copy it and remove it also. Name of the part is also edited in this option and this option shows the volume of model and support material that will be used to produce the part and also shows the time require to build that part.

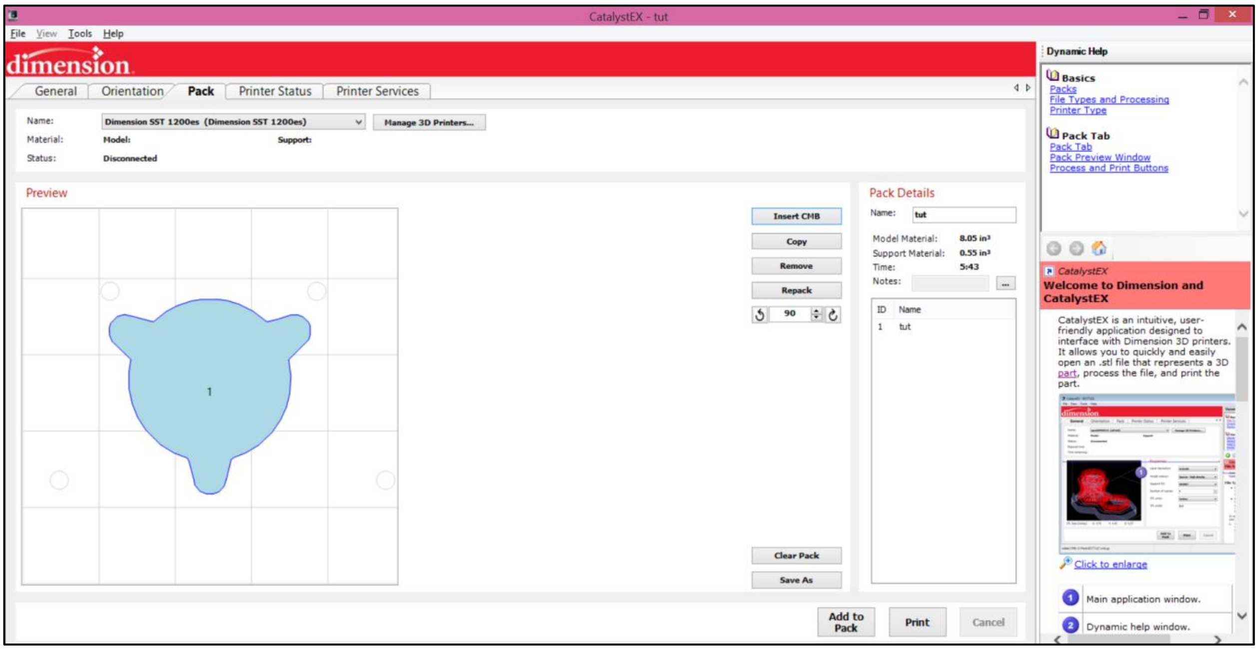


Figure 4.10 pack details

Step 10: Finally print option selected to start the production of the part.

Reference

[1] CatalystEx 4.4 software at center of Excellence, LD College of Engineering, Ahmedabad.

Quiz

1. Explain the step to print the parts in FDM machine.
2. Discuss the importance of simulation in RP.

Criteria	**%**	**10**	**9-8**	**7-6**	**5**
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70-89%.	Student give the correct answers between 50-69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*______		
Total Marks					

Teacher Sign

Experiment – 5

Fabrication the physical part on a RP machine

Objective: (a)To understand the entire process of RP

Relevant CO: (a) Create component with RP applications. (b) Apply fundamentals of rapid prototyping techniques. (c) Use appropriate tooling for rapid prototyping process.

5.1 Introduction to CAD part

Rapid prototyping is a group of techniques used to quickly fabricate a scale model of physical part or assembly by using three dimensional computer aided design data. Construction of the part usually has done using 3d printing or additive layer manufacturing technology. As with CNC subtractive methods the computer aided design , computer aided manufacturing CAD-CAM workflow in the tradition rapid prototyping process start with the creation of geometry data, either as a 3d solid using a cad workstation, or 2d slices using a scanning device. For rapid prototyping this data must represent a valid geometric model whose boundary surfaces enclose a finite volume contain no holes exposing the interior, and do not fold back on them. In other word the object must have an “inside”. The model is valid if for each point in 3d space the computer can determine uniquely whether that point lies inside, on the boundary surface of the model.CAD post process will approximate the application vendors internal CAD geometric forms with a simplified mathematical form, which in turns is expressed in a specified data format which is common feature in additive manufacturing : STL (stereo lithography) a de facto standard for transferring solid geometric models to SFF machine.

After the STL file is provided as an input to the RP machine using the CATALYST software, the orientation is set as per the support material estimation and also the time duration required. Here the detail drawing of the printed part is on below fig. 5.1 CAD model was developed in SOLIDWORKS 2017.

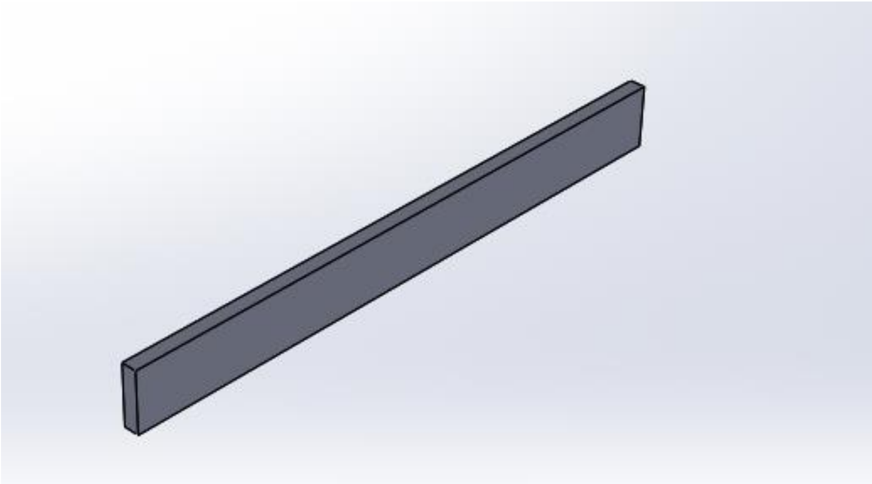


FIG-5.1 CAD MODEL IN SOLIDWORK

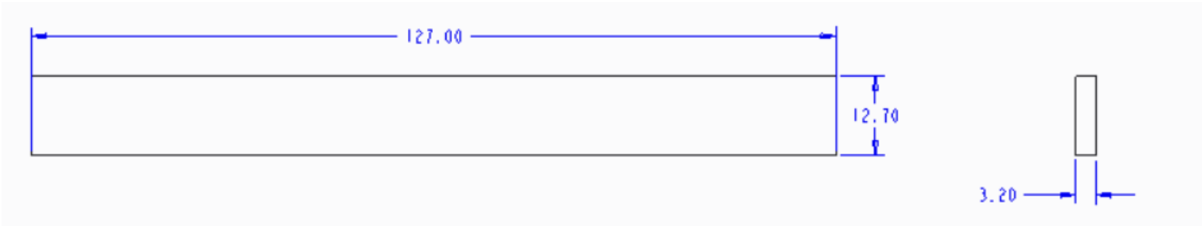


Fig. 5.2 detain drawing of printed component

5.2 Machine Specification

Height / width /depth	1143/737/838
Weight	148 kg
Model material	ABS plus in nine material
Support material	Soluble (SST 1200es) :breakaway (BST 1200es)
Layer thickness	0.33mm
Scale	1:1
Model interior fill style	Sparse High Density
Support style	smart
3D Model	shown in fig 5.3
Power requirements	100-240 V AC – 7A 50 Hz 1200 W dedicated circuit within 2m do not use extension cord or a power trip, using these can

	possibly cause intermittent power issues.
Air Circulation	115mm minimum space behind printer for air circulation. 153 mm minimum space around printer for air circulation
Environment	15 ‘C to 30 ‘C
Relative humidity range	30 to 70 percent, non condensing
Heat emission	1080 watts=3686 BTU / hr typical
	1380 watts = 4710 BTU /hr Max

Fig. 5.3 Dimensions SST 1200ES

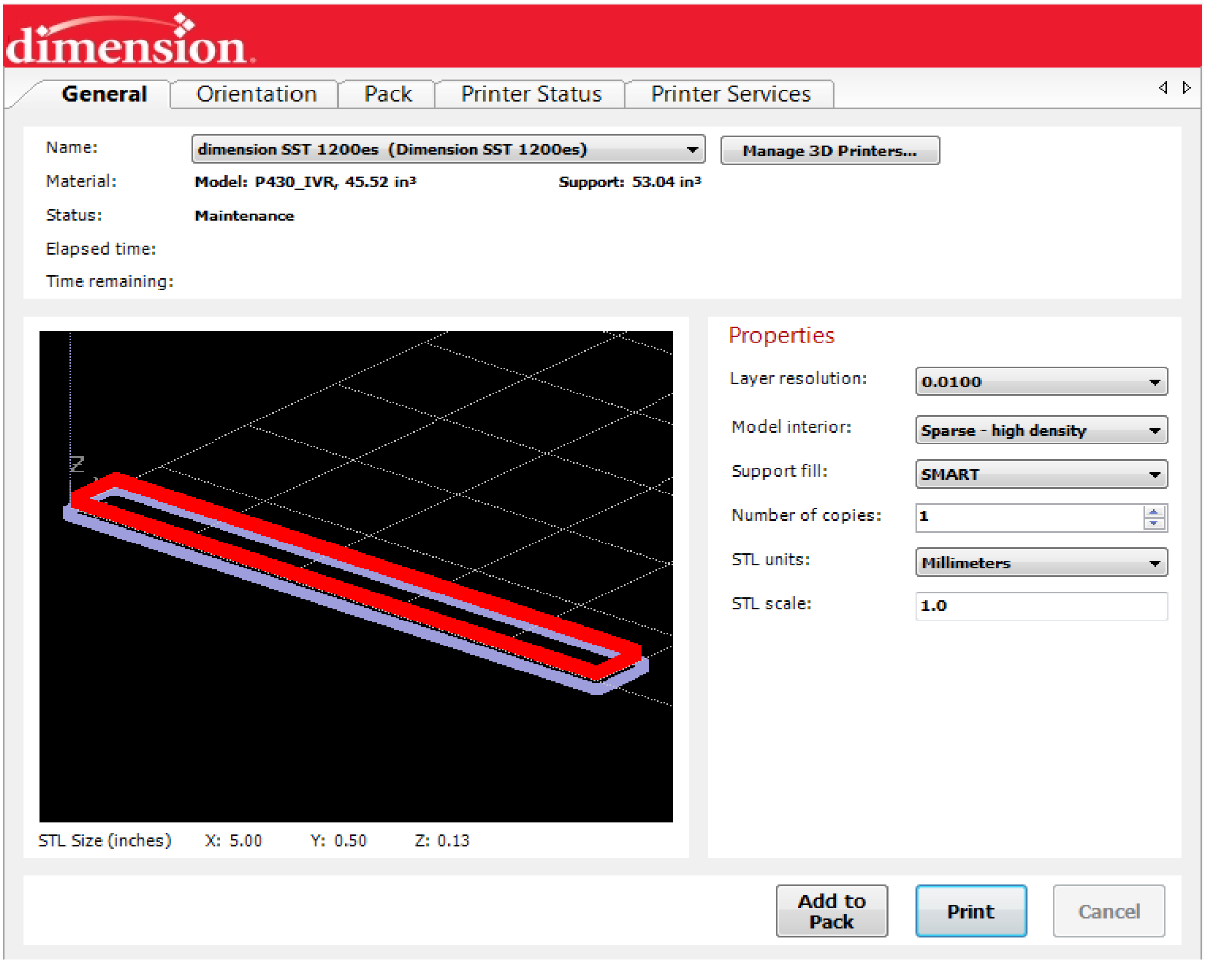


Fig. 5.4 Component Loading

Part developed after then post processed and is being separated from the support material. Here part developed does not involve complex feature and hence it does not involve post processing and removal of support material through the help pf chemical solvent. Here the support material can be separated from the part directly by tearing it off. Final part is shown in fig. 5.4 this part was used for flexural strength test as per ASTM standard ASTM – D790 for material characterization of ABS plastic.

Fig. 5.5 Printed Part

Quiz

1. Enlist various command which is being used in FDM and SLA machine.
2. How to set process parameter while printing parts on SLA?

Criteria	%	10	9-8	7-6	5
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70-89%.	Student give the correct answers between 50-69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*______		
Total Marks					

Teacher Sign

Experiment- 6

Learning techniques for fabricating an assembly

Objective: (a)To understand the entire process of RP

Relevant CO: (a) Create component with RP applications. (b) Apply fundamentals of rapid prototyping techniques. (c) Use appropriate tooling for rapid prototyping process.

6.1 Introduction

An assembly is an end product consisting of solids in point, line or surface contact. The solids made of different materials. The contacts can be stationary, rolling or sliding. Assemblies can be articulated by having moving contacts.

The traditional approach fabrication involves producing paths first and then assembling them one by one. The process of assembly itself can be manual or automated through mechanized or robotic automation. Much if the progress in assembly modeling has occurred from this traditional viewpoint.

There are four techniques of representation and reasoning techniques for fabricating an assembly in rapid prototyping:

1. Algorithmic

2. Knowledge based

3. Expert system based

4. ANN-based

Many representational and reasoning schemes have been proposed to address issues such as tolerance and mating, connectivity and mating, connectivity and precedence and assembly directions. Almost all these issues are closely related to the mating features on the pans. Hence, progress in assembly modeling has closely related 10 the mating features on the pans. Hence, progress in assembly modeling has depended much on progress in geometric and technological feature recognition.

6.2 Design consideration in assembly

- Tolerance
- Mating
- Connectivity
- Precedence
- Assembly direction

Almost any RP process that can deposit more than one material in each layer and with supports easily removed can be modified to build MM assemblies. When multi-material assembly is made by means of layer-based RP process, all component regions within each layer are built within the corresponding layer build cycle. Hence may traditional assembly issues such as precedence and assembly direction become irrelevant. However, information regarding location dimensions, tolerance, mating relationships and mating types continues to be highly important.

6.3 Approaches of fabrication of assembly

6.3.1 Layer based fabrication methods approach

In fabricating articulated assemblies using layer-based fabrication methods approach, a graph model organizes components in the given assembly by their boundary mating intonation to create an n-manifold (NM) representation. An NM is a connected point set where every point has a neighborhood topologically equivalent to an open ball of En. Local mating information is also explicitly represented, so slicing operations can be performed directly on model. In particular, slicing is performed using a dexel encoding approach that eliminates the need for intermediate tessellation of curved bounding surfaces.

6.3.2 Dexel Approach

The object is intersected by set of parallel and equidistant rays (i.e., infinite straight lines). Next the points of intersection of each ray with the object are noted. Each pair of points defining a straight-line segment. That is totally inside a given object material makes up a dexel. Drexel's corresponding to different material regions within the ray via are identified through an algorithmic approach.

The dexels so obtained are fleshed out into boxes, so the object can be approximated by resulting collections of boxes corresponding to different material regions. Thus, alter slicing the MM assembly, there will be different 2 D regions of the heterogeneous materials. The dexel model of the object is then combined with the 3D assembly model to assimilate mating intonation.

Tolerances are appended to the end points of each dexel such that positive, negative, and zero values indicate interference clearance and neutral fits respectively. Collision free tool paths (path of liquefier heads in FDM) are calculated on the basis based of a longest first scheduling approach. This novel approach facilitates Filling of MM regions simultaneously and efficiently.

6.4 Inevitable impact on assembly and joining operations

An assembly is a collection of manufactured parts, brought together by assembly operations to perform one or more of several primary functions an assembly operation is defined as the process or series of acts involved in actual realization of an assembly. Joining finalizes assembly operating and generates joints.

6.5 Virtual Assembly Analysis (VAA)

The current design and analysis practices for verifying a design concept are usually performed after selecting a final design concept. Prediction of various effects corresponding to specified assembly processes in up-front design is critical to understanding the performance of an assembly. VAA is a transparent and remote virtual simulation and testing paradigm utilized in a service-oriented collaboration environment. A VAA tool embedded in the assembly design process can be used to represent an assembly and imply the physical effects of a joint.

6.6 Assembly design formalism and assembly design model generation

The assembly design formalism specifies assembly/joining relations symbolically and it is used as the mechanism to perform product assembly design tasks. This assembly formalism is comprised of five phases: spatial relationship specification, mating feature extraction, joint feature formation and extraction, assembly feature formation and assembly engineering relation construction. By interactively assigning spatial relationships the designer can assemble components together to make friar products and infer the degrees of freedom remaining on the components.

In assigning spatial relationships, mating features are defined and extracted from parts. Mating feature extraction is a preliminary step to capturing joining information. This process provides geometric information directly related to assembly operation.

The mating feature is not sufficient to represent a joining operational. The designer can specify specific joining methods and constraints such as welding conditions and fixture locations in joint features.

Assembly engineering relations of the entire assembly are constructed based on the assembly features after specifying the spatial relationships and joining relationships between components. The mating binds and an assembly relation model are used to represent the engineering relationships on the entire structure. Their approach was to represent all of the assembly design concepts explicitly and also in a universally acceptable manner.

References:

1. "Rapid prototyping: laser based and other technologies", Patri K. Venuvinod, weiyin Ma, pp. 334-340

Quiz

1. Define term: allowance, tolerances.
2. Enlist various approach for assembly. Explain pros and cons of them.

Criteria	**%**	**10**	**9-8**	**7-6**	**5**
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70-89%.	Student give the correct answers between 50-69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*______		
Total Marks					

Teacher Sign

Experiment- 7

Prepare a CAD model with complex geometry and Study effect of slicing parameters on final product manufactured through RP.

Objective: (a) to understand the effect of process parameter on final product

Relevant CO: (a) Create component with RP applications.

(b) Apply fundamentals of rapid prototyping techniques.

7.1 Introduction:

Rapid prototyping is finding applications in diverse fields in the industry today, with prototypes used for form, fit and function. Design engineers around the world use rapid prototyping to pre estimate product characteristics like shape, manufacturability and finish. Especially when it comes to manufacturing precise parts like aerospace components and parts with critical dimensions, it becomes imperative to check for surface finish a good surface finish on the parts helps eliminate dimensional inaccuracy and cost due to subsequent post processing of the part to attain the desired surface finish. Common surface finishes include the staircase effect, chordal effect, support structure burrs and errors due to starting and ending of deposition. Fused deposition modeling is a layered manufacturing process. In all layered manufacturing process the slicing of the CAD model leaves a characteristic effect called the staircase effect on the part produced. This error cannot be eliminated but can be scaled down by reducing the slice thickness.

The chordal error is induced when STL files are generated from the CAD model. All the curved surfaces in the CAD model are approximated as a series of triangles, hence leading to a non-smooth surface. A rough solution to this problem is to do a positive offset to the surface , build the prototype and then do surface finishing operation to bring it back to the original. This would however never result in a perfect model. It is confirmed that the surface finish problem cannot be completely eliminated. Hence one has to come up with a way to reduce the problem by a certain degree. This can be done by careful process parameter control.

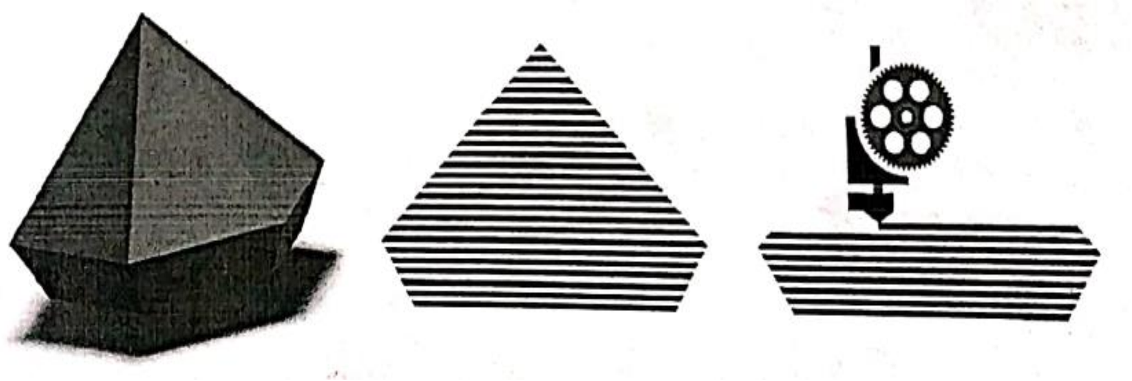


Figure 7.1 slicing of solid model

A number of algorithms have been reported for slicing faceted models with uniform layer thickness (Luo and Ma 1995 and Liao and Chiu 2001a and references therein). Some researchers have also explored adaptive slicing using a variable layer thickness (Tata *et al.* 1998 and Tyberg and Bohn 1998). This section focuses on the basic slicing algorithms applicable to a faceted surface model with uniform slicing. Adaptive slicing will be discussed in the next section together with direct slicing. To efficiently perform model slicing for rapid prototyping applications, the input STL geometry must be organized in a concise data structure.

7.2 Model Slicing and Skin Contour Determination

A STL facet model used for rapid prototyping applications contains a collection of planar faces. These faces define an approximate boundary representation for the object. During subsequent tool path generation, we need to slice the model based on either uniform layer thickness or adaptively variable layer thickness. In this section, we use uniform slicing to illustrate the slicing algorithm. As for adaptive slicing, one only needs to determine the corresponding adaptive layer thickness and the slicing algorithms are the same. A generalized discussion of adaptive slicing will be presented in the next section.

Based on a user-entered layer thickness, a sequence of parallel slicing planes can be defined for model slicing. As a convention, we assume that the model has been properly oriented such that the z-axis will be the building direction. Let d be the layer thickness and n be the total number of slicing planes excluding the bottom plane with z = Zmin that are not used during the slicing procedure. Further, let Zmax and Zmin be the extreme z-coordinatesof the STL model. The total number of layers (valid slicing planes) required is then defined by the following equation

$$n = \frac{Z_{max} - Z_{min}}{d}$$

For RP applications, one further needs to convert the surface contour points into skin contour points for later tool path generation. The determination of skin contours is mainly based on the tolerance requirement. Figure 5 -26 illustrates several cases with different tolerance requirements.

Figure a) shows a model produced using a 'top-down' approach. All the computed surface contours are directly used as skin contours for the current layer for model prototyping.

Figure b) shows a model produced using a 'bottom-up' approach. The computed surface contours are directly used as skin contours of the next layer.

Figure c) shows a model produced with negative tolerance. The produced model is always smaller than the actual computer model.

Figure d) shows a model produced with positive tolerance. The produced model is always larger than the computer model.

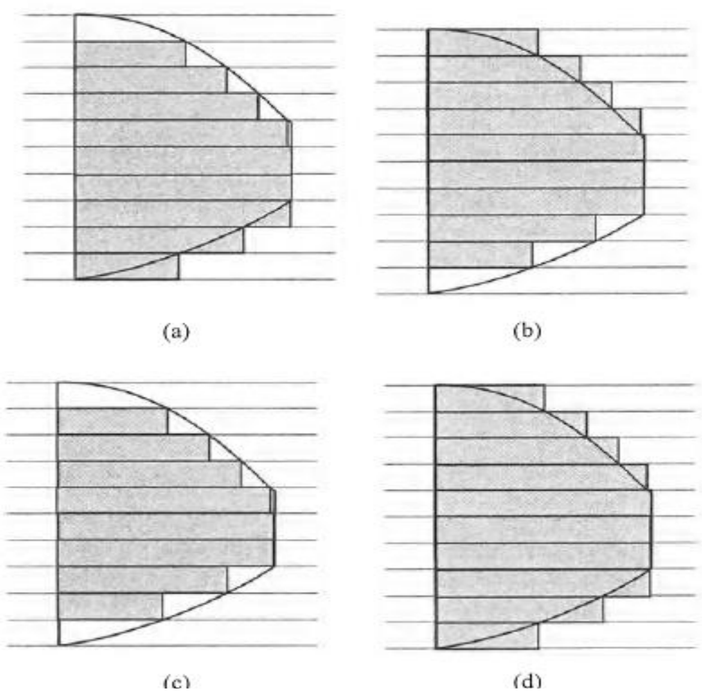


Figure 7.2: a) top down approach b) bottom up approach c) nagative tolerance d) positive tolerance

7.3 Direct and Adaptive slicing:

This section addresses adaptive slicing for obtaining a smooth surface finish while ensuring high building speed. Instead of working with a STL model, direct slicing algorithms are presented, i.e., the algorithms directly work with a CAD model. The discussion is mainly adapted from Ma *et a!.*(2003b) on· direct slicing of a NURBS-based surface model, but is applicable to all parametric surface or B-rep solid models. The general approach is also based on the work reported in (Kulkarni and Dutta 1996) on generic adaptive slicing and (Dolenc and Makela 1994) on adaptive slicing of a STL model. The procedure is subdivided into the following major steps.

Peak feature point identification: When producing prototype models with uniform layer thickness, there is no guarantee that important features of an object, such as horizontal features and other important feature points, are properly reproduced. With adaptive slicing, one can place a layer anywhere and hence all the peak features can be reproduced on the prototype model. In order to do so, all the peak features in a CAD model are first identified from the model surfaces as a set of feature points. These feature points subdivide the CAD model into slabs along the slicing direction, i.e., the z-direction.

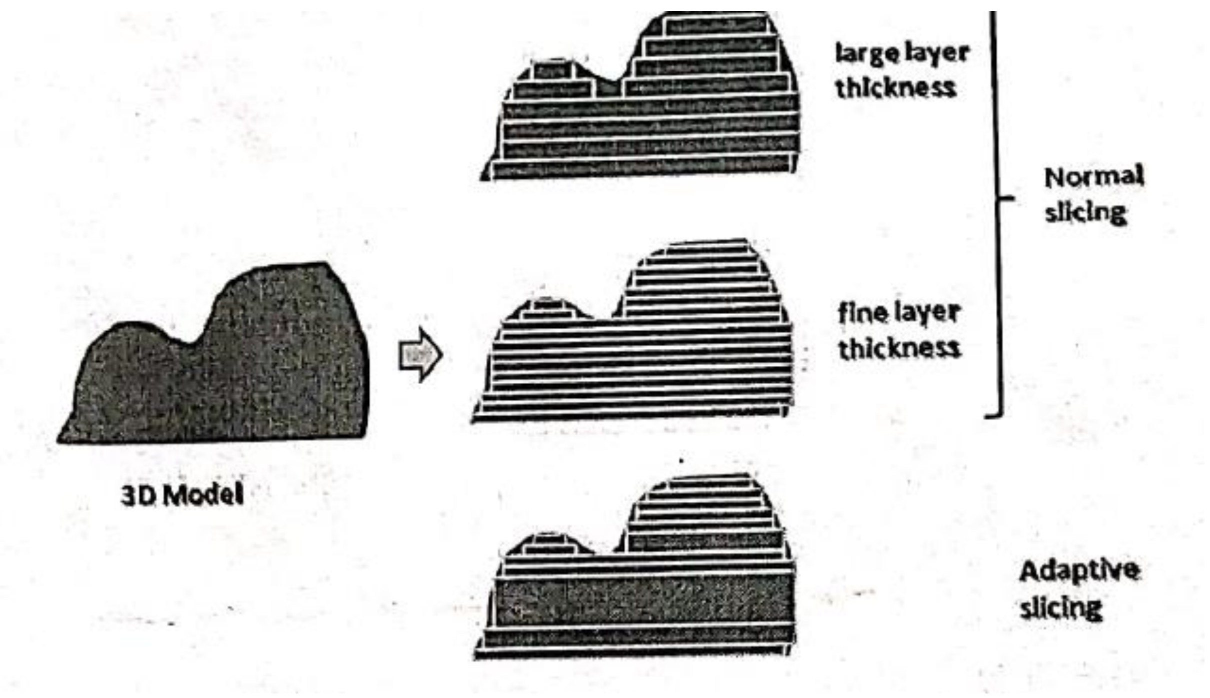


Figure 7.3 normal slicing and adaptive slicing

Adaptive slicing with arbitrary tolerance control: An adaptive slicing algorithm based on surface curvature along the vertical direction at the reference level/points is applied to each of the slabs with a pre-specified cusp height tolerance, and the minimum and maximum layer thickness. The skin contours on each layer are obtained from the allowable layer thickness, the local geometry information, and the given tolerance.

7.4 Adaptive layer thickness determination:

The tolerance requirement of a RP part is an important input for layer thickness determination. The tolerance distribution can be either negative, positive or a combination of both as illustrated in Figure c. The negative tolerance shown in Figure 5-33a can be used for situations where the fabricated RP part acts as a core pattern. The positive tolerance shown in Figure 5 -33b is often used in situations where a post-treatment operation, such as polishing, can be entertained. Both the cases of negative and positive tolerances are addressed in (Kulkarni and Dutta 1996) as a containment problem. In other general situations, a mixed tolerance as shown in Figure c might be desirable for faithfully representing the model shape or for satisfying other fitting conditions. This section provides a generalization of the containment problem where the user may use an arbitrary combination of both negative and positive tolerances. It is therefore possible for users to control the fitting conditions irrespective of whether the RP model is to be used as a core pattern or is followed by some post treatment operations. In this case, the same distribution of the mixed tolerance occurs at all layers. This feature is different from the situation pointed out in (Sabourin *et a l.*1996, Kulkarni and Dutta 1996) where the RP part is skewed.

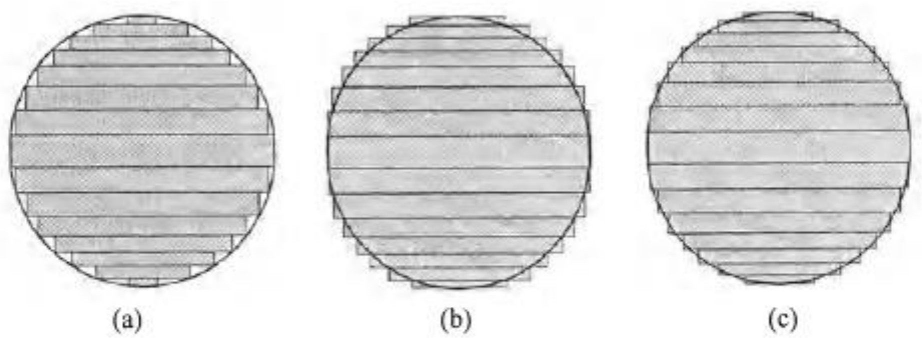


Figure 7.4: a) negative tolerance b) positive tolerance c) mixed tolerance

7.5 Identification of peak features:

Peak features of an object are easily missed when performing slicing in Layered manufacturing (Dolenc and Makela 1 994). Figure 3 illustrates two slicing strategies. All the peak features are preserved with the second strategy shown in Figure 3 b. This is however not the case for the first strategy shown in Figure 3 a. A peak feature may occur at places including a corner, a boundary curve, and an interior area of a surface. A peak feature may also be a horizontal edge or a horizontal face. For the purpose of layered manufacturing, all peak features can be handled with characteristic/feature points on the individual surfaces.

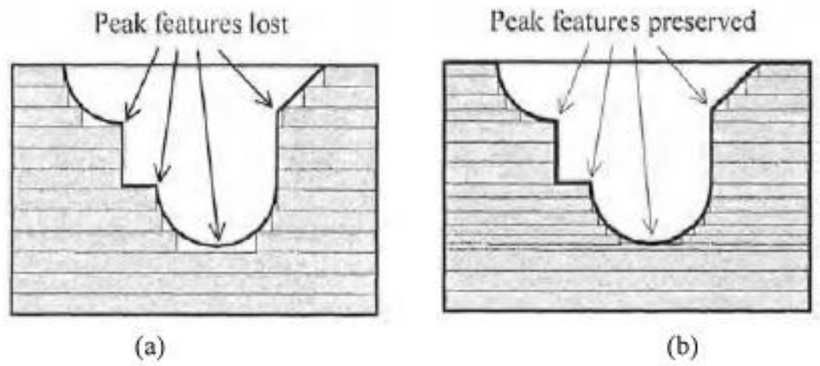


Figure 7.5 (a) peak features lost with uniform slicing; (b) peak feature preserved with adaptive slicing

Quiz

1. Discuss the effect of layer thickness on curve surface.
2. How can overcome the issue related high layer thickness.

Criteria	%	10	9-8	7-6	5
Knowledge	30	Students give the correct answers 90% or more.	Student give the correct answers between 70-89%.	Student give the correct answers between 50-69%.	Student gives the correct answers less than 50%.
Quality of report	35	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tables, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Participation	20	Participation 25% Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	15	Timely Submission	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Criteria	**%**	**Level of Marks**	**Multiplication**	**Total**	**Remarks**
Knowledge	30		0.3 *_____		
Quality of report	35		0.35*_____		
Participation	20		0.2*_____		
Punctuality	15		0.15*______		
Total Marks					

Teacher Sign

Acknowledgement

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