Presentation for
RAPID PROTOTYPING TEHNOLOGIES
DEPARTMENT OF MECHANICAL ENGINEERING
M.TECH : I SEM

by

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1. Fundamentals of Rapid Prototyping

2. Rapid Prototyping Technologies

3. Applications and Benefits of Rapid Prototyping

RAPID PROTOTYPING

Rapid Prototyping (RP)

A family of fabrication processes developed to make engineering prototypes in minimum lead time based on a CAD model of the item .

Traditional method is machining Can require significant lead-times – several weeks, depending on part complexity and difficulty in ordering materials.

RP allows a part to be made in hours or days, given that a computer model of the part has been generated on a CAD system

RP – Two Basic Categories:

1. Material removal RP - machining, using a dedicated CNC machine that is available to the design department on short notice
   - Starting material is often wax
     - Easy to machine
     - Can be melted and resolidified
   - The CNC machines are often small - called desktop machining
2. Material addition RP - adds layers of material one at a time to build the solid part from bottom to top

Starting Materials in Material Addition RP

1. Liquid monomers that are cured layer by layer into solid polymers

2. Powders that are aggregated and bonded layer by layer

3. Solid sheets that are laminated to create the solid part

Additional Methods

- In addition to starting material, the various material addition RP technologies use different methods of building and adding layers to create the solid part

- There is a correlation between starting material and part building techniques

Steps to Prepare Control Instructions

1. Geometric modeling - model the component on a CAD system to define its enclosed volume

2. Tessellation of the geometric model - the CAD model is converted into a computerized format that approximates its surfaces by facets (triangles or polygons)

3. Slicing of the model into layers - computerized model is sliced into closely-spaced parallel horizontal layers

Classification of RP Technologies

- There are various ways to classify the RP techniques that have currently been developed

- The RP classification used here is based on the form of the starting material:

  1. Liquid-based

  2. Solid-based

  3. Powder-based

Liquid-Based Rapid Prototyping Systems

- Starting material is a liquid

- About a dozen RP technologies are in this category

- Includes the following processes:

  – Stereolithography

  – Solid ground curing

  – Droplet deposition manufacturing

Stereolithography (STL)

RP process for fabricating a solid plastic part out of a photosensitive liquid polymer using a directed laser beam to solidify the polymer

- Part fabrication is accomplished as a series of layers - each layer is added onto the previous layer to gradually build the 3-D geometry

- The first addition RP technology - introduced 1988 by 3D Systems Inc. based on the work of Charles Hull More installations than any other RP method
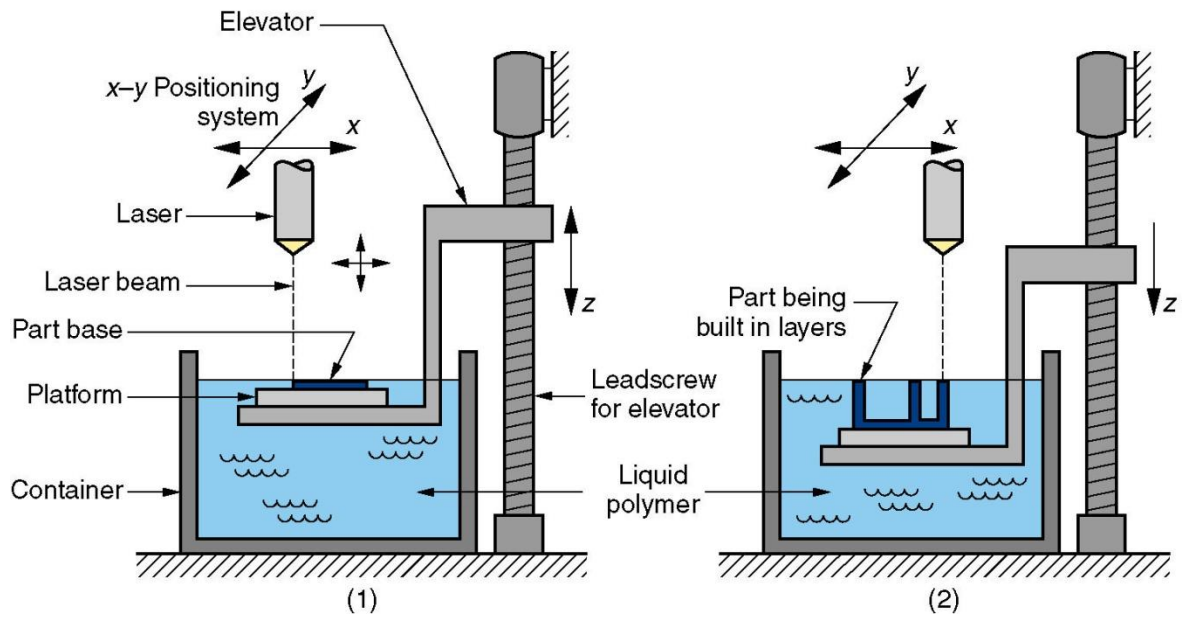
Stereolithography

Figure 1.0 Stereolithography: (1) at the start of the process, in which the initial layer is added to the platform; and (2) after several layers have been added so that the part geometry gradually takes form.

Solid Ground Curing (SGC)

Like stereolithography, SGC works by curing a photosensitive polymer layer by layer to create a solid model based on CAD geometric data

- Instead of using a scanning laser beam to cure a given layer, the entire layer is exposed to a UV source through a mask above the liquid polymer
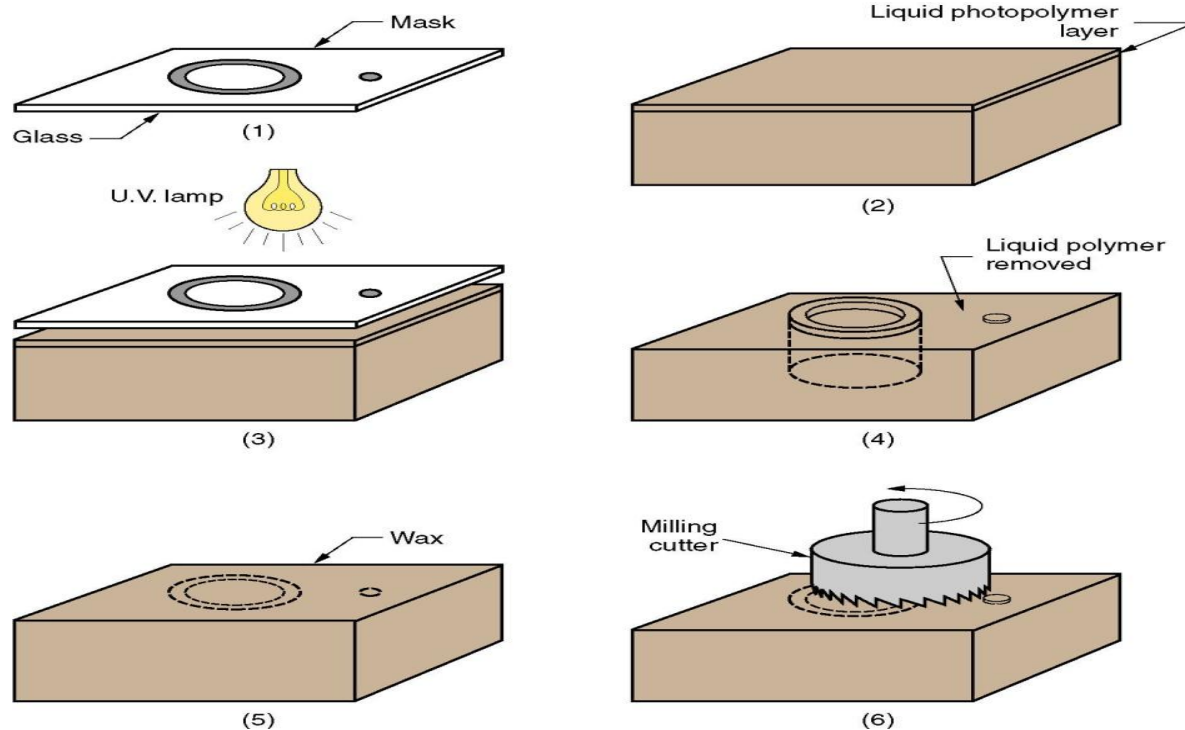- Hardening takes 2 to 3 s for each layer

Solid Ground Curing

Figure 2.0 SGC steps for each layer: (1) mask preparation, (2) applying liquid photopolymer layer,(3) mask positioning and exposure of layer, (4) uncured polymer removed from surface, (5) wax filling, (6) milling for flatness and thickness.

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Facts about SGC

- Sequence for each layer takes about 90 seconds

- Time to produce a part by SGC is claimed to be about eight times faster than other RP systems

- The solid cubic form created in SGC consists of solid polymer and wax

- The wax provides support for fragile and overhanging features of the part during fabrication, but can be melted away later to leave the free-standing part

Droplet Deposition Manufacturing (DDM)

Starting material is melted and small droplets are shot by a nozzle onto previously formed layer Droplets cold weld to surface to form a new layer

- Deposition for each layer controlled by a moving x-y nozzle whose path is based on a cross section of a CAD geometric model that is sliced into layers .Work materials include wax and thermoplastics

## Solid-Based Rapid Prototyping Systems

- Starting material is a solid

- Solid-based RP systems include the following processes:

    – Laminated object manufacturing

    – Fused deposition modeling

Laminated Object Manufacturing (LOM)

Solid physical model made by stacking layers of sheet stock, each an outline of the cross-sectional shape of a CAD model that is sliced into layers

- Starting sheet stock includes paper, plastic, cellulose, metals, or fiber-reinforced materials
- The sheet is usually supplied with adhesive backing as rolls that are spooled between two reels
- After cutting, excess material in the layer remains in place to support the part during building

Laminated Object Manufacturing
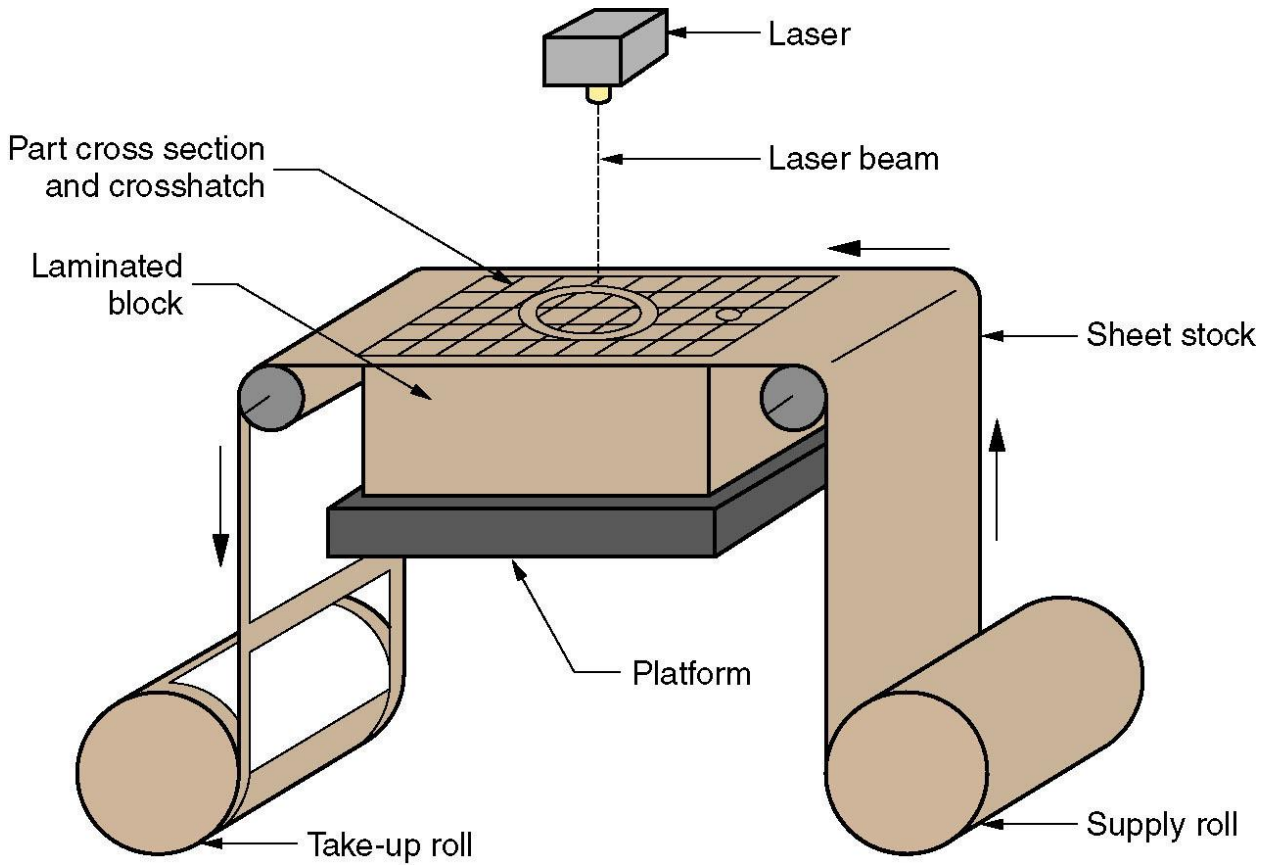
- Starting material is a powder

- Powder-based RP systems include the following:

  – Selective laser sintering
  – Three dimensional printing

Selective Laser Sintering (SLS)

Moving laser beam sinters heat-fusible powders in areas corresponding to the CAD geometry model one layer at a time to build the solid part

- After each layer is completed, a new layer of loose powders is spread across the surface

- Layer by layer, the powders are gradually bonded by the laser beam into a solid mass that forms the 3-D part geometry

- In areas not sintered, the powders are loose and can be poured out of completed part

Three Dimensional Printing (3DP)

Part is built layer-by-layer using an ink-jet printer to eject adhesive bonding material onto successive layers of powders

- Binder is deposited in areas corresponding to the cross sections of part, as determined by slicing the CAD geometric model into layers

- The binder holds the powders together to form the solid part, while the unbonded powders remain loose to be removed later

- To further strengthen the part, a sintering step can be applied to bond the individual powders

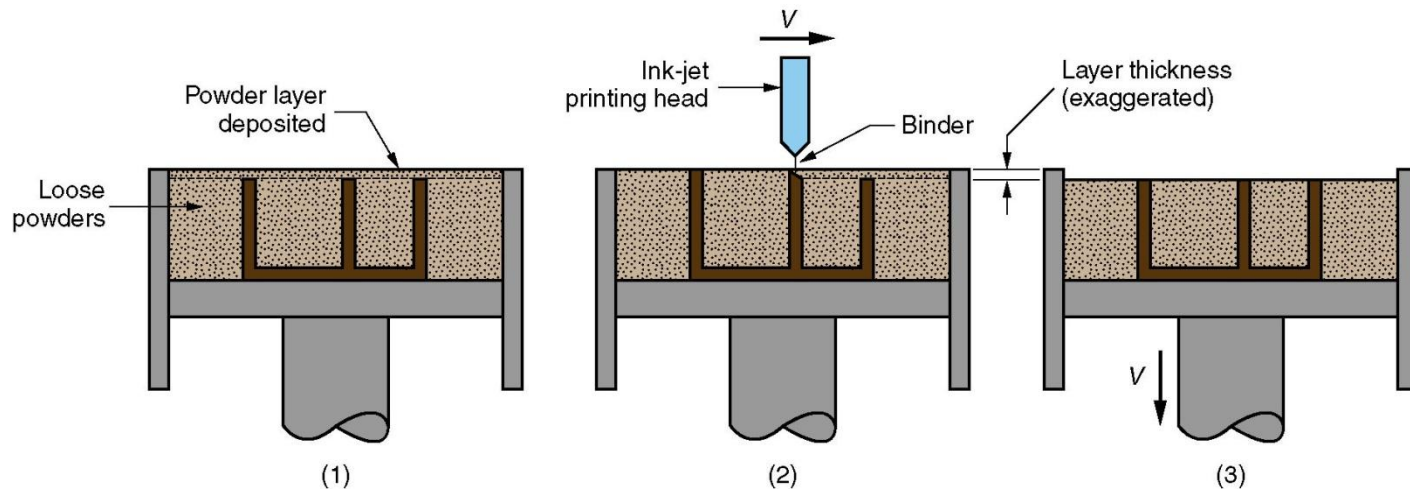# Three Dimensional Printing

Figure. Three dimensional printing: (1) powder layer is deposited, (2) ink-jet printing of areas that will become the part, and (3) piston is lowered for next layer (key: *v* = motion).

RP Applications

- Applications of rapid prototyping can be classified into three categories:

  1. Design

  2. Engineering analysis and planning

  3. Tooling and manufacturing

Design Applications

- Designers are able to confirm their design by building a real physical model in minimum time using RP

- Design benefits of RP:

  – Reduced lead times to produce prototypes

  – Improved ability to visualize part geometry

  – Early detection of design errors

  – Increased capability to compute mass properties

Problems with Rapid Prototyping

- Part accuracy:
  - Staircase appearance for a sloping part surface due to layering
  - Shrinkage and distortion of RP parts
- Limited variety of materials in RP
  - Mechanical performance of the fabricated parts is limited by the materials that must be used in the RP process

Rapid Prototyping Systems

The term *rapid prototyping* (RP) refers to a class of technologies that can automatically construct physical models from Computer-Aided Design (CAD) data.

These "three dimensional printers" allow designers to quickly create tangible prototypes of their designs, rather than just two-dimensional pictures.

- Most prototypes require from three to seventy-two hours to build, depending on the size and complexity of the object.

- This may seem slow, but it is much faster than the weeks or months required to make a prototype by traditional means such as machining.

- These dramatic time savings allow manufacturers to bring products to market faster and more cheaply.

Rapid Prototyping Systems

- Such models have numerous uses:

  – Excellent visual aids for communicating

  – Prototypes can be used for design testing.

  – Used to make tooling

  – Used to make production-quality parts

All RP techniques employ the same basic five-step process.

1. Create a CAD model of the design
2. Convert the CAD model to STL format (stereo lithography)
3. Slice the STL file into thin cross-sectional layers
4. Construct the model one layer atop another
5. Clean and finish the model

- **CAD Model Creation:**
  - First, the object to be built is modeled using a Computer-Aided Design (CAD) software package.

  - Solid modelers, such as Pro/ENGINEER, tend to represent 3-D objects more accurately than wire-frame modelers such as AutoCAD, and will therefore yield better results.

  - This process is identical for all of the RP build techniques.

- **Conversion to STL Format:**
  - To establish consistency, the STL (stereo lithography, the first RP technique) format has been adopted as the standard of the rapid prototyping industry.

  - The second step, therefore, is to convert the CAD file into STL format. This format represents a three-dimensional surface as an assembly of planar triangles

  - STL files use planar elements, they cannot represent curved surfaces exactly. Increasing the number of triangles improves the approximation

- **Slice the STL File:**
  - In the third step, a pre-processing program prepares the STL file to be built.

  - The pre-processing software slices the STL model into a number of layers from 0.01 mm to 0.7 mm thick, depending on the build technique.

  - The program may also generate an auxiliary structure to support the model during the build. Supports are useful for delicate features such as overhangs, internal cavities, and thin-walled sections.

- **Layer by Layer Construction:**
  - The fourth step is the actual construction of the part.

  - RP machines build one layer at a time from polymers, paper, or powdered metal.

  - Most machines are fairly autonomous, needing little human intervention.

- **Clean and Finish:**
  - The final step is post-processing. This involves removing the prototype from the machine and detaching any supports.

  - Some photosensitive materials need to be fully cured before use

  - Prototypes may also require minor cleaning and surface treatment.

  - Sanding, sealing, and/or painting the model will improve its appearance and durability.

Fused Deposition Modeling

- (FDM) is a solid-based rapid prototyping method that extrudes material, layer-by-layer, to build a model.

- A thread of plastic is fed into an extrusion head, where it is heated into a semi-liquid state and extruded through a very small hole onto the previous layer of material.

- Support material is also laid down in a similar manner.

Advantages of FDM Process

- High strength

- Cost-effective

- Waterproof

- ABS material

- Multiple material colors

FDM 2000 Specifications

Prodigy Specifications

•Build Volume: 10" x 10" x 10"
•Materials:ABS, Casting Wax
•Build Step Size: 0.005" to 0.030"

Build Volume: 8" x 8" x 10"

Materials: ABS, Casting Wax

Build Step Size: 0.007", 0.010", 0.013"

Up to 4x faster than the FDM 2000

Fused Deposition Modeling

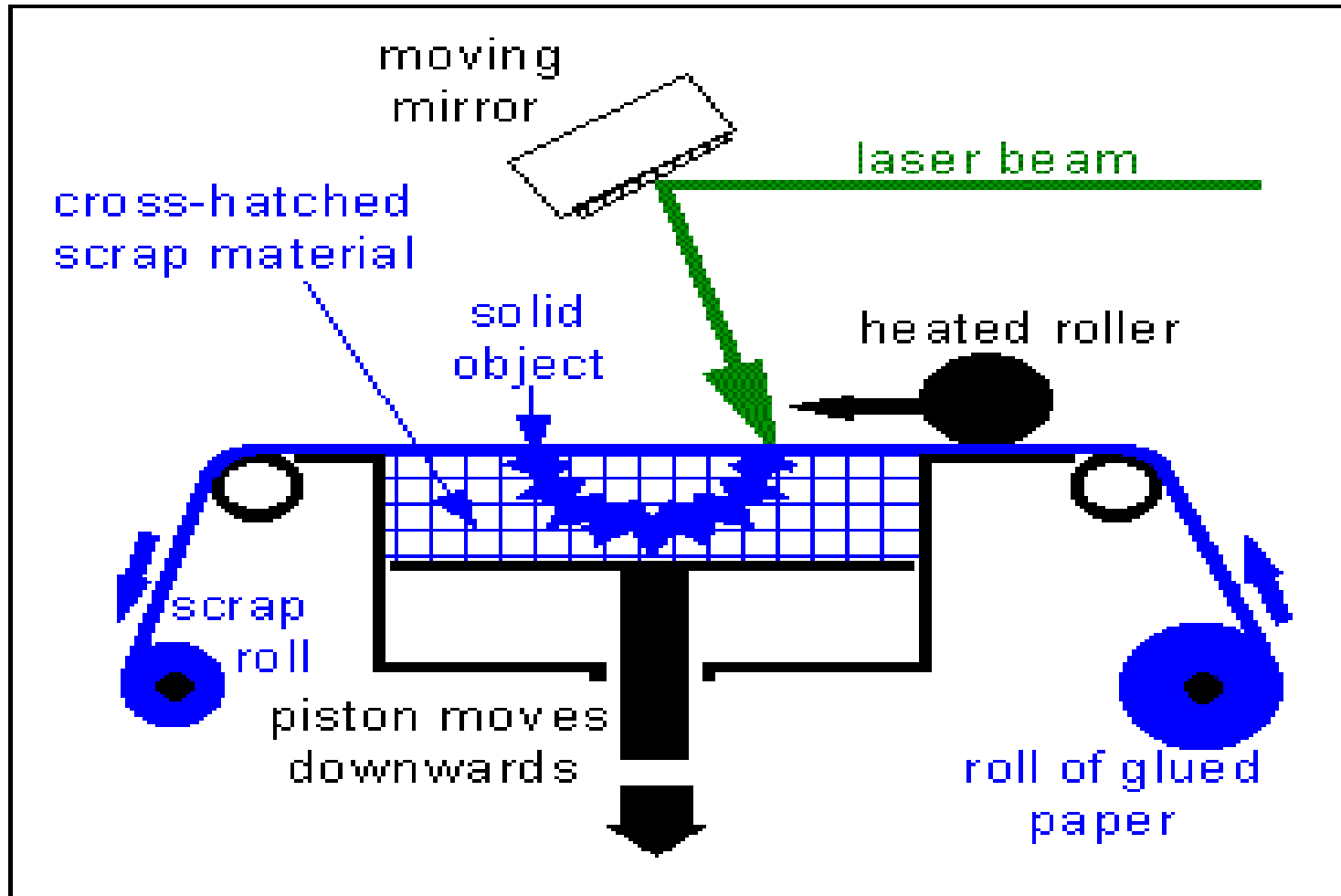# Examples of
Fused Deposition Modeling

Laminated Object Manufacture

- As the name implies the process laminates thin sheets of film (paper or plastic)

- The laser has only to cut/scan the periphery of each layer

- The process:
  - The build material (paper with a thermo-setting resin glue on its under side) is stretched from a supply roller across an anvil or platform to a take- up roller on the other side.

  - A heated roller passes over the paper bonding it to the platform or previous layer.

  - A laser, focused to penetrate through one thickness of paper cuts the profile of that layer. The excess paper around and inside the model is etched into small squares to facilitate its removal.

- The process continued:
  - The process of gluing and cutting continuous layer by layer until the model is complete.

  - To reduce the build time, double or even triple layers are cut at one time which increases the size of the steps on curved surfaces and the post processing necessary to smooth those surfaces.

- Applications of LOM objects:
  – LOM objects are durable, multilayered structures which can be machined, sanded, polished, coated and painted.

  – Used as precise patterns for secondary tooling processes such as rubber moulding, sand casting and direct investment casting.

  – Used for limited testing.

  – Used as visual models.

moving mirror

laser beam

cross-hatched scrap material

solid object

heated roller

scrap roll

piston moves downwards

roll of glued paper

Examples of Laminated Object Manufacture

- # Wind Turbine

  - In this case the LOM process was initially used to check the CAD geometry: subsequently the model was used as a sand casting pattern. The picture opposite shows 5 identical blades assembled around an SLA hub.

- A LOM model was built for a customer who required a prototype to test the fit and operation of internal components in an electrical housing.

- Prototype: It is a model fabricated to prove out a concept or an idea.

- Solid Modelling: It's a branch of CAD that produces 2D or 3D objects in an electronic format.

- Rapid prototyping is basically a additive manufacturing process used to quickly fabricate a model of a part using 3-D CAM data.

- It can also be defined as layer by layer fabrication of 3D physical models directly from CAD.

Need for Rapid Prototyping

- To increase effective communication.

- To decrease development time.

- To decrease costly mistakes.

- To minimize sustaining engineering changes.

- To extend product life time by adding necessary features & eliminating redundant features early in the design.

- Increasing the no of variants of products.

- Increase in product complexity.

- Decrease in product lifetime before obsolescence.

- Decrease in delivery time.

- Product development by Rapid prototyping by enabling better communication.

Conventional Machining

- Its not suitable for complex shapes because they are difficult to machine.

- Time consuming

- Very costly

- Tedious or very laborious.

- Skilled operator is required.

- Accuracy will be less.

- Increased product development time.

- Pre-processing:- CAD model slicing & setting algorithms applied for various RP systems

- Post-processing:-Cleaning operations required to finish a part after removing it from RP machine.

- Materials for Rapid Prototyping: Paper, Wax, Plastics, Resins, Metallic powders.
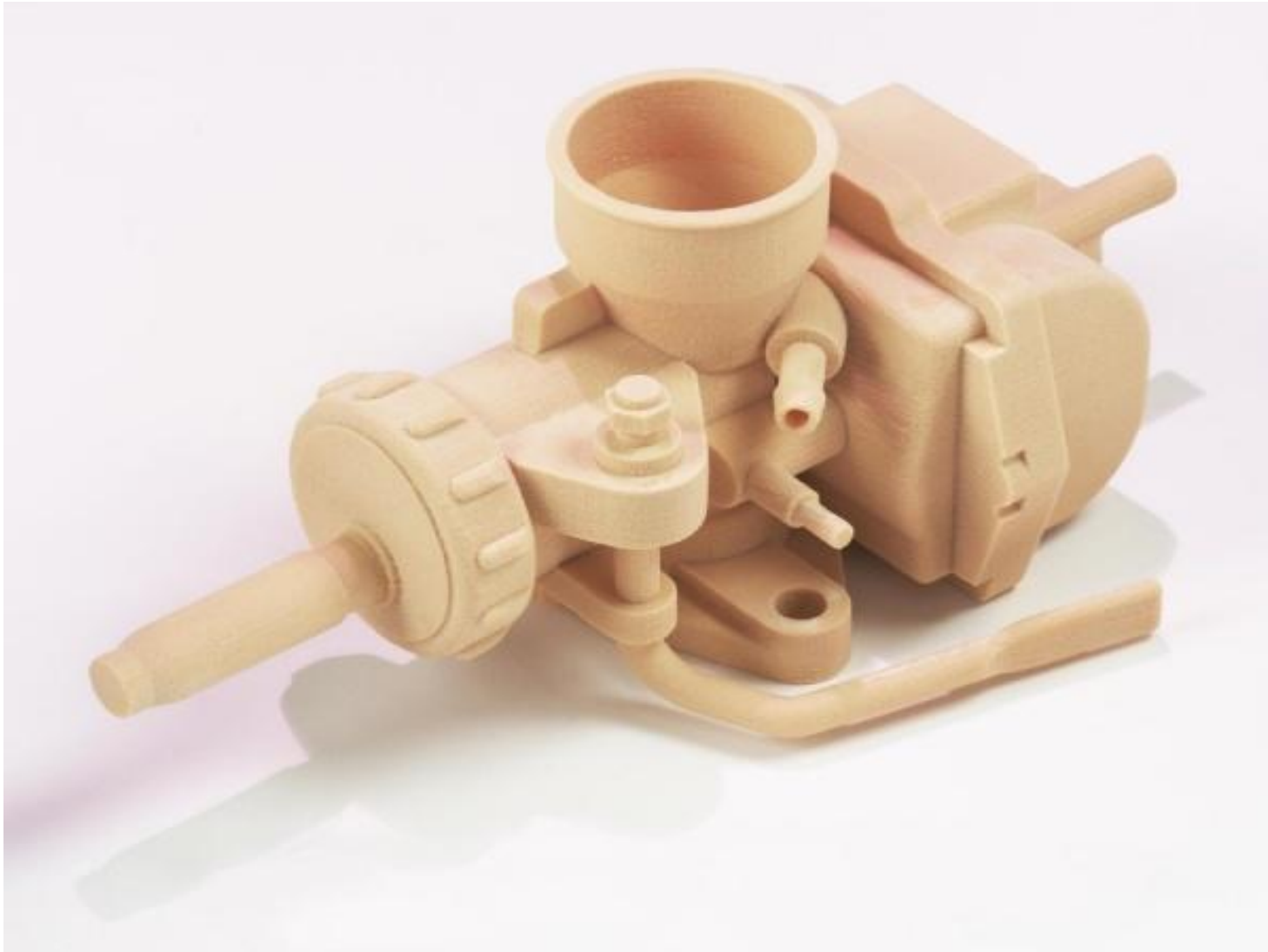
Methodology of Rapid Prototyping

- Construct a CAD model.

- Convert it to STL format.

- RP machine processes .STL file by creating sliced layers of model.

- First layer of model is created.

- Model is then lowered by thickness of next layer.

- Process is repeated until completion of model

- The model & any supports are removed.

- Surface of the model is then finished and cleaned.

Software

- **SLA CONTROL AND SET UP SOFTWARE**: It operates on SLA 250 and SLA 500 machines. It has got three packages.

- a) **SLA VIEW**: UNIX based system for viewing and positioning.

- b) **BRIDGE WORKS**: UNIX based software for generating support structures.

- c) SLA SLICE: Slicing and system operation software.

- **MAESTRO**: UNIX based software

- **MS WINDOWS NT SOFTWARE (3D LIGHT YEAR):** It is used for viewing, positioning, support generation and slicing, build station for operating SLA machine.

- **Build Materials Used:**
  - Epoxy Resin, Acrylate Resin
  - Epoxy Resin has better material properties and less hazardous but require large exposure time for curing.

SLA Hardware

- A **removable VAT** that holds the build resin.

- A detachable **perforated build platen** on a Z axis elevator frame

- An automated **resin level checking apparatus**

- VAT has a small amount of Z movement capability which allows computer to maintain a exact height per layer.

- A recoated blade rides along the track at the top of the rack and serves to smooth the liquid across the part surface to prevent any rounding off edges due to cohesion effects.

- Some systems have **Zaphyr recoater blade** which actually **softens up resin and delivers it evenly** across the part surface.

- Behind the build chamber resides the laser and optics required to cure resin.

- Laser unit is long rectangular about 4 feet long and remains stationary.

STL FORMAT

- Representation methods used to describe CAD geometry vary from one system to another.

- A standard interface is needed to convey geometric descriptions from various CAD packages to rapid prototyping systems.

- The STL (**STereoLithography**) **file, as the *de facto* standard, has been** used in many, if not all, rapid prototyping systems.

ADVANTAGES OF STL FILE

- It provides a simple method of representing 3D CAD data.

- It is already a *de facto standard and has been used by most CAD* systems and rapid prototyping systems.

- Finally, it can provide small and accurate files for data transfer for certain shapes.

TWO FORMATS OF STL FILE

- ASCII format
- Binary format
- The size of the ASCII STL file is larger than that of the binary format but is human readable.
- In a STL file, triangular facets are described by a set of *X, Y and Z* coordinates for each of the three vertices and a unit normal vector with *X, Y and Z to indicate which side of facet is an object.*
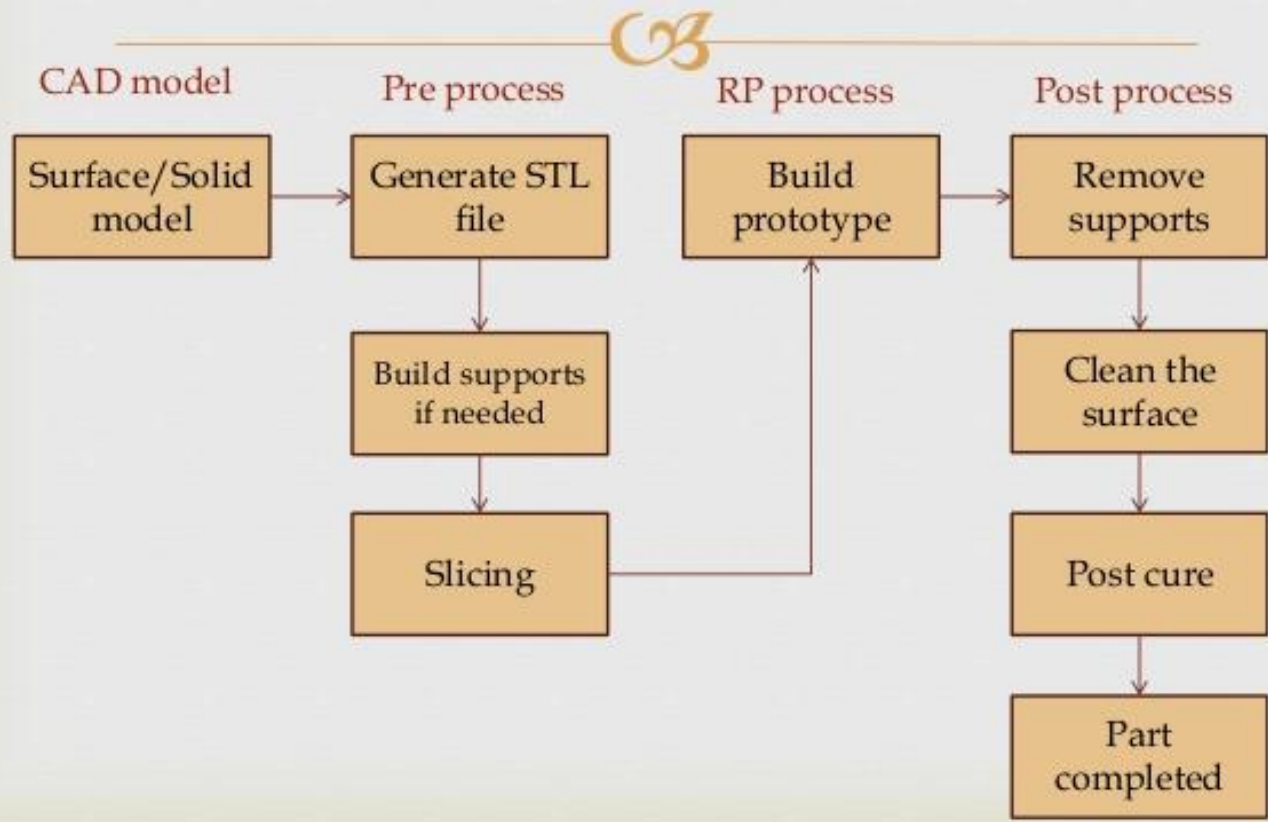
STL FORMAT…

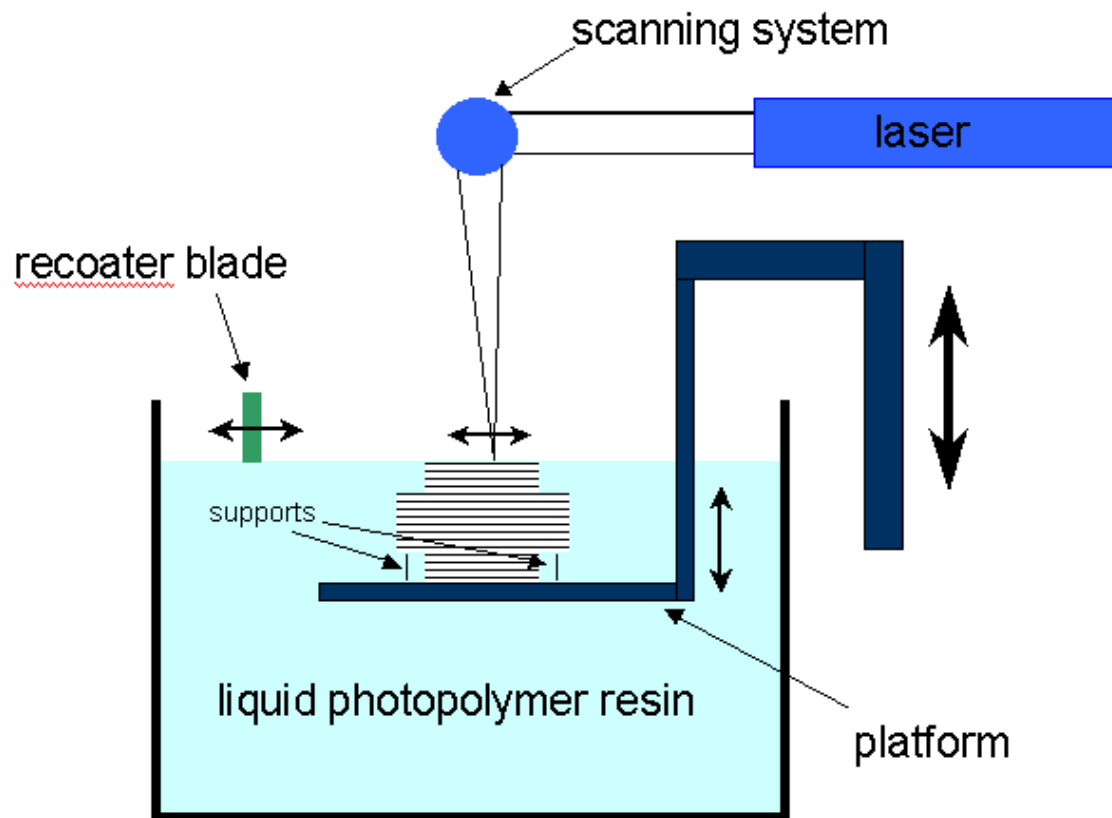- The STL file, conceived by the 3D Systems, USA, is created from the CAD database via an interface on the CAD system.

- This file consists of an unordered list of triangular facets representing the outside skin of an object.

Stereolithography

Stereolithography Apparatus Operation

- The process begins with the solid model in various CAD formats

- The solid model must consist of **enclosed volumes** before it is translated form CAD format into **.STL FILE**

- The solid model is oriented into the **positive octant of Cartesian co-ordinate** system and then translate out Z axis by at least 0.25 inches to allow for building of supports

- The solid model is also **oriented** for optimum build which involves placing complex curvatures in XY plane where possible and rotating for least Z height as well as to where least amount of supports are required.

- The .STL FILE is verified.

- The final .STL FILE one which supports in addition to original file are then sliced into horizontal cross sections and saved as slice file.

- The slice files are then masked to create four separate files that control SLA machine ending with 5 extensions L, R, V and PRM.

- Important one is V file. I.e. Vector file. The V file contains actual line data that the laser will follow to cure the shape of the part.

- R file is the range file which contains data for solid or open fields as well as re-coater blade parameters.

- The four build files are downloaded to SLA which begins building supports with platen adjust above the surface level. The first few support layers are actually cured into perforations into platen, thus providing a solid anchor for the rest of the part.

- By building, SLA uses laser to scan the cross section and fill across the surface of resin which is cured or hardened into the cross sectional shape.

- The platen is lowered as the slices are completed so that more resin is available in the upper surface of the part to be cured. Final step is Post Processing.

- **Post Processing:**
- Ultraviolet Oven (Post Curing Apparatus)
- An Alcohol Bath.
- Clean the part in the alcohol bath and then go for final curing.

- **Advantages:**
  - Parts have best surface quality
  - High Accuracy
  - High speed
  - Finely detailed features like thin vertical walls, sharp corners & tall columns can be fabricated with ease.
- **Disadvantages:**
  - It requires Post Processing. i.e. Post Curing.
  - Careful handling of raw materials required.
  - High cost of Photo Curable Resin.

- **Applications:**
  - Investment Casting.
  - Wind Tunnel Modeling.
  - Tooling.
  - Injection Mould Tools.

Helium Cadmium Laser System

Platform which moves up and down

Finished Part

Epoxy or Acrylate Resin

VAT
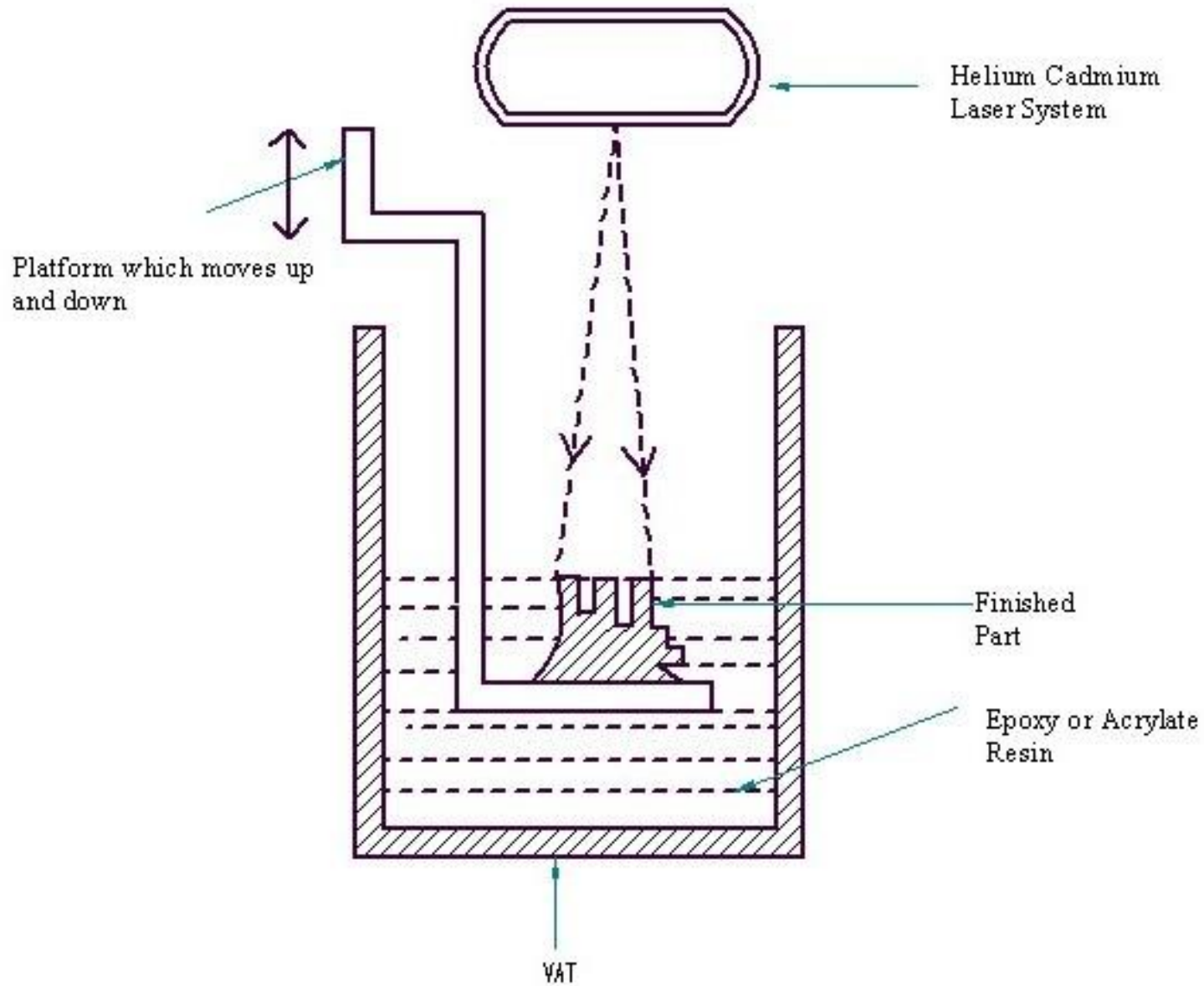
Selective Laser Sintering
(SLS)

- DTM sinter station 2500 is the machine used for the process.

- Selective Laser Sintering begins like most other rapid prototyping processes with a standard .

- STL CAD file format. **DTM view software** uses the .STL files. This software do the required orientation and scaling of parts.

- This machine has **auto nesting** capabilities which will place multiple part optimally in the build chamber **for best processing speed and results**. Once the .STL file is placed and parameters are set the model is directly built from the file.

Principle of Operation

selective laser sintering
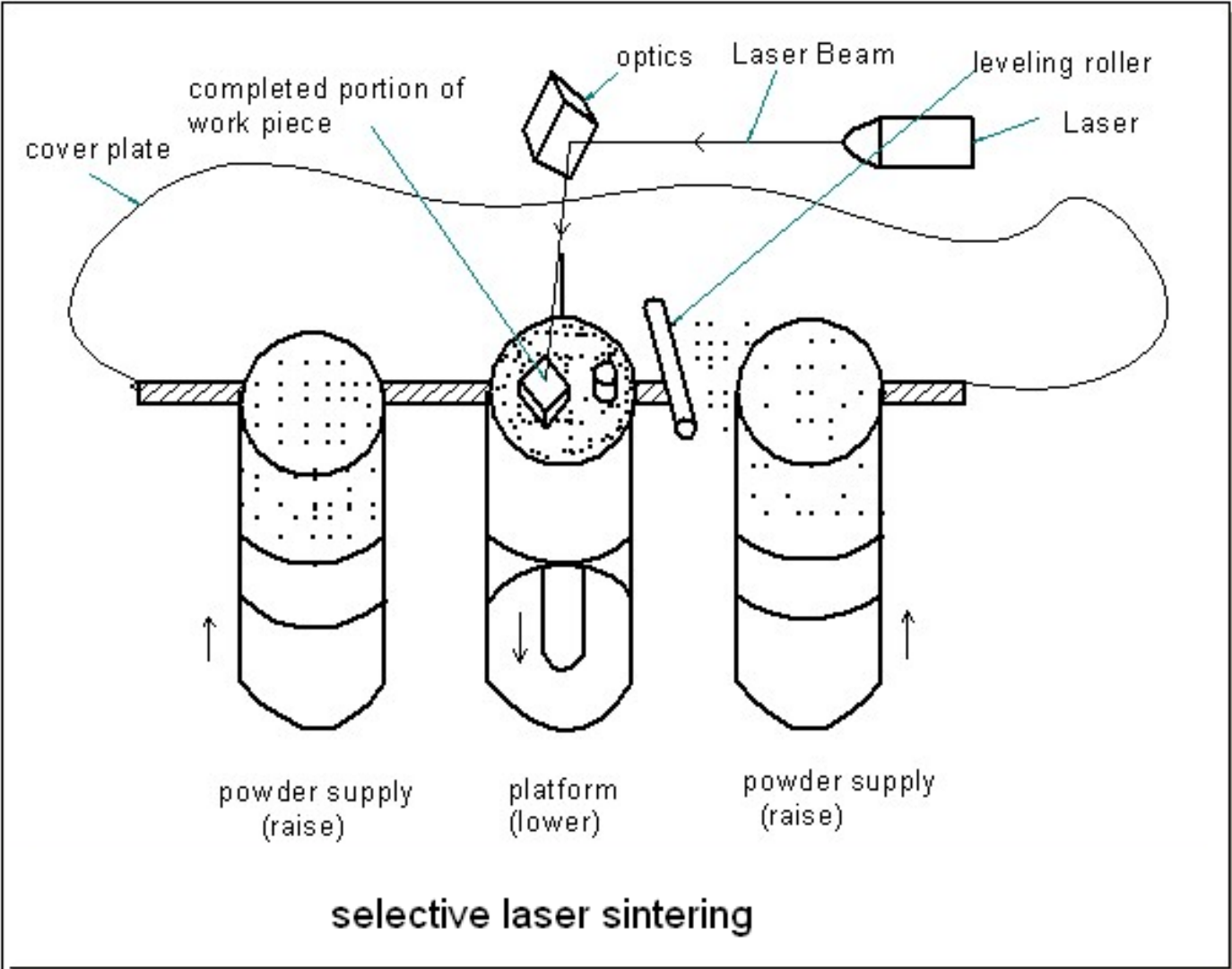
- The sinter station has build piston at the center and feed piston on the either side.

- The model is built layer by layer like other rapid prototyping process so that the build piston will begin at the top of its range and will lower in increments of the set layer size as parts are built.

- With the build piston at the top a thin layer of powder is spread across the build area by the roller from one of the feed piston. The laser then cures in a raster sweeps motion across the area of the parts being built.

- The part piston lowers and more powder is deposited and the process is continued until all of the part is built.

- The build media is removed from the machine. It is a cake of powder.

- This cake is taken to the breakout station where excess powder is removed from the part manually with brushes.

- The excess powder that has been removed can be kept for recycling and can be reused.

- Some material needs additional finishing. Some of the finishing techniques include grid blasting, sanding, polishing, drilling, taping and coating .

- **Purpose of Selective Laser Sintering:**
  - To provide a prototyping tool
  - To decrease the time and cost of design to product cycle.
  - It can use wide variety of materials to accommodate multiple application throughout the manufacturing process.

scanning system

CO$_2$ laser

Temperature-controlled build chamber with nitrogen atmosphere

Powder-leveling roller

powder bed on build piston

powder feed

excess powder takeup
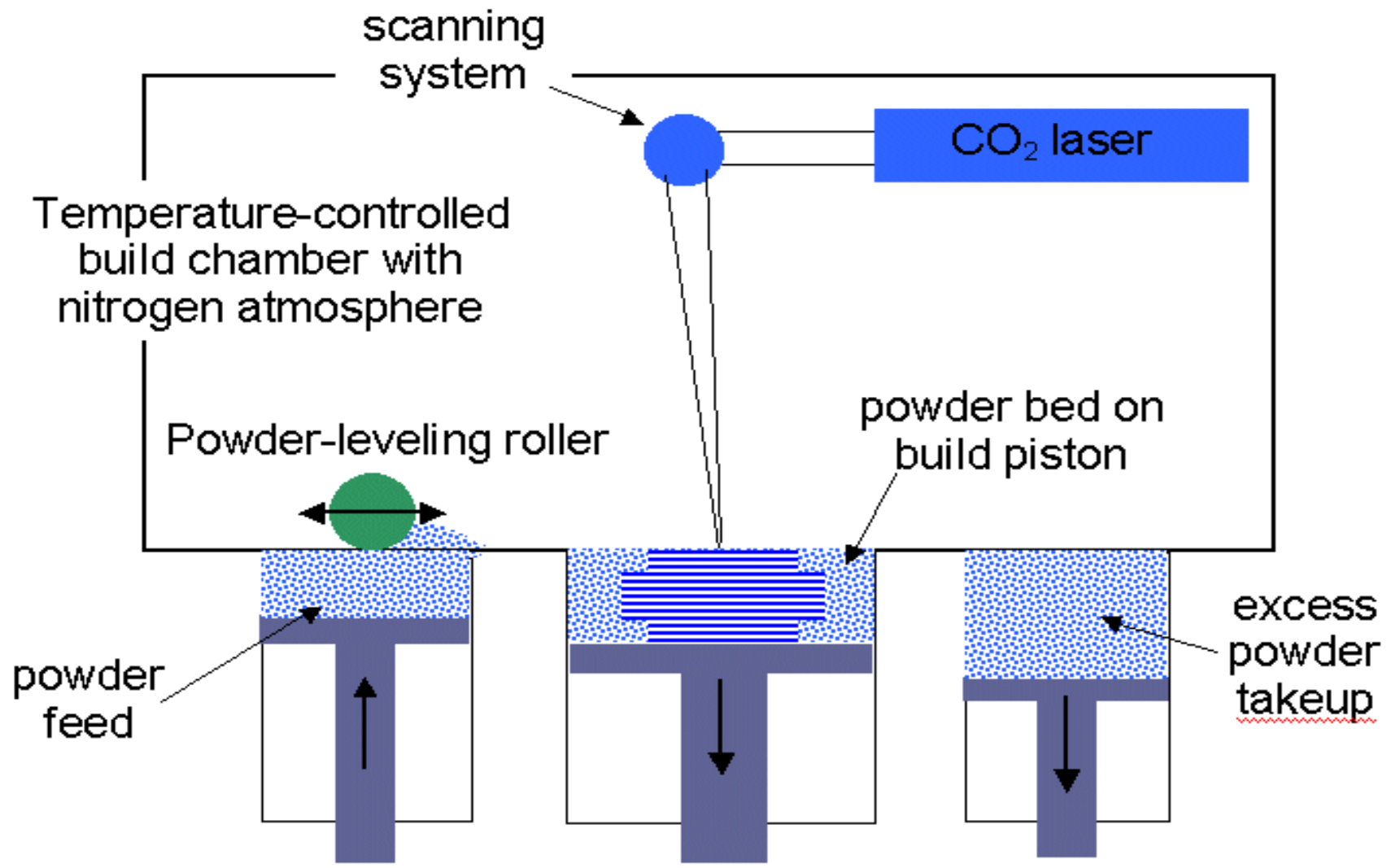
- **Applications:**

  1. As conceptual models.

  2. Functional prototypes.

  3. As Pattern masters.

- **Advantages:**

  1. Wide range of build materials.

  2. High throughput capabilities.

  3. Self supporting build envelop.

  4. Parts are completed faster.

  5. Damage is less.

  6. Less wastage of material.

- **Disadvantages:**

    1. Initial cost of system is high.

    2. High operational and maintenance cost.

    3. Peripheral and facility requirement.

Fused Deposition Modeling

Introduction:

- Fused Deposition Modeling is an extrusion based rapid prototyping process although it works on the same layer by layer principle as other RP systems.

- Fused Deposition Modeling relies on standard STL data file for input and is capable of using **multiple build materials** in a build or support relationship.

Software Used:

- FDM machine uses **Quick Slice software** to manipulate and prepare the incoming STL data for use in FDM machines. Software can be operated on various types of workstations from **UNIX to PC based**.

Build Materials:

- Investment Casting Wax.

- Acrilonitrile Butadine Styrene plastic.

- Elastomer.

Extrusion Head :

   It is a key to FDM technology.

   Compact and removable unit.

    It consists of Drive Blocks, Heating Chamber and Tips.

Heated Filament

Liqufier Head

Extrusion Tip

Support

Foam Base

Build Platform

Finished Part

Support material spool

Build Material Spool
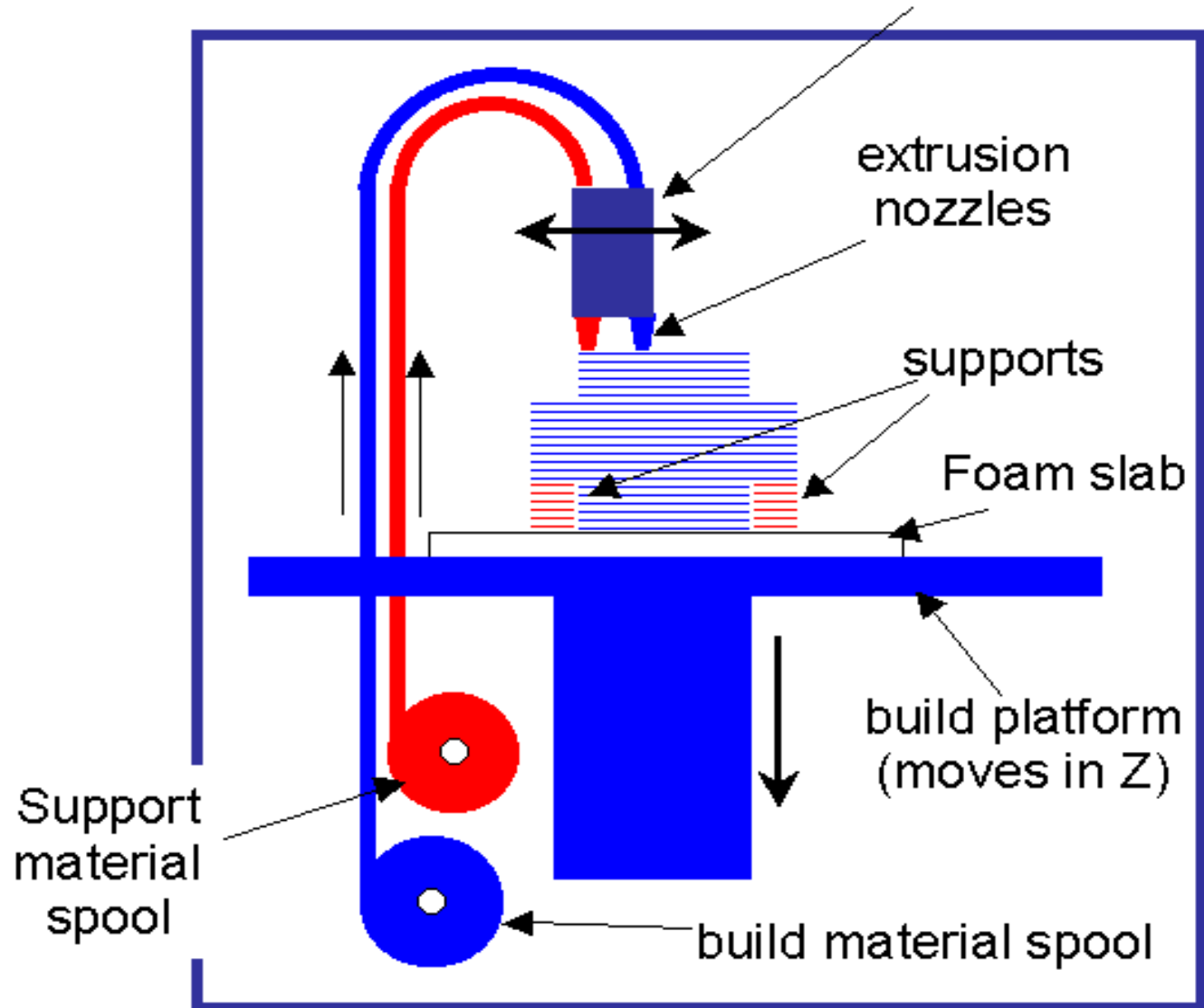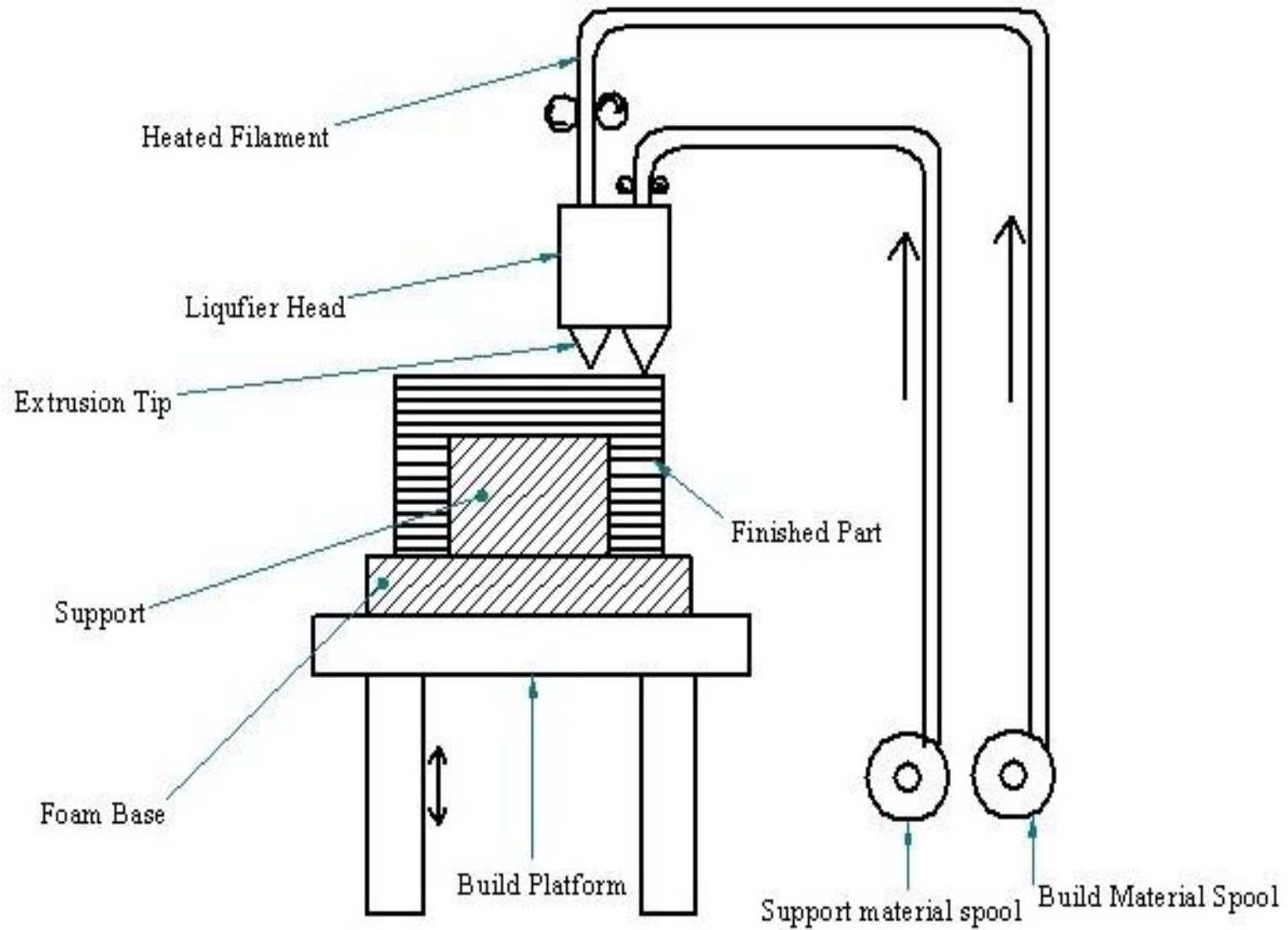
Drive Blocks:

- These are **raw material feeding mechanisms** and are mounted on back of head . These are computer controlled.

- Capable of **precision loading and unloading of filament**.

- It consists of **two parallel wheels** attached to a small electric motor by gears.

- The wheels have a **plastic and rubber thread** and are spaced approximately **0.07inches** apart and turn opposite to one another.

- When the wheels are turned in and end of the filament is placed between them, they continue to push or pull the material depending on direction of rotation.

- When loading the filament is pushed horizontally into the head through a hole, a little larger than the filament diameter which is the entry to the heating chamber.

Heating chamber

- It is a **90^0 curved elbow wrapped in a heating element** which serves two primary functions:
  - To change the direction of the filament flow so that the material is extruded vertically downwards.
  - To serve as a melting area for the material
- The heating element is electronically controlled and has feedback thermocouple to allow for a stable temperature throughout.

- The heating elements are held at a **temperature just above the melting point** of the material so that the filament passes from the exit of the chamber is in molten state. This **allows for smooth extrusion** as well as **time control on material placement**.

- At the end of the heating chamber which is about 4 inch long is the extrusion orifice or tip.

- The two tips are externally threaded and screwed up into the heating chamber exit and are used to reduce the extruded filament diameter to allow for better detailed modeling.

- The tips are heated by heating chamber up to above the melting point of the material.

- The tips can be removed and replaced with different size openings, the two most common being 0.012 inch and 0.025 inches.

- The extruding surface of the tip is flat serving as the hot shearing surface to maintain a smooth upper finish of extruded material.

- The tip is the point at which the material is deposited onto a foam substrate to build the model.

- The foam substrate is an expendable work table on which parts are built.

- The substrate is about 1 inch thick and is passed on into a removable tray by one quarter inch pins.
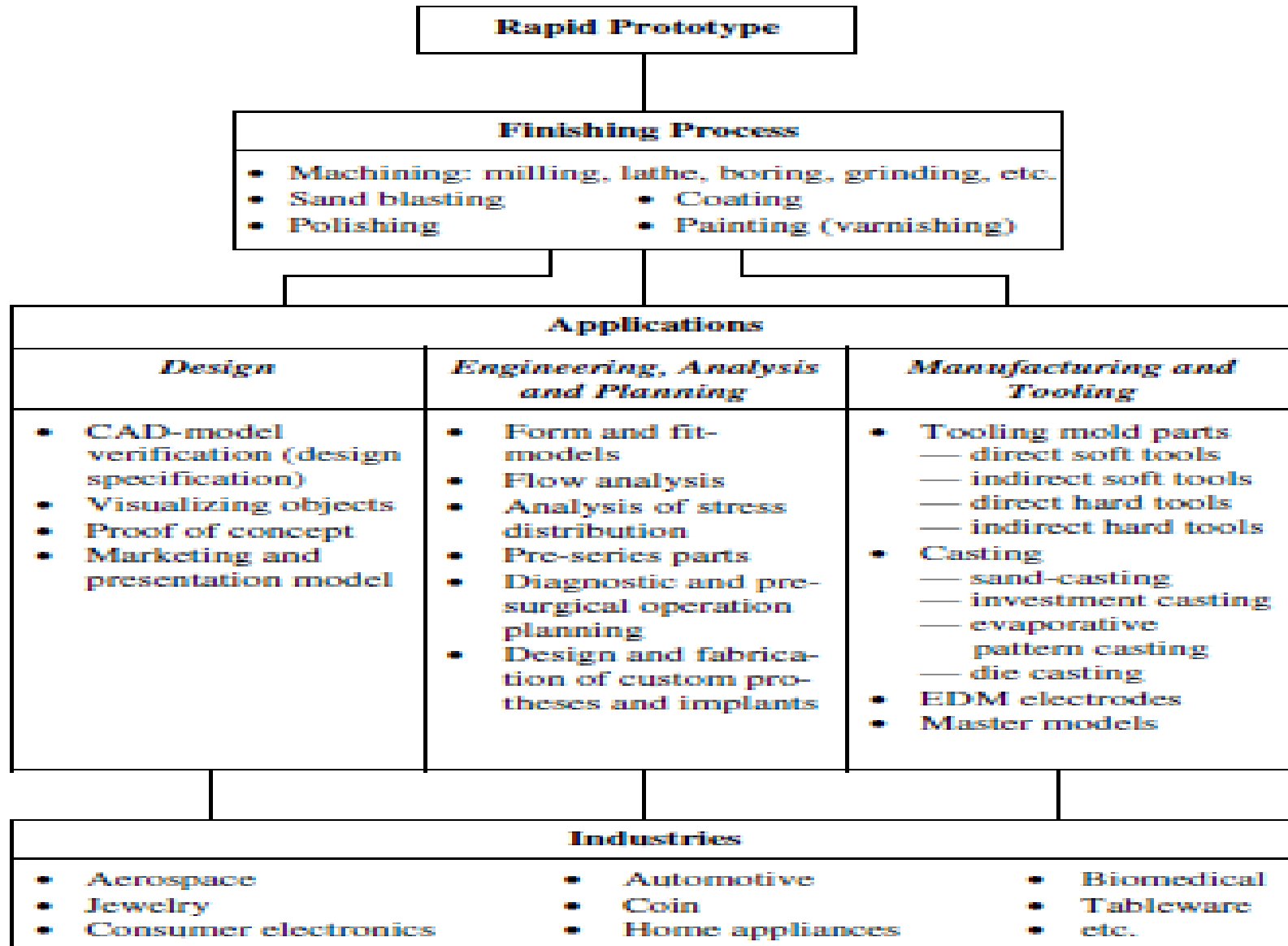
Rapid Prototype

Finishing Process
- Machining: milling, lathe, boring, grinding, etc.
- Sand blasting
- Polishing
- Coating
- Painting (varnishing)

Applications

Design	Engineering, Analysis and Planning	Manufacturing and Tooling
• CAD-model verification (design specification) • Visualizing objects • Proof of concept • Marketing and presentation model	• Form and fit-models • Flow analysis • Analysis of stress distribution • Pre-series parts • Diagnostic and pre-surgical operation planning • Design and fabrication of custom prostheses and implants	• Tooling mold parts — direct soft tools — indirect soft tools — direct hard tools — indirect hard tools • Casting — sand-casting — investment casting — evaporative pattern casting — die casting • EDM electrodes • Master models

Industries
- Aerospace
- Jewelry
- Consumer electronics
- Automotive
- Coin
- Home appliances
- Biomedical
- Tableware
- etc.

Figure 7.1: Typical application areas of RP

APPLICATIONS IN DESIGN

CAD Model Verification

This is the initial objective and strength of RP systems, in that designers often need the physical part to confirm the design that they have created in the CAD system. This is especially important for parts or products designed to fulfill aesthetic functions or that are intricately designed to fulfill functional requirements.

APPLICATIONS IN ENGINEERING, ANALYSIS AND PLANNING

Other than creating a physical model for visualization or proofing purposes, designers are also interested in the engineering aspects of their designs. This invariably relates to the functions of the design. RP technologies become important as they are able to provide the

information necessary to ensure sound engineering and function of the product. What makes it more attractive is that it also save development time and reduce costs. Based on the improved performance of processes and materials available in current RP technologies, some applications for functional models are presented in the following sections.

APPLICATIONS IN MANUFACTURING AND TOOLING

Central to the theme of rapid tooling is the ability to produce multiple copies of a prototype with functional material properties in short lead-times. Apart from mechanical properties, the material can also include functionalities such as color dyes, transparency, flexibility and the like. Two issues are to be addressed here: tooling proofs and process planning. Tooling proofs refer to getting the tooling right so that there will not be a need to do a tool change during production because of process problems. Process planning is meant for laying down the process plans for the manufacture as well as assembly of the product based on the prototypes produced.

- **Aerospace Industry**

   With the various advantages that RP technologies promise, it is only natural that high value added industries like the aerospace industry have taken special interest in it even though initial investment costs may be high.

Bio-Medical applications

- From Manufacturing of medical devices and customized implants and prostheses to surgical planning and education,RP can be applied to enhance medical applications and health care delivery.

AUTOMOTIVE INDUSTRY

Volkswagen has utilized Helysis's LOM to speed up the development of a large, complex gearbox housing for its Golf and Passat car lines [26]. The CAD model for the housing was extremely complex and difficult to visualize. VW wanted to build a LOM part to check the design of the CAD model and then use the part for packaging studies.

Using traditional methods, such a prototype would be costly and time consuming to build, and it may not be always possible to include all fine details of the design. Fabrication of the model based on drawings was often subjected to human interpretation, and consequently is error-prone, thus further complicating the prototyping process. All these difficulties were avoided by using RP technology as the fabrication of the model was based entirely on the CAD model created.

The gearbox housing was too large for the build volume of the LOM machine. The CAD model was thus split into five sections and re-assembled after fabrication. It took about ten days to make and finish all five sections, and once they were completed, patternmakers glued them together to complete the final model. The LOM model was first used for verifying the design, and subsequently, to develop sand-casting tooling for the creation of metal prototypes. The RP process had shrunk the prototype development time from eight weeks to less than two, and considerable time and cost savings were achieved.

JEWELRY INDUSTRY

Figure 7.16: An investment cast silver alloy prototype of a broach (right), the full-scale wax pattern produced from the silicon rubber molding (center), and the two-time scaled SLA model to aid visualization (left)

slope of the model were visible. With the use of better resin and finer layer thickness, this problem was reduced but not fully eliminated. Further processing was found to be necessary, and abrasive jet deburring was identified to be most suitable [46].

Though post-processing of SLA models is necessary in the manufacture of jewelry, the ability to create models quickly (a few hours compared to days or even weeks, depending on the complexity of the design) and its suitability for use in the manufacturing process offer great promise in improving design and manufacture in the jewelry industry.

THANK YOU