Rapid Prototyping & Rapid Tooling
Rapid Prototyping achievements

- Reduction in prototyping times (from weeks to days)
- Reduction in prototyping costs (from thousands to hundreds $)
- Increase of the possible design iterations (from 2-3 to 8-9)
- Increase of possible form, fit, function tests

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Shorter design cycle

Reduced Time-to-Market
Rapid Prototyping

1. Computer model
2. Mechanical model
3. Visual model
4. Production product

Mechanical functional model
Rapid Prototyping Market

2001

- 3,55 Millions of models produced worldwide
- 400 Service providers
- 8000 Machines sold since 1993
Useful Conditions for RP

- Single unique item or small number of copies needed
- Shape of object is in computer form
- Shape is too complex to be economically generated using conventional methods
Rapid Prototyping Technologies

• Six basic commercial technologies:

StereoLithography (SL)
Laminated Object Manufacturing (LOM)
Selective Laser Sintering (SLS)
Fused Deposition Modeling (FDM)
Solid Ground Curing (SGC)
Inkjet technologies (3D Plotting, MJM, 3DP..)
Rapid Prototyping Examples

Examples of parts made by rapid prototyping processes.
Rapid Prototyping Examples / 2
### Characteristics of Rapid Prototyping Technologies

<table>
<thead>
<tr>
<th>Supply phase</th>
<th>Process</th>
<th>Layer creation technique</th>
<th>Phase change type</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid</td>
<td>Stereolithography</td>
<td>Liquid layer curing</td>
<td>Photopolymerization</td>
<td>Photopolymers (acrylates, epoxies, colorable resins, filled resins)</td>
</tr>
<tr>
<td></td>
<td>Solid-based curing</td>
<td>Liquid layer curing and milling</td>
<td>Photopolymerization</td>
<td>Photopolymers</td>
</tr>
<tr>
<td></td>
<td>Fused-deposition modeling</td>
<td>Extrusion of melted polymer</td>
<td>Solidification by cooling</td>
<td>Polymers (ABS,polyacrylate, etc.), wax, metals and ceramics with binder.</td>
</tr>
<tr>
<td></td>
<td>Ballistic-particle manufacturing</td>
<td>Droplet deposition</td>
<td>Solidification by cooling</td>
<td>Polymers, wax</td>
</tr>
<tr>
<td>Powder</td>
<td>Three-dimensional printing</td>
<td>Layer of powder and binder droplet deposition</td>
<td>No phase change</td>
<td>Ceramic, polymer and metal powders with binder.</td>
</tr>
<tr>
<td></td>
<td>Selective laser sintering</td>
<td>Layer of powder</td>
<td>Laser driven sintering melting and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>solidification</td>
<td>Polymers, metals with binder, metals, ceramics and sand with binder.</td>
</tr>
<tr>
<td>Solid</td>
<td>Laminated-object manufacturing</td>
<td>Deposition of sheet material</td>
<td>No phase change</td>
<td>Paper, polymers.</td>
</tr>
</tbody>
</table>
# The Most Important Commercial
## Rapid Prototyping Technologies at a Glance

<table>
<thead>
<tr>
<th>Technology</th>
<th>Stereo-lithography</th>
<th>Stereo-lithography</th>
<th>Wide Area Thermal Inkjet</th>
<th>Selective Laser Sintering</th>
<th>Fused Deposition Modeling</th>
<th>Single Jet Inkjet</th>
<th>Three Dimensional Printing</th>
<th>Laminated Object Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acronym</td>
<td>SLA</td>
<td>SLA</td>
<td>MJM</td>
<td>SLS</td>
<td>FDM</td>
<td>MM</td>
<td>3DP</td>
<td>LOM</td>
</tr>
<tr>
<td>Vendor</td>
<td>Sony</td>
<td>3D Systems</td>
<td>Stratasys</td>
<td>Solidscape</td>
<td>Z Corp.</td>
<td>Cubic Technologies</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### General Qualitative Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>SLA</th>
<th>SLA</th>
<th>MJM</th>
<th>SLS</th>
<th>FDM</th>
<th>MM</th>
<th>3DP</th>
<th>LOM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Part Size (inches)</strong></td>
<td>39 x 31 x 20</td>
<td>20 x 20 x 24</td>
<td>10 x 8 x 8</td>
<td>15 x 13 x 18</td>
<td>24 x 20 x 24</td>
<td>12 x 6 x 9</td>
<td>20 x 24 x 16</td>
<td>32 x 22 x 20</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>very good (uses dual beams for approx. 2X speed-up)</td>
<td>average</td>
<td>good</td>
<td>average to fair</td>
<td>poor</td>
<td>poor</td>
<td>excellent</td>
<td>good</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>very good</td>
<td>very good</td>
<td>good</td>
<td>good</td>
<td>fair</td>
<td>excellent</td>
<td>fair</td>
<td>fair</td>
</tr>
<tr>
<td><strong>Surface Finish</strong></td>
<td>very good</td>
<td>very good</td>
<td>fair</td>
<td>fair</td>
<td>fair</td>
<td>excellent</td>
<td>fair</td>
<td>fair to poor (depending on application)</td>
</tr>
<tr>
<td><strong>Strengths</strong></td>
<td>very large part size, accuracy, speed</td>
<td>large part size, accuracy</td>
<td>office OK</td>
<td>accuracy, materials</td>
<td>office OK, price, materials</td>
<td>accuracy, finish, office OK</td>
<td>speed, office OK, price, color, price</td>
<td>large part size, good for large castings, material cost</td>
</tr>
<tr>
<td><strong>Weaknesses</strong></td>
<td>post processing, messy liquids</td>
<td>post processing, messy liquids</td>
<td>size and weight, fragile parts, limited materials, part size</td>
<td>size and weight, system price, surface finish</td>
<td>speed</td>
<td>speed, limited materials, part size</td>
<td>limited materials, fragile parts, finish</td>
<td>part stability, smoke finish, accuracy</td>
</tr>
</tbody>
</table>
Stereolithography
SL

- 3D Systems, Valencia, CA
- patent 1986, \textit{beginning of RP}
- photopolymerization using UV laser
- accuracy 0.025 mm
- epoxies, acrylates
Stereolitography SL
Stereolithography SL
Stereolithography Machines
Stereolithography Process
SL Applications
SL Applications
Stereo-lithography

The computational steps in producing a stereolithography file.

a) Three-dimensional description of part.
b) The part is divided into slices (only one in 10 is shown).
c) Support material is planned.
d) A set of tool directions is determined to manufacture each slice.
RP Sequence

- CAD solid model
- `.STL’ file
- Slicing the file
- Final build file
- Fabrication of part
- Post processing
CAD Solid Model

- Solid model or closed surface model required
‘.STL’ File

- Software generates a tessellated object description
- File consists of the X, Y, Z coordinates of the three vertices of each surface triangle, with an index to describe the orientation of the surface normal
- Support generation to hold overhung surfaces during build
Slicing the File

- Series of closely spaced horizontal planes are mathematically passed through the .stl file
- Generate a ‘.sli’ file: a series of closely spaced 2D cross-sections of the 3D object
- Typical Z thickness 0.006” (0.150 mm)
- Other Parameters chosen =fn(RP technology)
Common Support Structures

(a) A part with a protruding section which requires support material.
(b) Common support structures used in rapid-prototyping machines.

Part sliced
Supports sliced
RP technology parameters set (layer thickness, scan speed,...)
Send file to RP machine
Fabrication of Part

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

Removal of part from platform

Removal of supports from part

Cleaning of part (wiping, rinsing, ... )

Finishing part (sanding, polishing, ... )
Laminated Object Manufacturing
LOM

- Cubic Technologies, Carson, CA (former Helisys)
- patent 1985
- cross-sectional cutouts fused together
- accuracy 0.076 mm
- paper, plastic
Laminated Object Manufacturing
LOM
Laminated Object Manufacturing  LOM
Laminated-Object Manufacturing

(a) Schematic illustration of the laminated-object-manufacturing process. Source: Helysis, Inc.

(b) Crankshaft-part example made by LOM. Source: After L. Wood.
LOM Applications
Selective Laser Sintering

SLS

- 3D Systems, Valencia, CA (former DTM)
- patent 1989, Carl Deckard’s master thesis
- fusing polymeric powders with CO2 laser
- accuracy 0.040 mm
- polycarbonate, nylon, wax, glass-filled nylon, powder coated metals or ceramics
Selective Laser Sintering

How the SLS System Works

- Scanning Mirrors
- Leveling Roller
- Laser
Selective Laser Sintering  SLS
Selective Laser Sintering

Schematic illustration of the selective laser sintering process. Source: After C. Deckard and P.F. McClure.
SLS Applications
Fused Deposition Modeling
FDM

- Stratasys, Eden Prarie, MN
- patent 1992
- robotically guided fiber extrusion
- accuracy 0.127 mm
- casting and machinable waxes, polyolefin, ABS, PC
Fused Deposition Modeling
FDM

The FDM Extrusion Head

- Filament
- Drive Wheels
- Liquifier
- Tip
- Direction
- Vector Motion
Fused Deposition Modeling  FDM
(a) Schematic illustration of the fused-deposition-modeling process.

(b) The FDM 5000, a fused-deposition-modeling-machine. Source: Courtesy of Stratysis, Inc.
FDM Machines
FDM Applications
Solid-Base Curing
SBC

- Cubital, Troy, MI (Failed 2000)
- patent 1991
- photopolymerization using UV light passing through a mask
- accuracy 0.510 mm
- Photopolymers
Solid-Base Curing

Solid-Base Curing
3D Plotting

- Solidscape Inc., Marrimack, NH
- Inkjet technology
- Dual heads deposit part material (thermoplastic) and support material (wax)
- Accuracy 0.025 mm (layers 0.013 mm)
- Thermoplastic (build)
- Wax, fatty esters (support)
3D Plotting

CAD Interface
.STL, DXF & HPGL Files

Control Software

Control Electronics

Planar Mechanism

Model

Build Substrate

Build Table

X-Y Motion

Drop-On Demand Jets

Overhang Support

Z-Motion
3D Plotting
3D Plotting Applications
Multi-jet Modelling
MJM

- Accelerated Tech., 3D Systems, Solidimension Ltd
- Inkjet technology
- Multiple heads deposit support material and part material cured immediately by UV light
- Accuracy 0.020 mm
- Photopolymers
Multi-jet Modelling
MJM
MJM Applications
3D Printing 3DP

- Z Corporation, Burlington, MA
- Printing head deposits binder solution on build powder
- Accuracy 0.076 mm
- Waxes, acrylates, epoxies
3D Printing

3D Printing
3D Printing Applications
Investment Casting

Manufacturing steps for investment casting that uses rapid-prototyped wax parts as blanks. This approach uses a flask for the investment, but a shell method can also be used. Source: 3D Systems, Inc.
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
Sand Casting Using Rapid-Prototyped Patterns

1. Produce pattern using rapid prototyping process.

2. Produce sand core from mold produced through rapid prototyping.

3. Place drag half of pattern on mold board in drag half of flask

4. Preparing drag half of mold.

Manufacturing steps in sand casting that uses rapid-prototyped patterns.

Source: 3D Systems, Inc.
Sand Casting (continued)

5. Roll drag over, place cope half of pattern and flask.
   Note: sprue and risers are standard inserts

6. Preparing cope half of mold; this step must be repeated for each half of the mold

7. Separate flask — remove all patterns.
   Place core in place, close flask.

8. Flask closed and clamped, ready for pouring of molten metal.
Rapid Tooling

Rapid tooling for a rear-wiper-motor cover
Benefits to RP Technologies

Visualization, verification, iteration, and design optimization
Communication tool for simultaneous engineering
Form-fit-function tests
Marketing studies of consumer preferences
Metal prototypes fabricated from polymer parts
Tooling fabricated from polymer parts
Conclusions

• Rapid prototyping is a new tool, which used appropriately ...
  – allows the manufacturing enterprise to run smoother
  – increases throughput and product quality
• New uses and applications are discovered everyday
• Future areas include new materials directly deposited (metals, ceramics)