RAPID PROTOTYPING
OR
ADDITIVE MANUFACTURING

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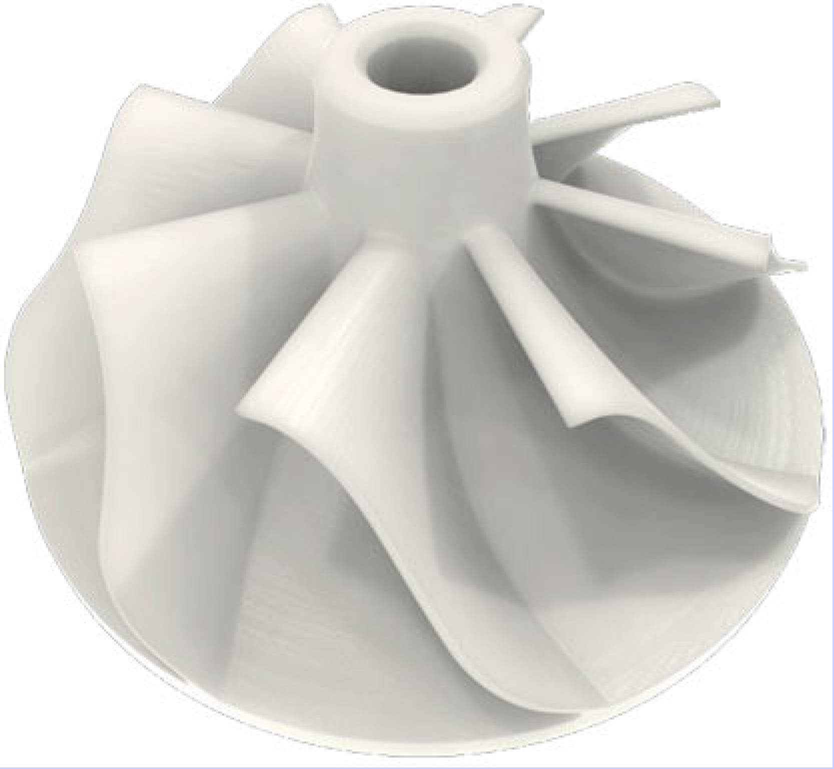

Rapid Prototyping : An Overview

•RP refers to a class of technologies that can automatically construct physical models from CAD data

•These "Three Dimensional Printers" allow designers to quickly create tangible prototypes of their designs, rather than just two-dimensional pictures

USES

•Prototypes make excellent visual aids for communicating ideas with co-workers or customers.

•Prototypes can be used for design testing

•RP technique can also be used for making tooling (known as Rapid Tooling)

Most prototypes require from 3 to 72 hours to build depending on the size and complexity of the object

Rapid Prototype : An Overview (contn.)

- At least six different RP techniques are commercially available
- These techniques are collectively known as Solid Free-form Fabrication, Computer Automated Manufacturing or Layered Manufacturing

PROCESS

- A software package “slices” the CAD model into a number of thin (~0.1 mm) layers
- These layers are then built up one atop another
- RP is an additive process, combining layers of papers, wax or plastic to create a solid object.

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Rapid Prototyping

- RP's additive nature allows it to create objects with complicated internal features that can not be manufactured by other means

LIMITATIONS

- Part volume is generally limited to 0.125 cubic meters or less depending on the RP machine
- Metal prototypes are difficult to make
- For metal parts, large production runs or simple objects, conventional manufacturing techniques are usually more economical

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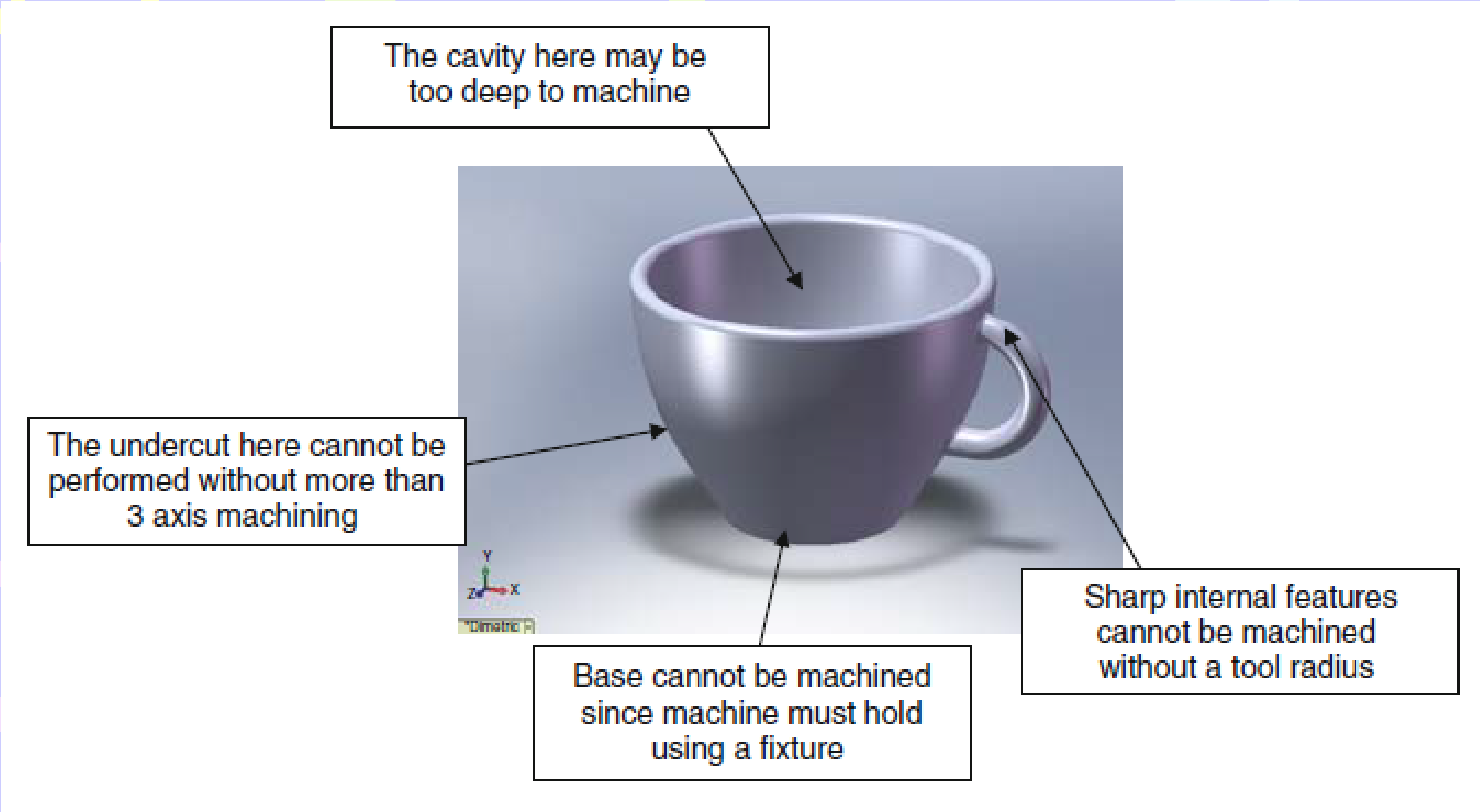
Additive vs Subtractive Manufacturing



Features that represent problems using CNC machining.

Source: Gibson, Additive Manufacturing

Benefits

AM benefits: Weight reduction

TRADITIONAL DESIGN

Source: SAVING project

- A conventional steel buckle weights 155 g[1)]
- Weight should be reduced on a like-for-like basis within the SAVING project
- Project partners are Plunkett Associates, Crucible Industrial Design, EOS, 3T PRD, Simpleware, Delcam, University of Exeter

AM OPTIMIZED DESIGN

Source: SAVING project

- Titanium buckle designed with AM weighs 70 g – reduction of 55%
- For an Airbus 380 with all economy seating (853 seats), this would mean a reduction of 72.5 kg
- Over the airplane's lifetime, 3.3 million liters of fuel or approx. EUR 2 m could be saved, assuming a saving of 45,000 liters per kg and airplane lifetime

1) 120 g when made of aluminum

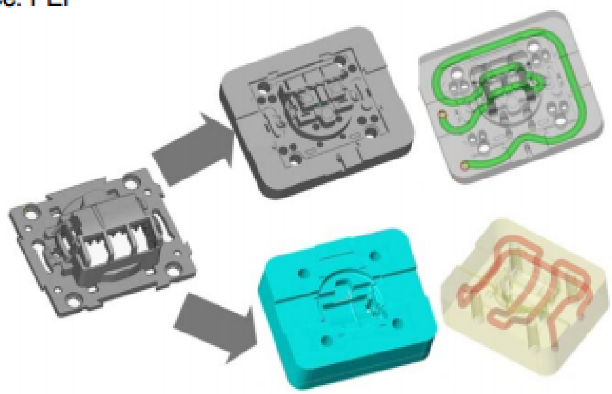
Source: SAVING project / Crucible Industrial Design Ltd.; Roland Berger

Benefits

AM benefits: Complexity for free

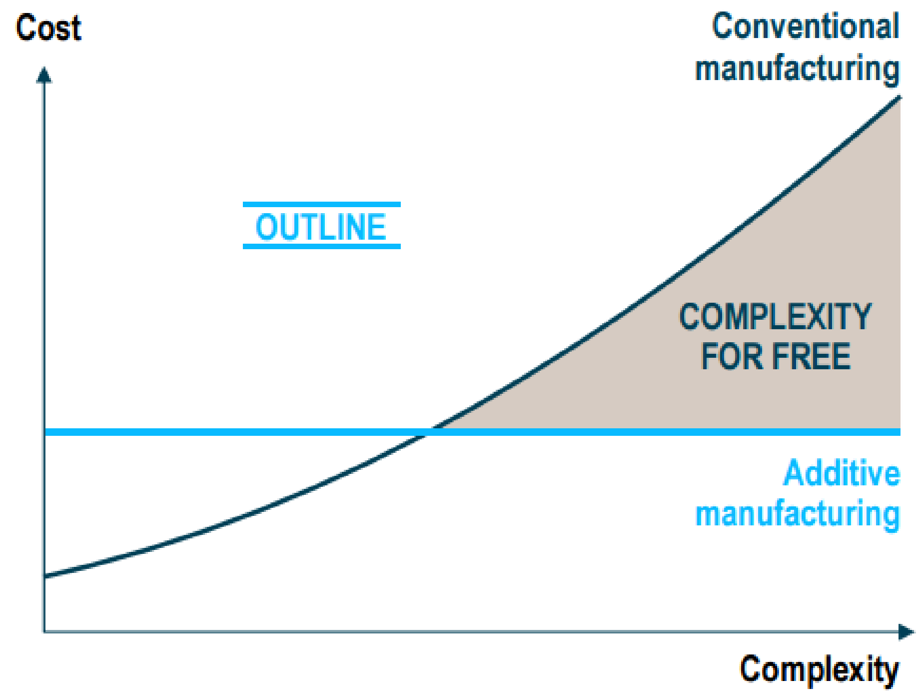
AM ENABLES NEW GEOMETRIC SHAPES ...

Source: PEP



> AM enables the manufacturing of new geometric shapes that are not possible with conventional methods

> Example: AM makes it possible to design advanced cooling channels that cool tools/ components better and therefore reduce cycle time



... AT NO ADDITIONAL COST

Source: Roland Berger

Benefits

AM for customized medical products

DENTAL CROWNS/BRIDGES

Source: EOS

- **AM holds a large share of the dental crowns and bridges market –** Geometry is scanned and processed via CAD/CAM. More than 30 million crowns, copings and bridges have already been made on AM machines over the last 6 years
- **Increasing market share –** Experts estimate that more than 10,000 copings are produced every day using AM
- **Faster production –** One AM machine produces up to 450 crowns per day, while a dental technician can make around 40

IMPLANTS

Source: EOS

- **AM offers advantages with regard to manufacturing time, geometric fit and materials –** Example of a skull implant with modified surface structure
- **Improved fit via AM –** Based on 3D scans of the skull, the resulting implant fits perfectly into the skull cap, leads to faster recovery and reduces operation time

Additive manufacturing will replace conventional manufacturing methods for customized products

Source: Roland Berger

Rapid Prototyping : The Basic Process

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

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Rapid Prototyping: CAD Model Creation

- The object to be built is modeled using a Computer-Aided Design 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

- **The various CAD packages use a number of different algorithms to represent solid objects**
- **To establish consistency, the STL (stereolithography) format has been adopted as the standard of the RP industry**
- **This format represents a 3-dimensional surface as an assembly of planar triangles, like the facets of a cut jewel.**
- **The file contains the coordinates of the vertices and the direction of the outward normal of each triangle**
- **Increasing the number of triangles improves the approximation**

Slice the STL File

- **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 also generates an auxiliary structure to support the model during the build**

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Layer by Layer Construction

- Actual construction of the part
- Using one of several techniques, RP machines build one layer at a time from polymer, paper, or powdered metal
- Most machines are fairly autonomous, needing little human intervention

Rapid Prototyping Techniques

Stereolithography:

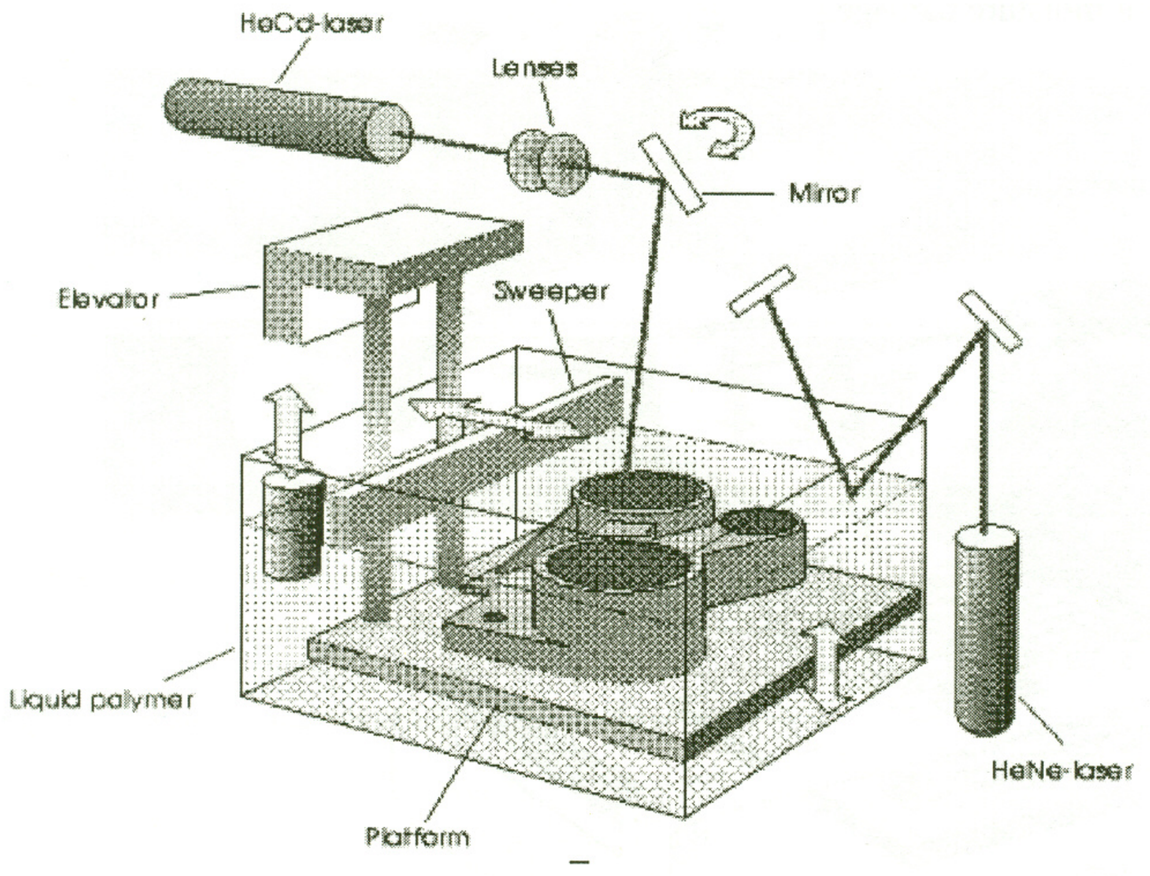

Figure 1: Schematic diagram of stereolithography. [7]

- Patented in 1986
- Builds three-dimensional models from liquid photosensitive polymers that solidify when exposed to ultraviolet light

Stereolithography : The Process

- The model is built upon a platform situated just below the surface in a vat of liquid epoxy or acrylate resin
- A low-power highly focused UV laser traces out the first layer, solidifying the model's cross section while leaving excess areas liquid
- Next, an elevator incrementally lowers the platform into the liquid polymer
- A sweeper re-coats the solidified layer with liquid, and the laser traces the second layer atop the first
- The process is repeated until the prototype is complete

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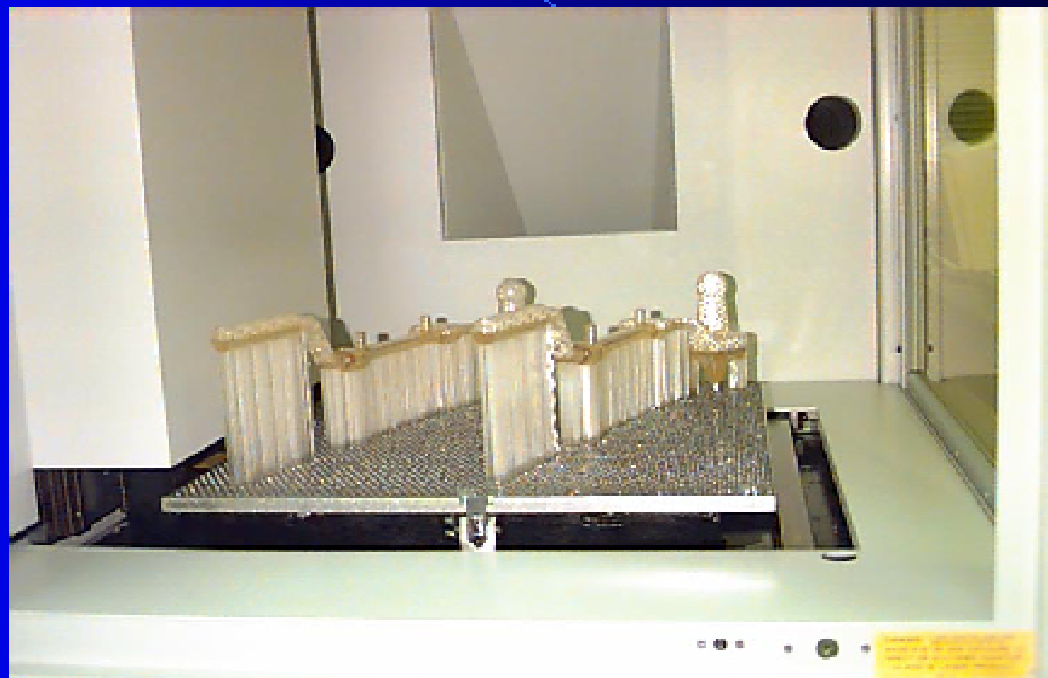
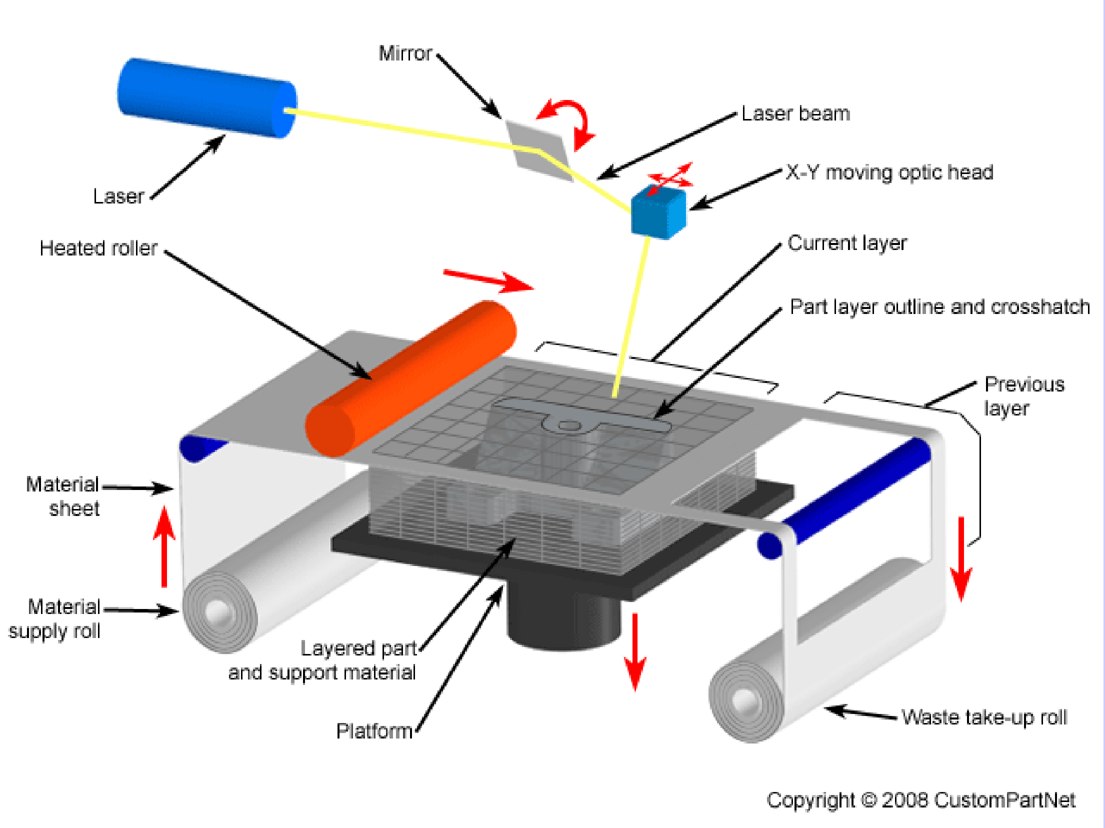
Fabrication of Part



Models built on stereolithography apparatus.
Part and supports shown attached to platform.

Laminated Object Manufacturing

- Layers of adhesive- coated sheet material are bonded together to form a prototype
- The original material consists of paper laminated with heat-activated glue and rolled up on spool
- A feeder/collector mechanism advances the sheet over the build platform with a soft base
- A heated roller applies pressure to bond the paper to the base
- A focused laser cuts the outline of the first layer into the paper



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Selective Laser Sintering

- Patented in 1989, uses a laser beam to selectively fuse powdered materials, such as nylon, elastomer, and metal, into a solid object
- Parts are built upon a platform which sits just below the surface in a bin of the heat-fusable powder
- The platform is lowered by the height of the next layer and powder is reapplied
- The process is repeated until the part is complete

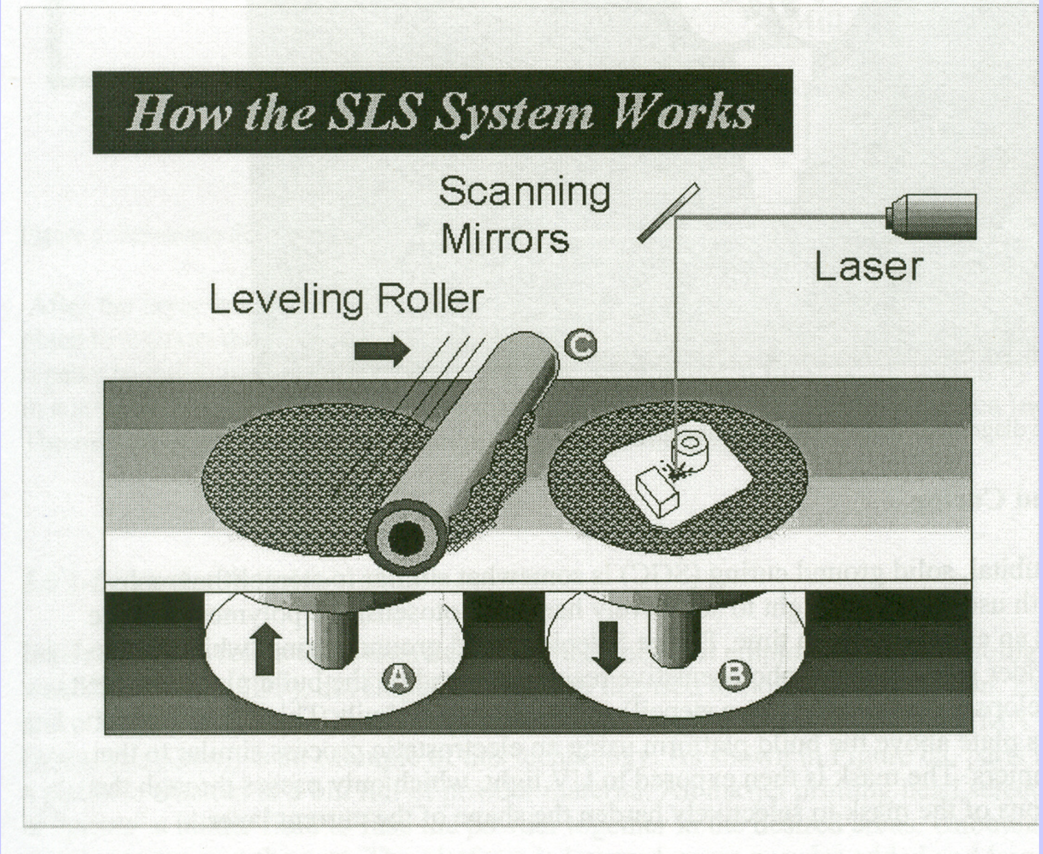

Figure 3: Schematic diagram of selective laser sintering.[9]

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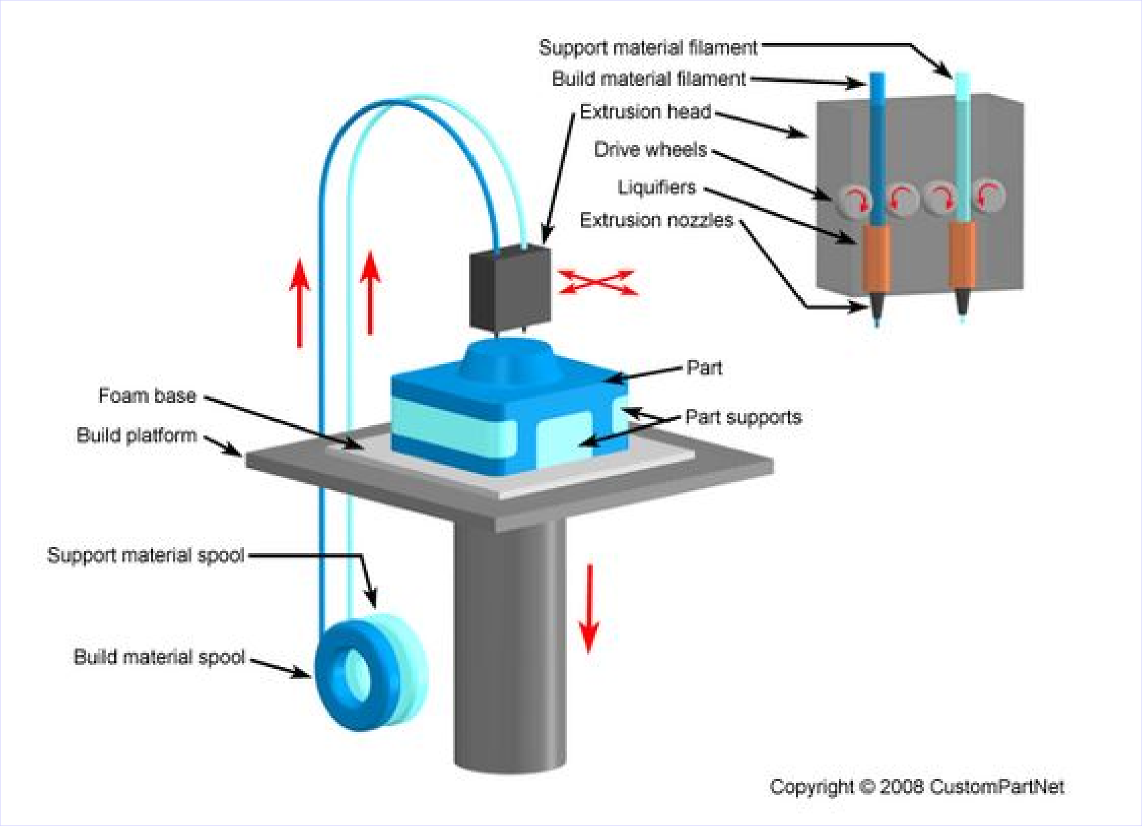
Fused Deposition Modeling

- Filaments of heated thermoplastic are extruded from a tip that moves in the X-Y plane
- Like a baker decorating a cake, the controlled extrusion head deposits very thin beads of material onto the build platform to form the first layer
- The platform is maintained at a lower temperature, so that the thermoplastic quickly hardens
- After the platform lowers, the extrusion head deposits a second layer upon the first



Applications of Rapid Prototyping

- Rapid prototyping is widely used in the automotive, aerospace, medical, and consumer products industries
- Nearly all applications fall into one of the following categories: prototyping, rapid tooling, or rapid manufacturing

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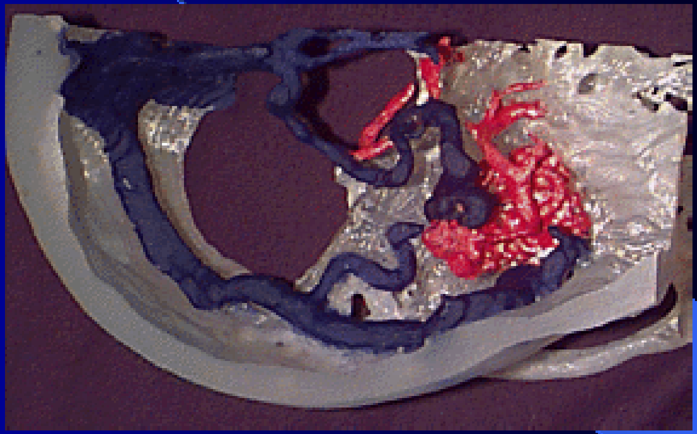
Form, Fit, Function

Seen here attached to the US Navy's M4A1 machine gun, an ABS prototype stock was tested on the firing range with live ammunition. Prototype built on FDM system from Stratasys.

Manufacturing Example: Investment Casting

- Wax pattern build from Stratasys multi-jet droplet technique
- Pattern used in investment casting to fabricate metal ring
- Allows for design modifications and quick turnaround of metal band

Medical Uses



Models of Cerebral Arterio-venous Malformation and surrounding skull, with data from a CT Angiogram. Built by stereolithgraphy RP process. Allows advanced neurosurgical planning.

Prototyping

- The primary use of rapid prototyping is to quickly make prototypes for communication and testing purposes

- Prototypes dramatically improve communication because most people, including engineers, find three-dimensional objects easier to understand than two-dimensional drawings

- Such improved understanding leads to substantial cost and time savings

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Prototyping

- Prototypes are also useful for testing a design, to see if it performs as desired or needs improvement

- In addition to being fast, RP models can do a few things metal prototypes cannot. For example, Porsche used a transparent stereolithography model of the 911 GTI transmission housing to visually study oil flow

Rapid Tooling

- **Tooling is one of the slowest and most expensive steps in the manufacturing process, because of the extremely high quality required**
- **Tools often have complex geometries, 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**

Rapid Tooling : Indirect Tooling

RP parts are used as patterns for making molds and dies

Vacuum Casting :

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 mold can be used to cast up to 20 polyurethane replicas of the original RP pattern.

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Indirect Tooling

Sand Casting:

A RP model is used as the positive pattern around which the sand mold is built

Investment Casting

Some RP prototypes can be used as investment casting patterns. The pattern must not expand when heated, or it will crack the ceramic shell during autoclaving.

Injection molding

First, a stereolithography machine is used to make a match-plate positive pattern of the desired molding. To form the mold, the SLA pattern is plated with nickel, which is then reinforced with a stiff ceramic material. The two mold halves are separated to remove the pattern, leaving a matched die set that can produce tens of thousands of injection moldings

Direct Tooling

RapidTool:

- **A DTM process that selectively sinters polymer-coated steel pellets together to produce a metal mold. The mold 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 mold can produce up to 50,000 injection moldings**

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Direct Tooling

Laser-Engineered Net Shaping (LENS)

Process developed at Sandia National Laboratories and Stanford University that can create metal tools from CAD data. Materials include stainless steel, Inconel, tool steel, tungsten, and titanium carbide cermets. A laser beam melts the top layer of the part in areas where material is to be added. Powder metal is injected into the molten pool, which then solidifies. Layer after layer is added until the part is complete. Unlike traditional powder metal processing, LENS produces fully dense parts, since the metal is melted, not merely sintered. The resulting parts have exceptional mechanical properties, but the process currently works only for parts with simple, uniform cross sections

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Rapid Manufacturing(RM)

- For short production runs, RM is much cheaper, since it does not require tooling. RM is also ideal for producing custom parts tailored to the user's exact specifications
- A University of Delaware research project uses a digitized 3-D model of a person's head to construct a custom-fitted helmet
- NASA is experimenting with using RP machines to produce spacesuit gloves fitted to each astronaut's hands