Additive Manufacturing Technology and Trends

MCA Session Topic: Generalizing Fundamental AM Principles

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Deep Dive Goal

1. ~~Conceptualization and CAD~~
2. ~~Conversion to STL/AMF~~
3. ~~Transfer to AM Machine and STL File Manipulation~~
4. ~~Machine Setup~~
5. ***Build****
6. ~~Removal and Cleanup~~
7. ~~Post-Processing~~
8. ~~Application~~

- "We Can ~~Do~~ Build It"
- *Deep Dive isn't done until everyone performs build processes with 0 compromises
- "Tradeoffs" != "Compromises" (find print setting tradeoffs to exceed your 3D printing goals)

“Build It” here… Build It Anywhere

Machine Movements

Active vs. Passive

Motors & Gears

Motors & Jets

Mirrors & Motors & Masks

Mirrors & Lasers & Lenses

Materials & Bonding Methods

Plastic Filament, Heat & Pressure

Glue & powder

Resin & UV

Resin & Lasers

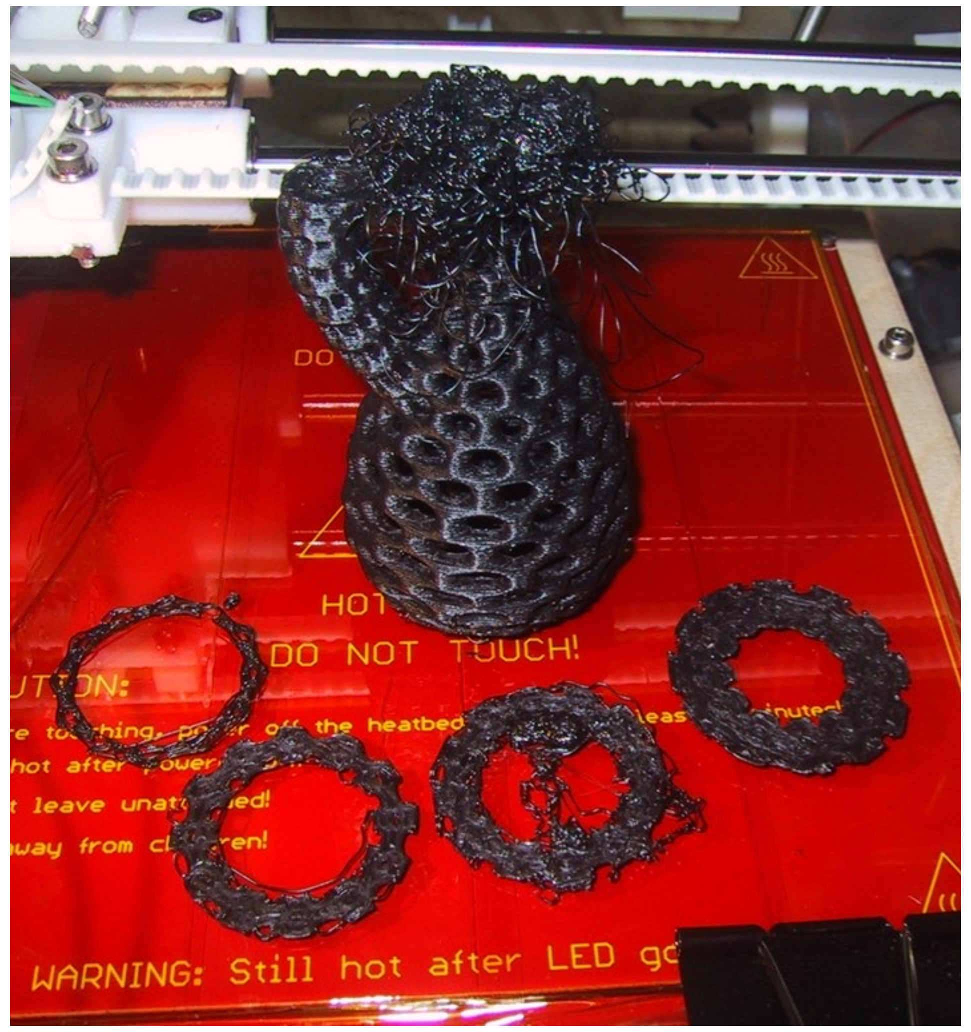
Special Powders & Lasers

Machine Movement Overview

- Machine component movements and material bonding methods must work together
- A machine with specific movements can use different materials
- Material properties are part of designing an AM machine
  - This makes AM fundamentally different than any other manufacturing technology
  - The machine component movement capabilities are always better than the tolerances of the produced part
  - Analogous to designing a Quality Assurance device
- Non-linear relationship between machine movement accuracy and final part accuracy

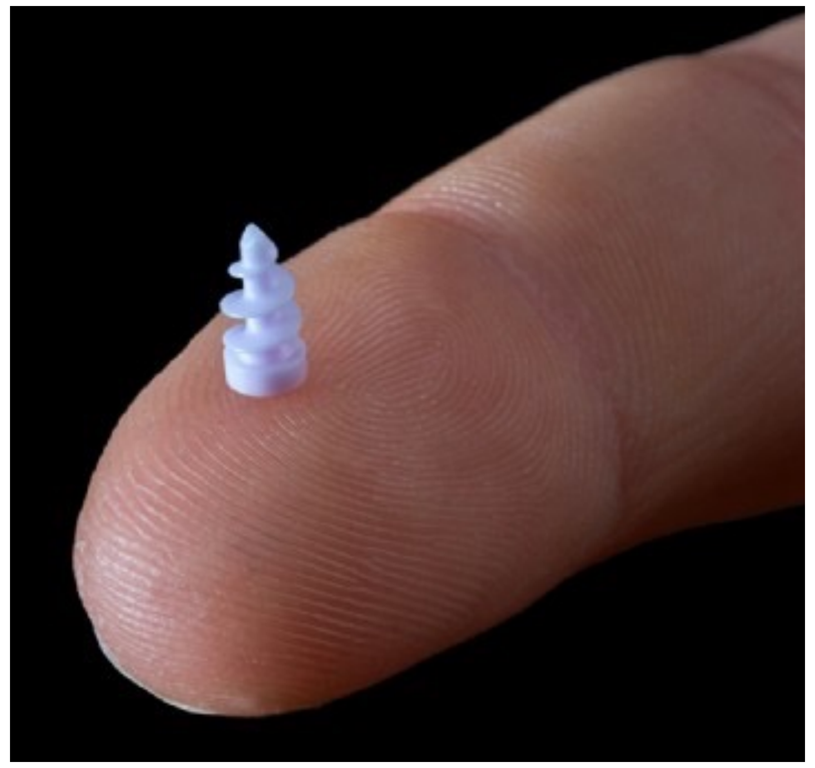
Materials & Bonding Methods Overview cont…

- Poor quality materials can cause good machines to make make really bad parts (and vice versa)
  - As the quality of the material increases, the machine approaches its full potential
  - Expensive and inexpensive can degrade in quality for many reasons



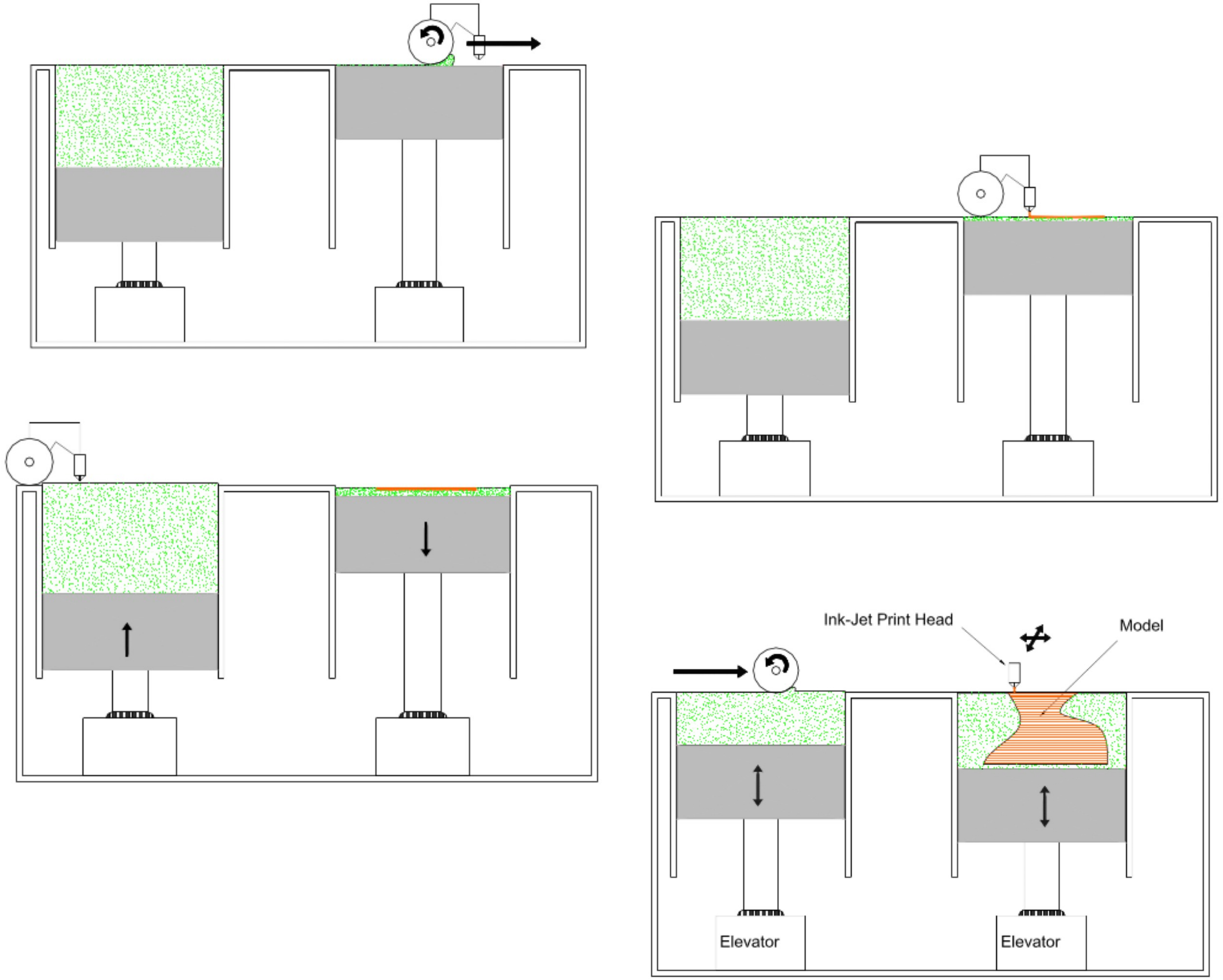
Materials & Bonding Methods Overview

- High quality materials can cause good machines to make really bad parts (and vice versa) ★
  - Some materials present unique challenges that depend more on the part's features than on the machine's capabilities
  - Geometric features and machine processes require extra attention when using materials with "special" material properties
  - Example: "~~Metal 3D Printers~~" Direct Metal Laser Sintering (DMLS) machines can produce Titanium and Ceramic parts



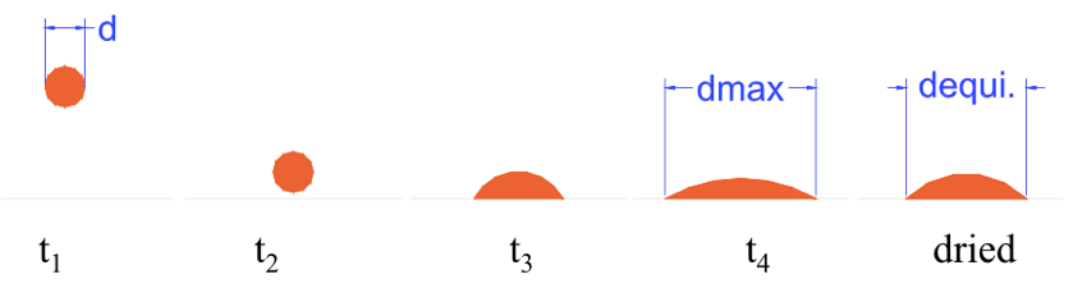
“3D Printer”

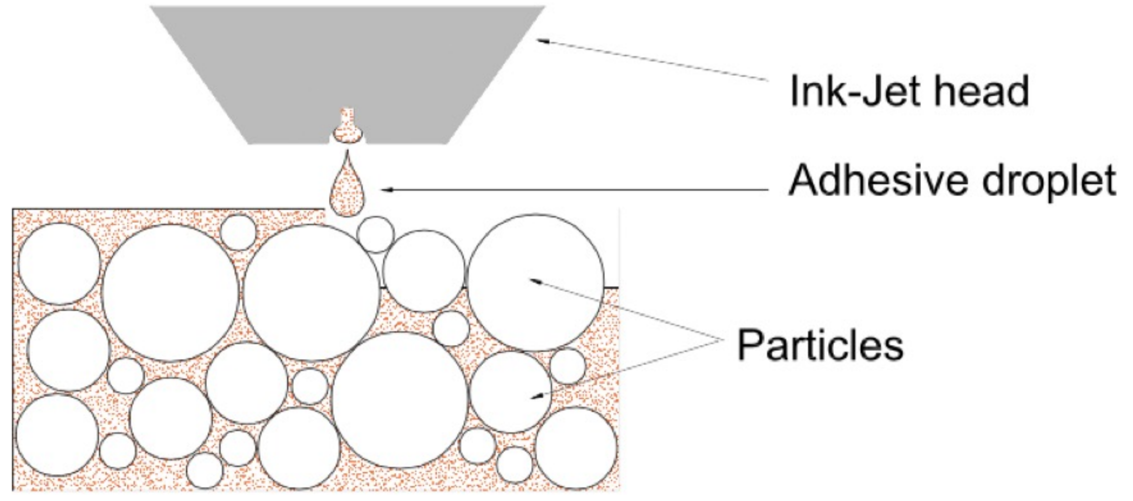
- Layers are formed through fusing powder using a liquid binder
  - Liquid binder is added via an ink-jet type printing process
  - Un-fused powder serves as passive support structure
- Process Sequence:
  - Sweep powder from source to build chamber
  - Glue powder using inkjet head
  - Move down a layer
  - Sweep and repeat



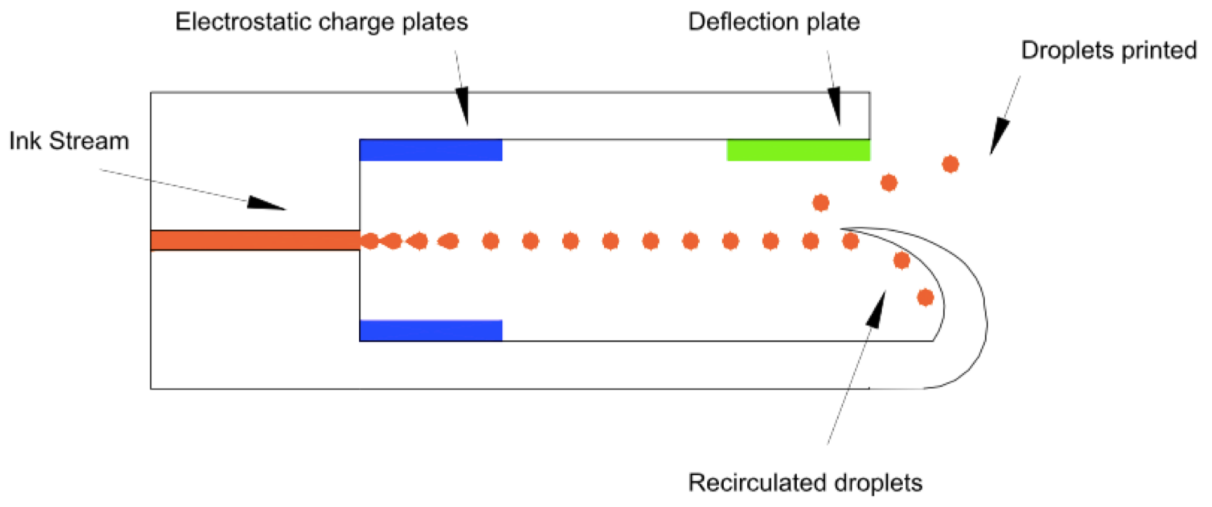
“3D Printer”

- Binder-Particle Interaction Considerations
  - Different droplet technologies affect part quality
  - Droplet and particle size are related, they both affect part quality
- Layer Generation Deposition Methods
  - Continuous Ink Jet
  - Drop-on-Demand
    - Piezoelectric
    - Thermal inkjet

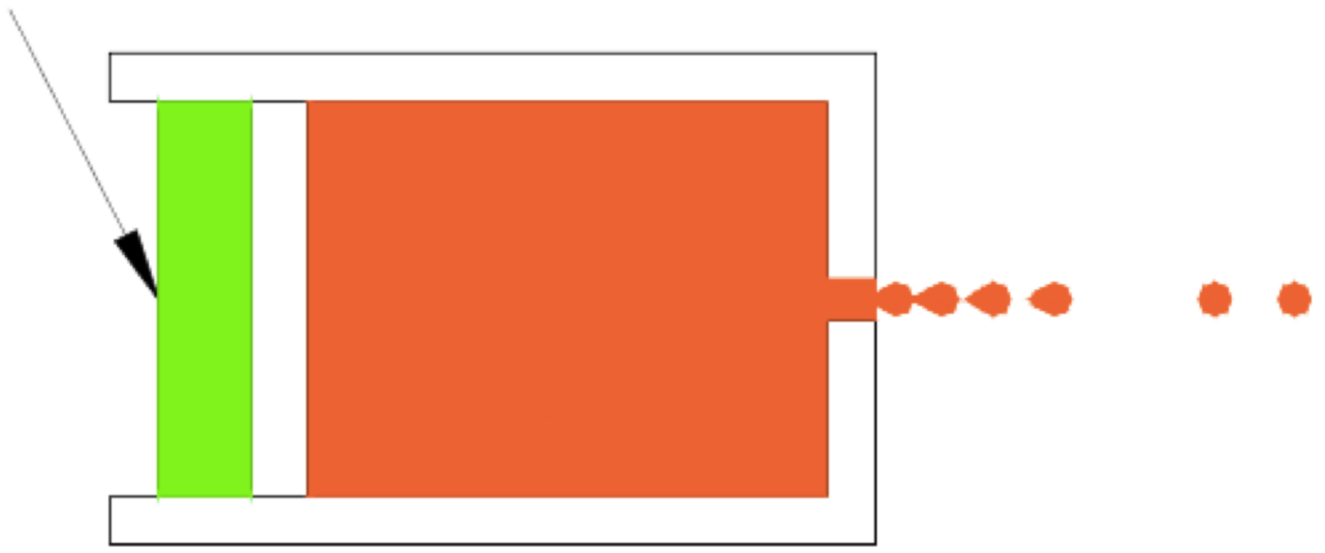




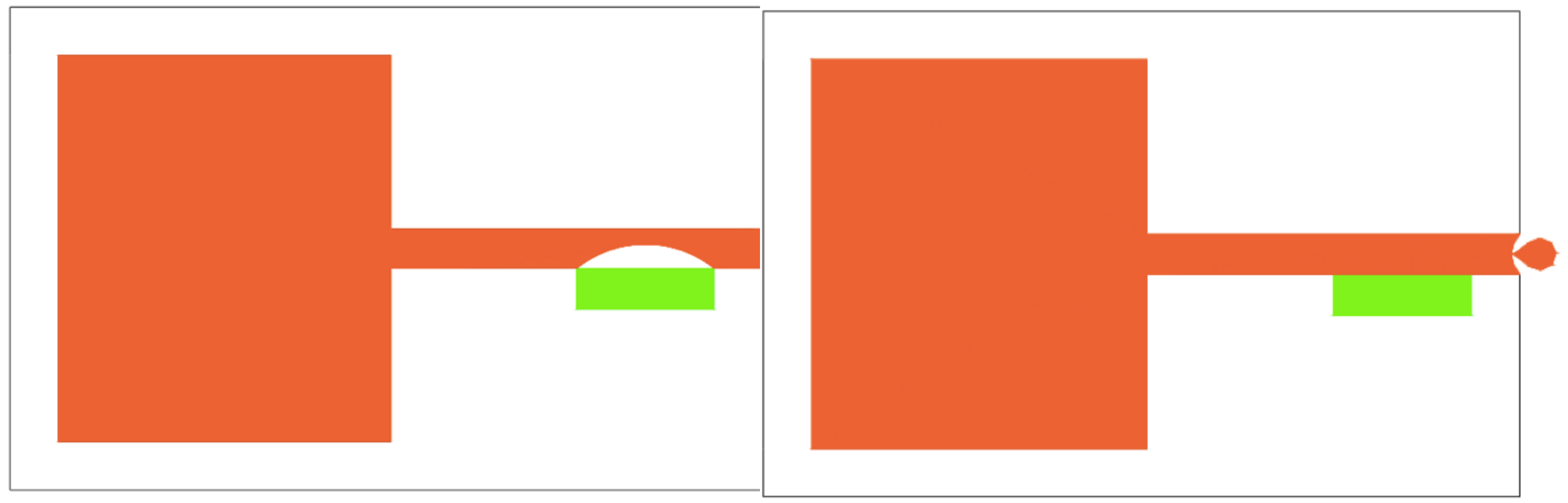
Continuous Ink Jet



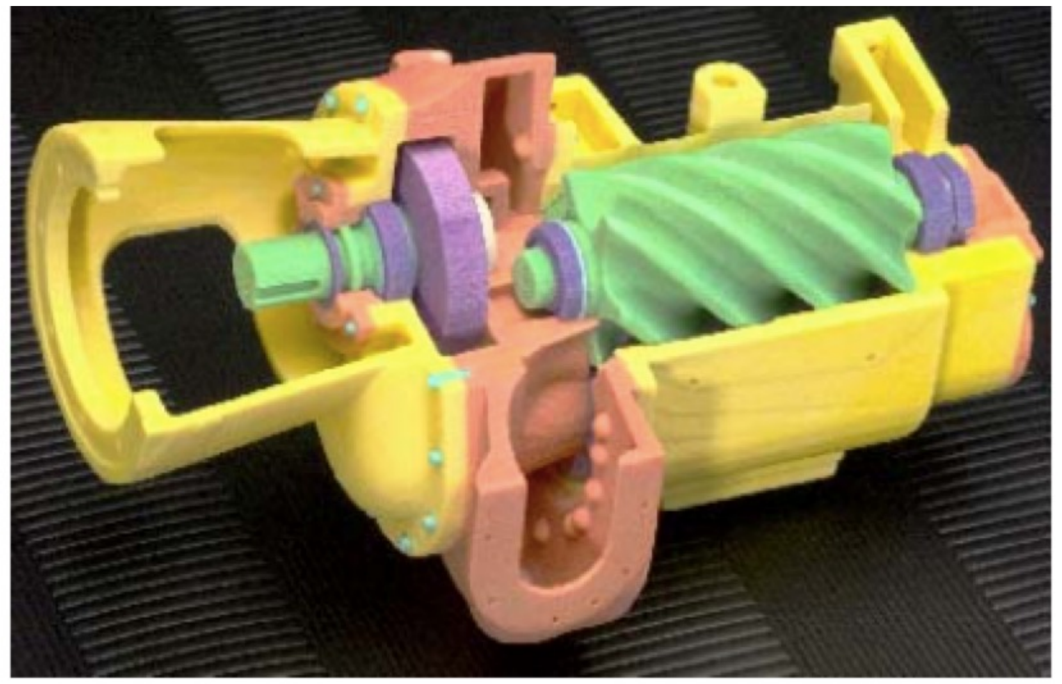
Piezoelectric

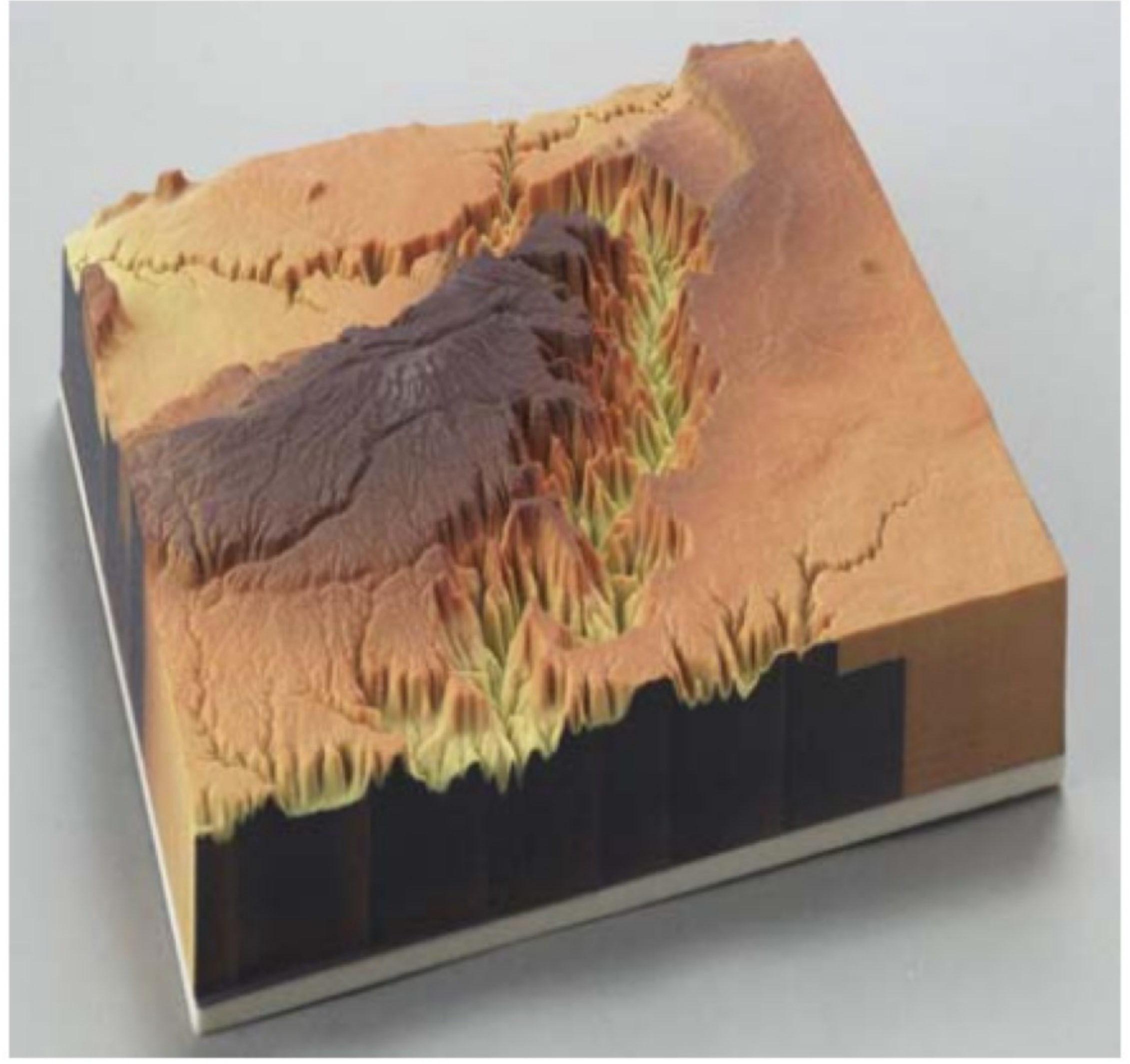


Thermal Inkjet



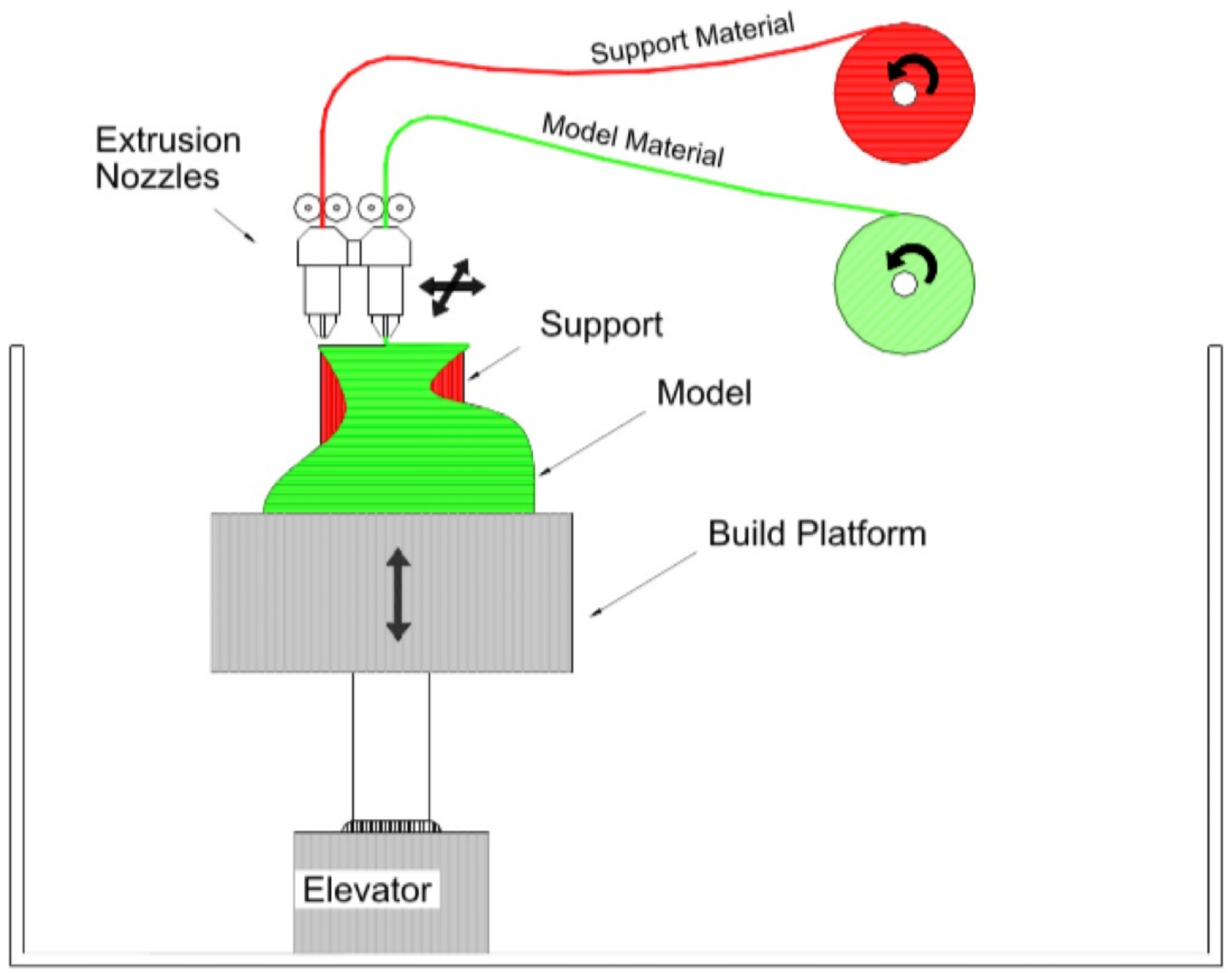
“3D Printer” Example Parts



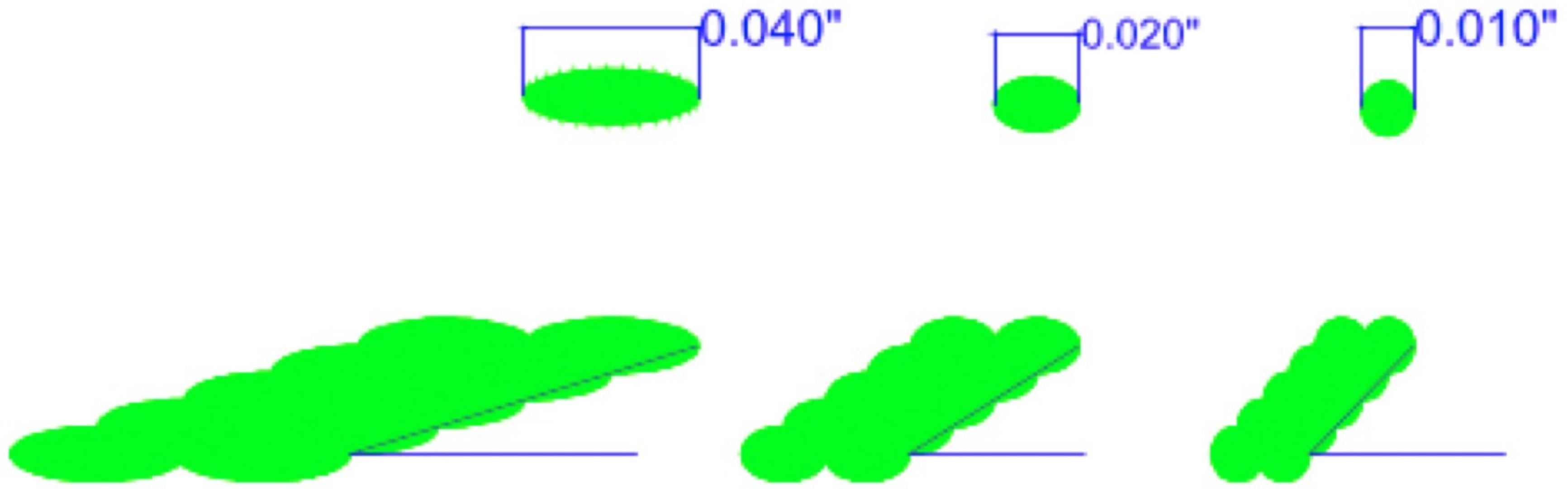


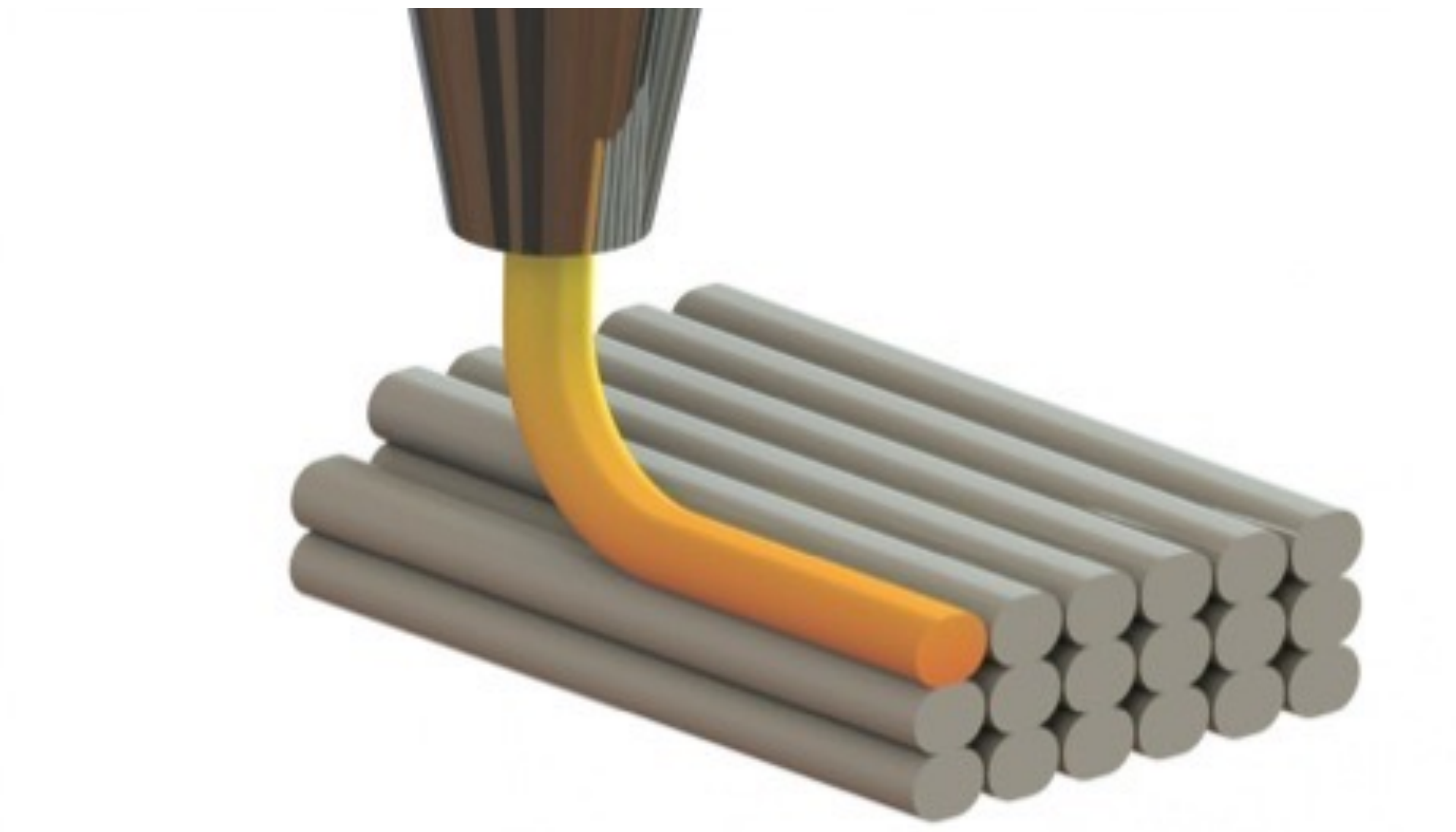
Fused Deposition Modeling (FDM)

- Extruder nozzles moved via x-y device
- Traversal speed is regulated by the desired beadwidth (bead width varies ~ 0.010”-0.040”)
- Combination of material feedrate and traversal speed (for a given nozzle diameter) controls the bead width
- Bead width affects the ability of the process to fill the interior region completely (raster filling)
- Also dependent on raster orientation and contour shape



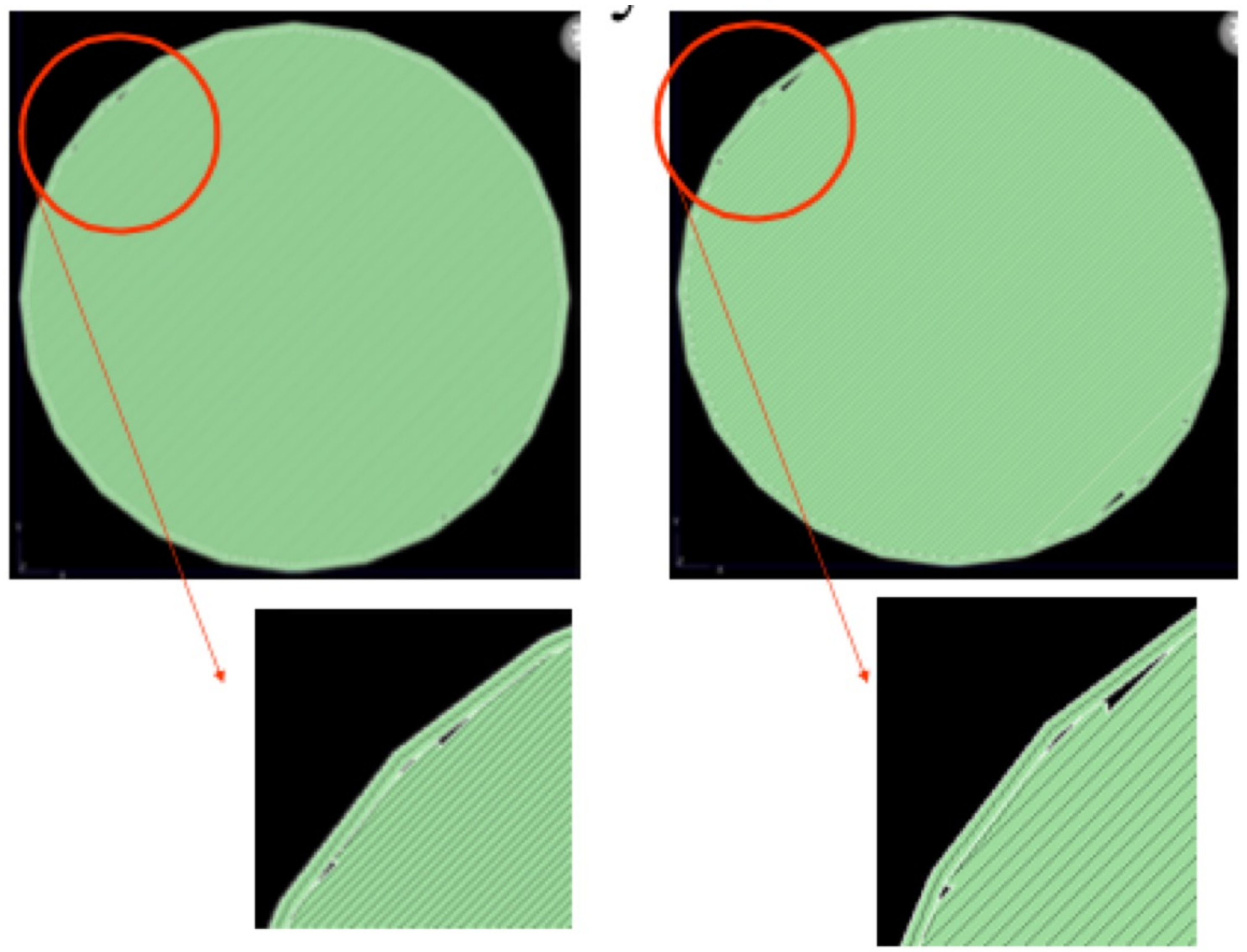
- Supports: affected by “bead”width
- Support angle
  - From horizontal, minimum angle such that at least ½ Bead will lie on top of layer below

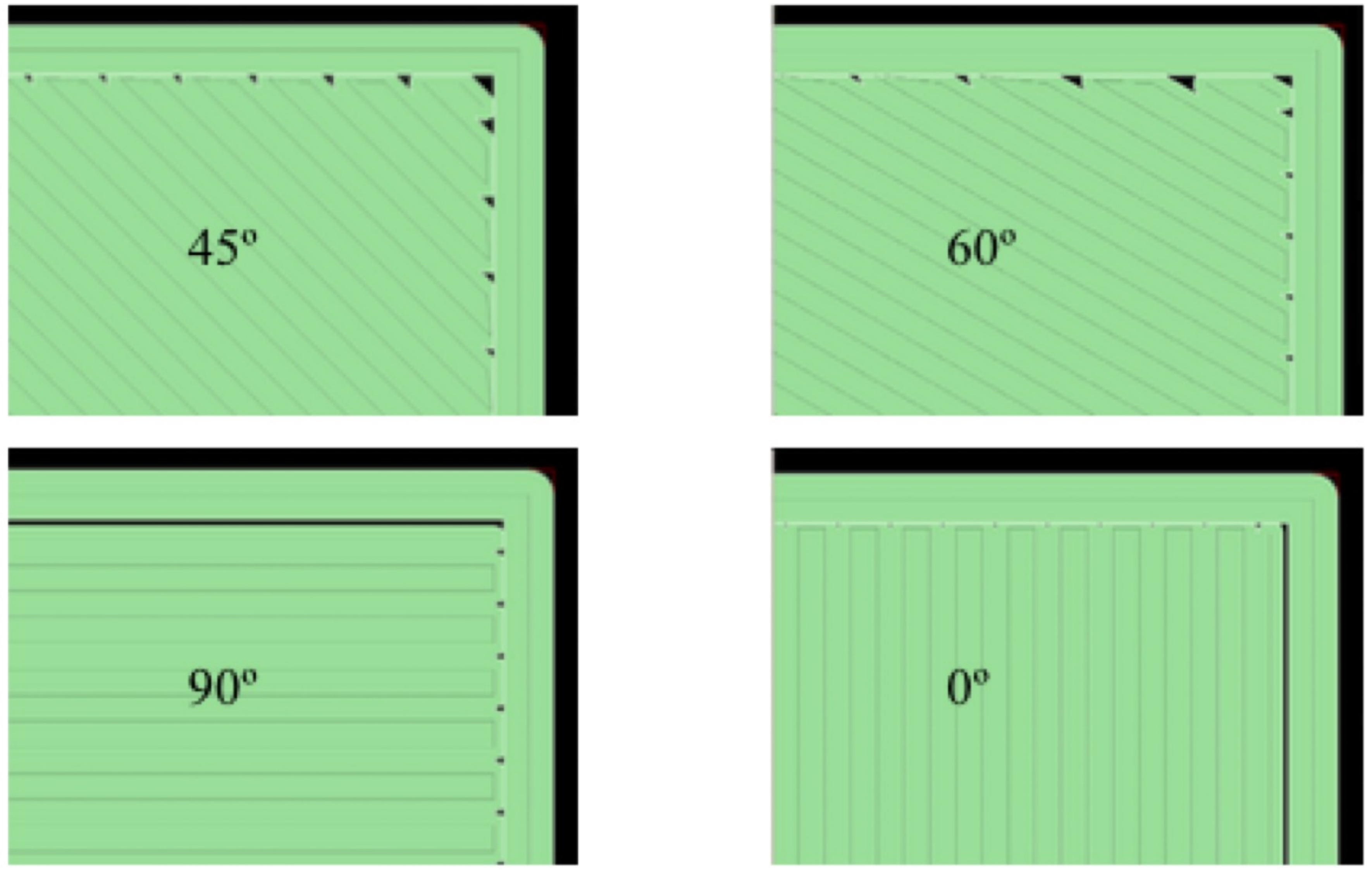


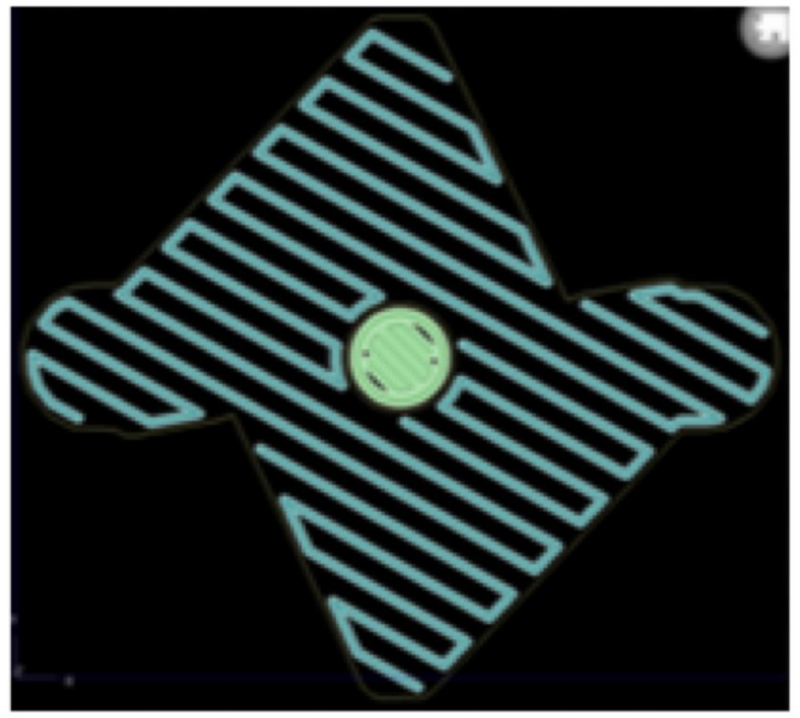


FDM Build Process Induced Error

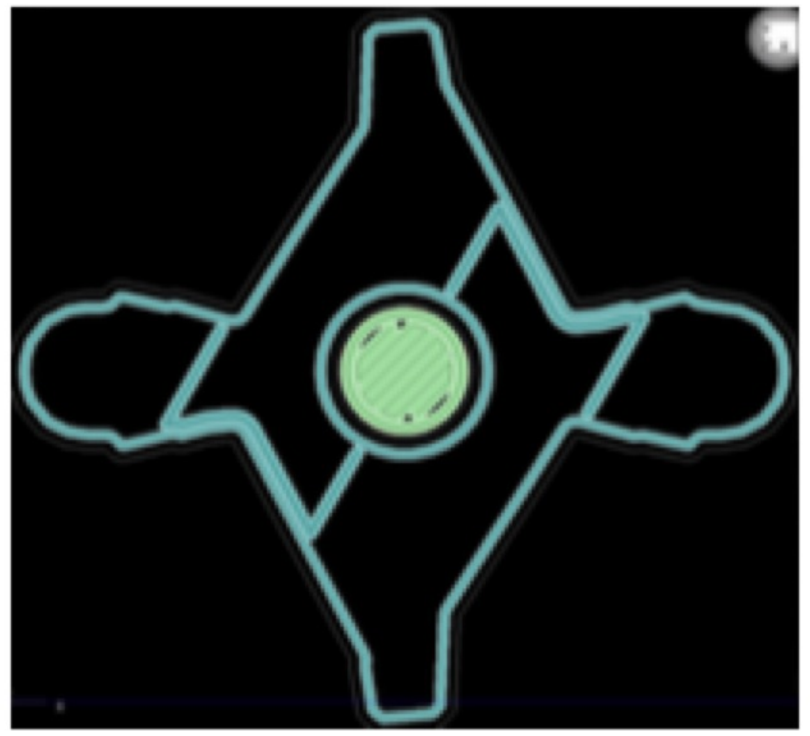
- Part “raster” fill types
- Raft/Base/Support styles



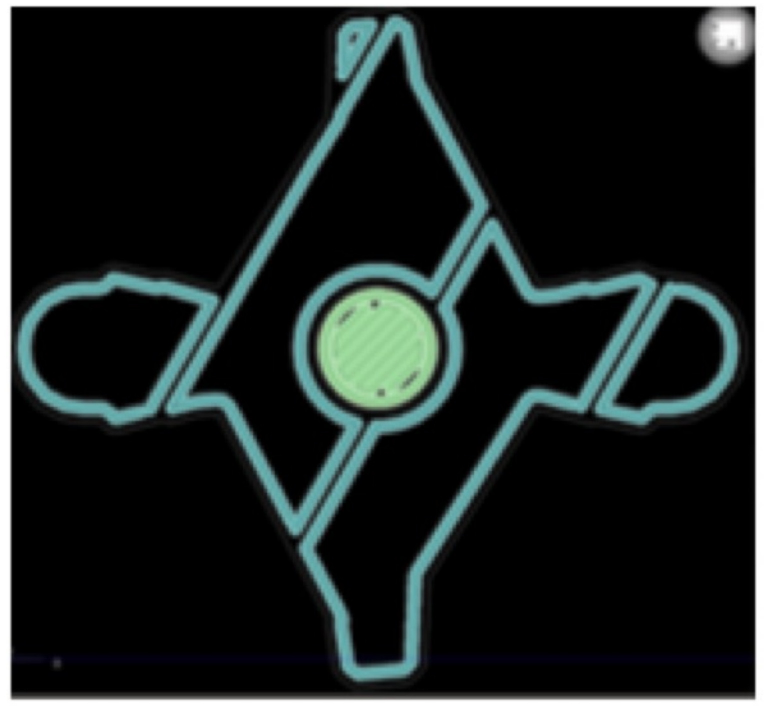




BASIC

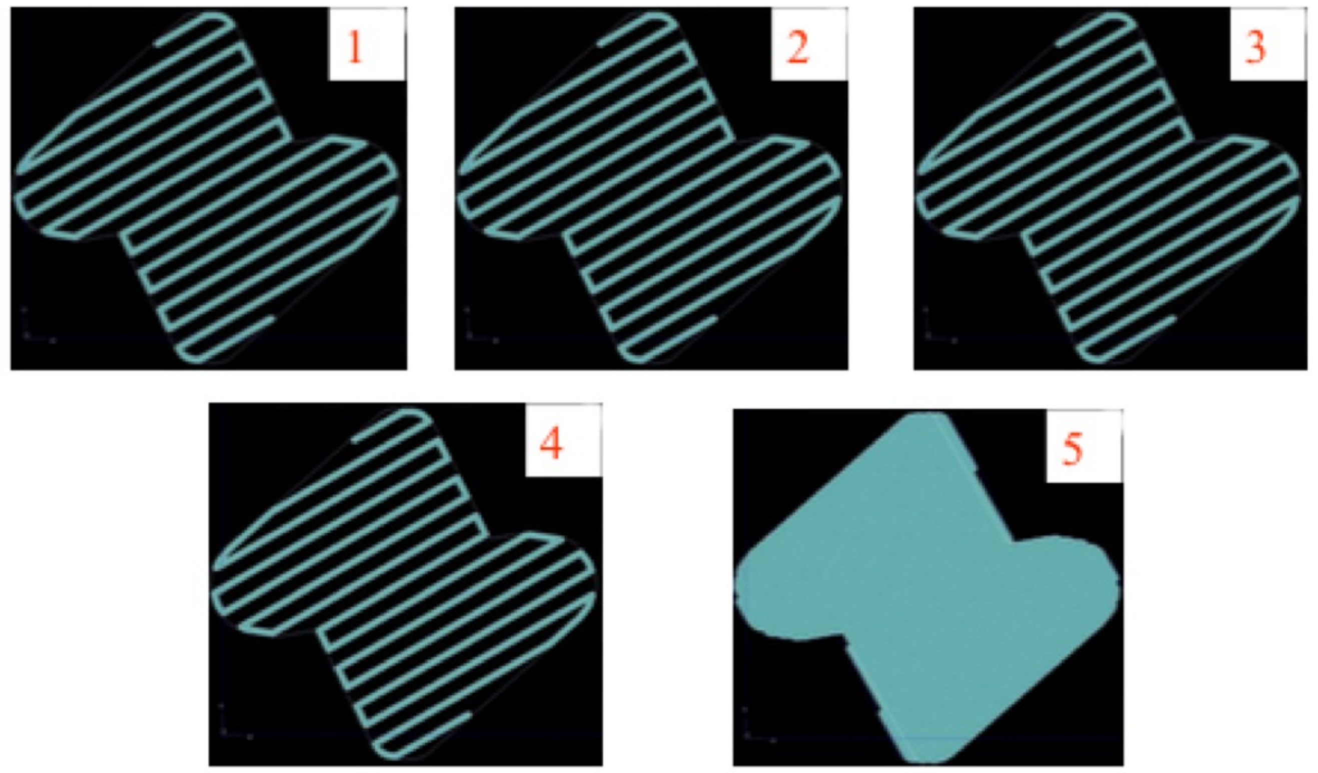


SPARSE



BREAKAWAY

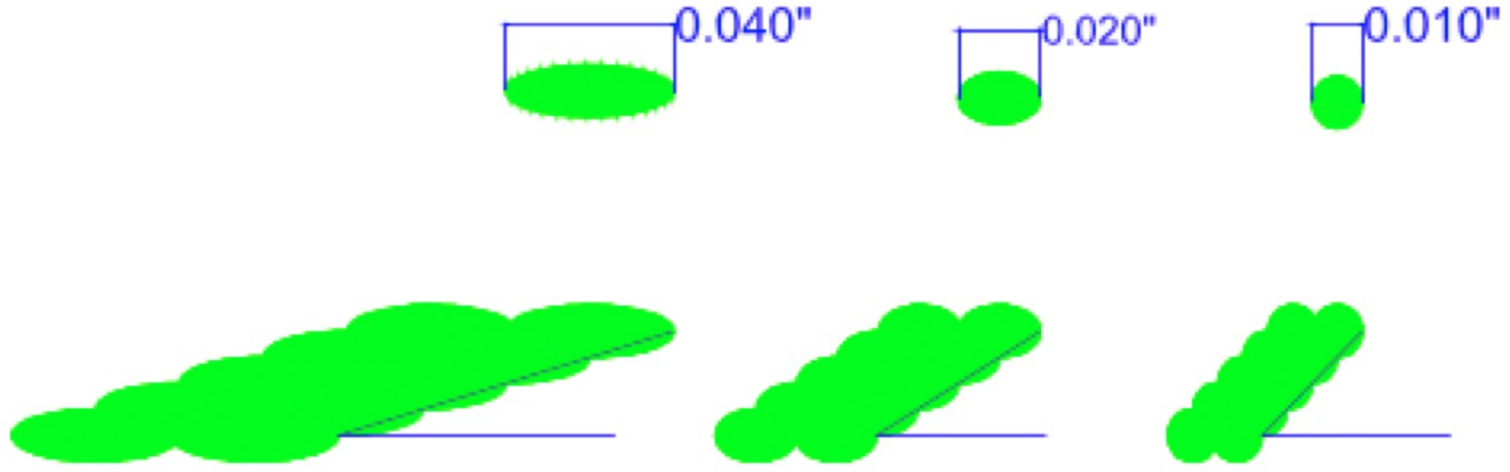
- Supports- begin with a “base” set of layers

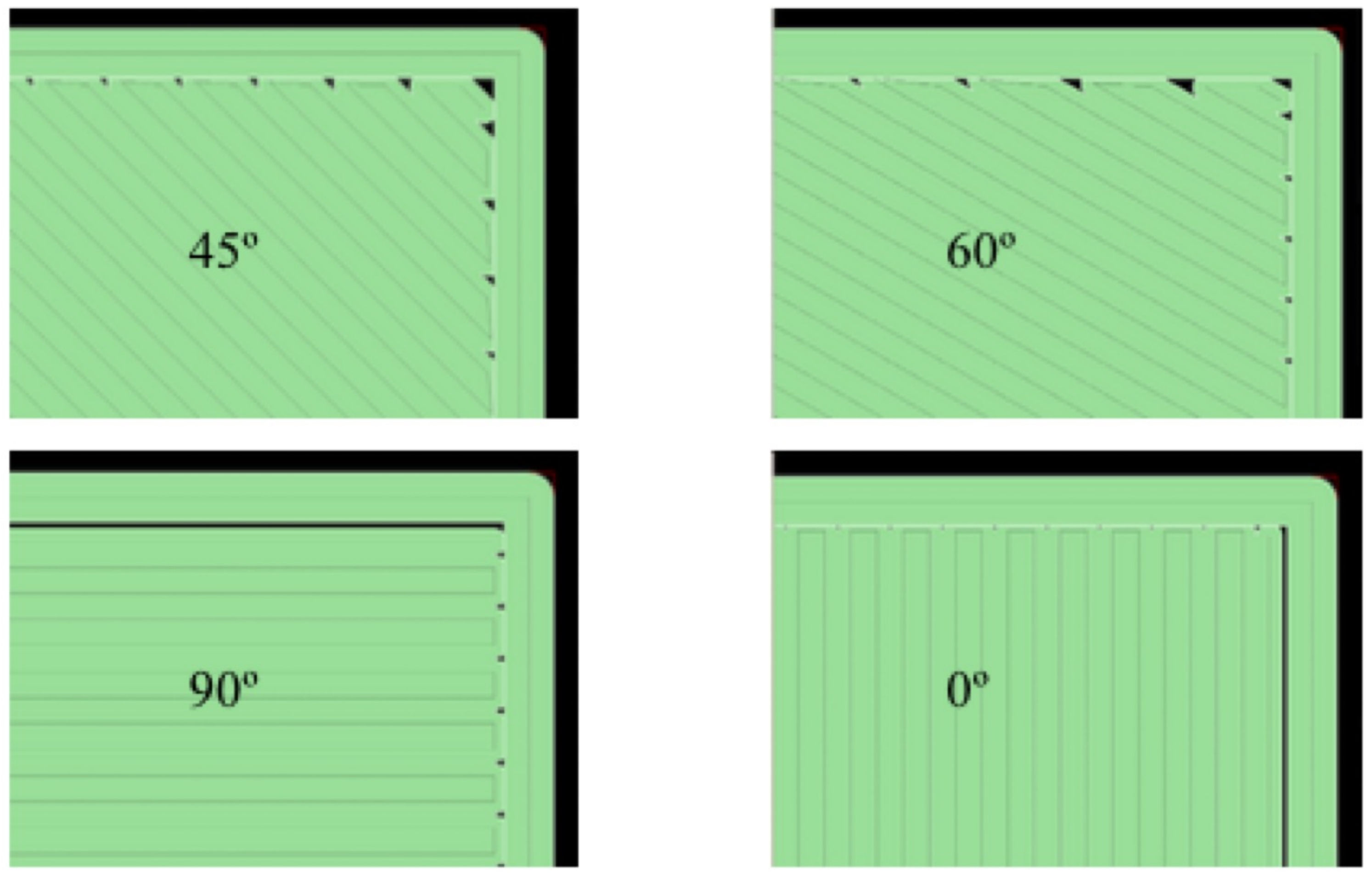


FDM: Materials

- Materials used in FDM are closer to functional materials, ABS and Polycarbonate
  - ABS (Acrylonitrile-Butadiene-Styrene)
  - Good strength, good hardness, available with water soluble supports
  - Tg:212°F
  - Tensile strength (2000psi-7000psi)
- Polycarbonate (“Lexan”)
  - Better strength, better hardness, not currently available with water soluble supports
  - Tg:293°F
  - Tensile strength (10,500psi)
- Anisotropic properties (inter laminate strength)
  - machine movements’ affect on bead shape assumes material is heated “just right”…
  - Material properties are a function of material, process temp and movement precision
  - Tg: 428°F

- Supports: affected by “bead”width
- Support angle
  - From horizontal, minimum angle such that at least ½ Bead will lie on top of layer below



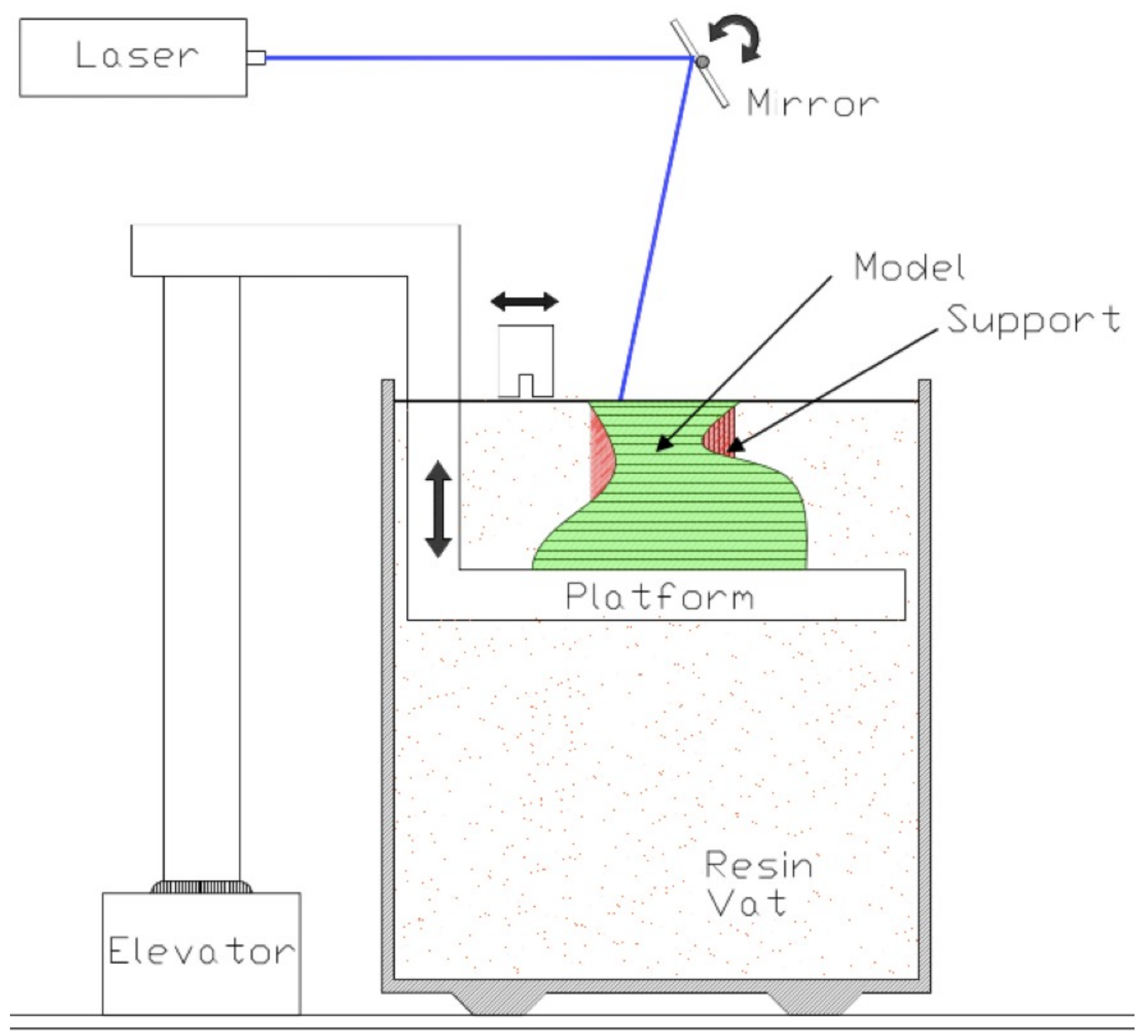


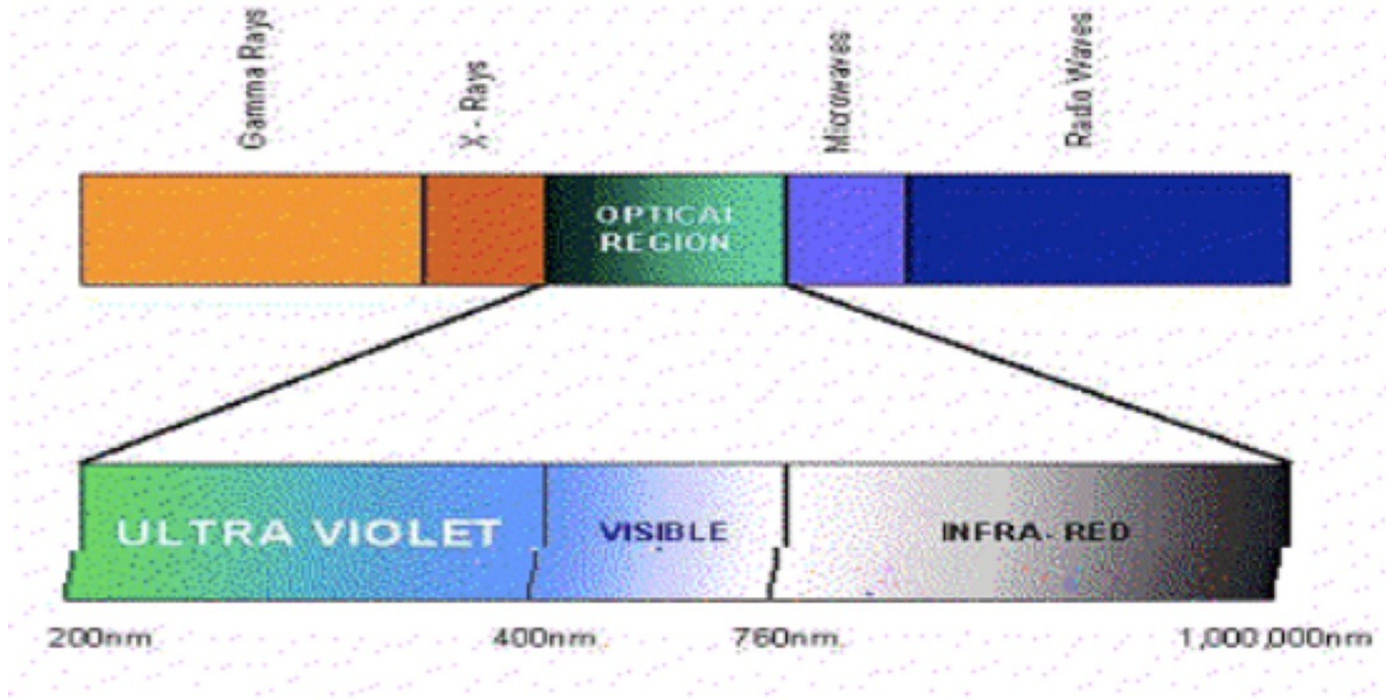
FDM Machine Examples

- Build speed is average to slow (< 200mm/s)
- Layer thicknesses are limited (0.004”to 0.013”)
- Large price range in machines, ~$20,000, up to $400K

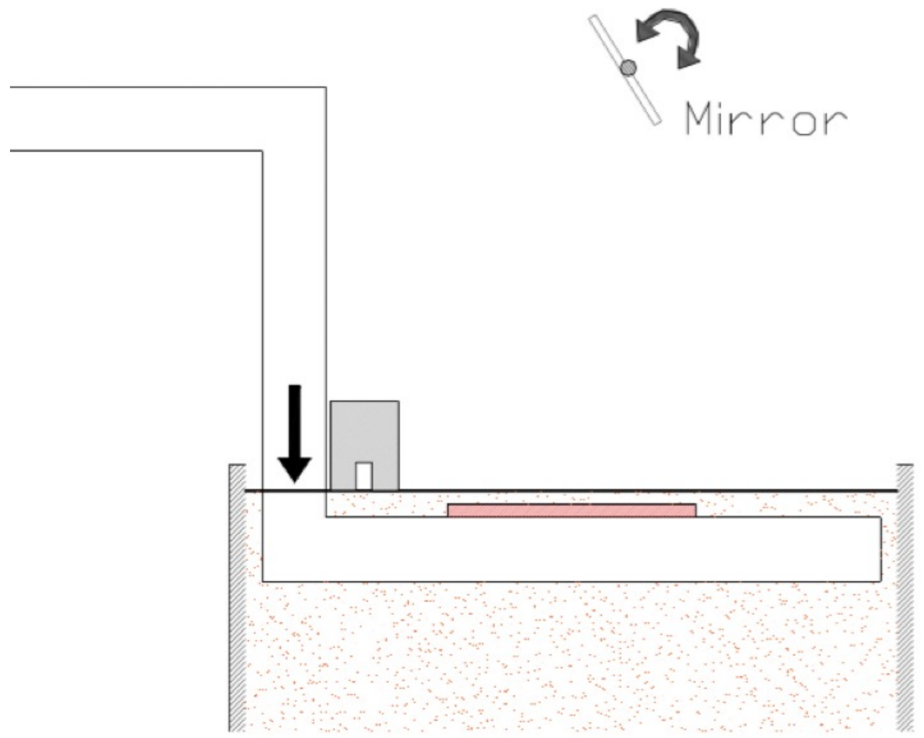
StereoLithography (SLA)

- A build platform moves down
- Passive since surrounded by resin
- Overhanging features still need support
- Layers are formed by curing photosensitive resin using a laser
- Resin is contained in a vat
- A build platform in the vat is used to position the next layer just below the surface of the resin
- Each layer is cured and fused to the preceding layer, forming a solid part

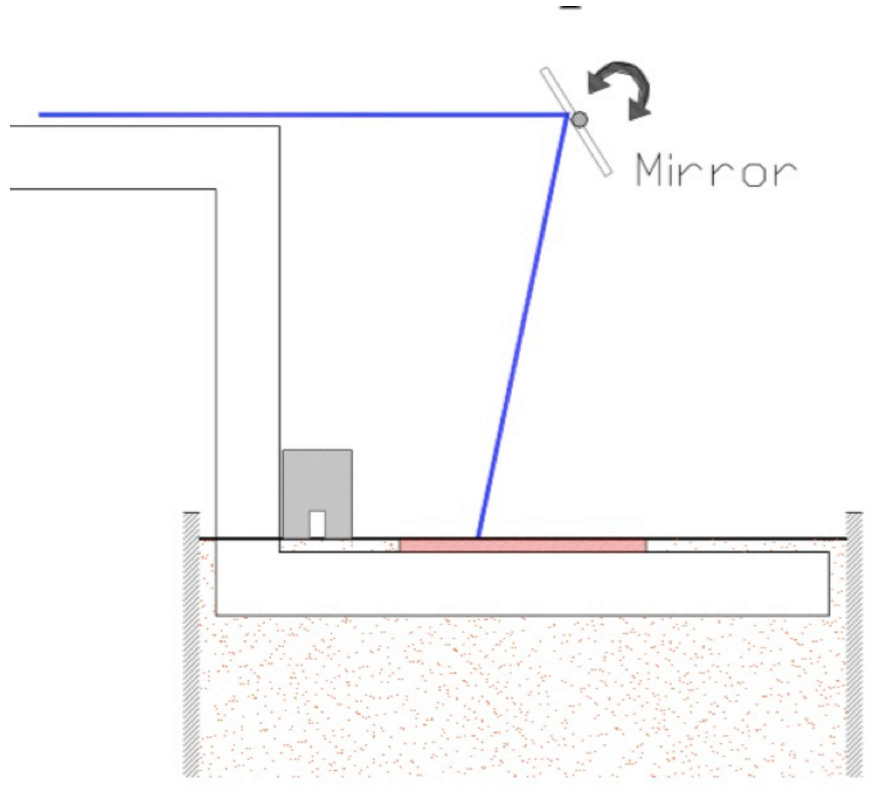




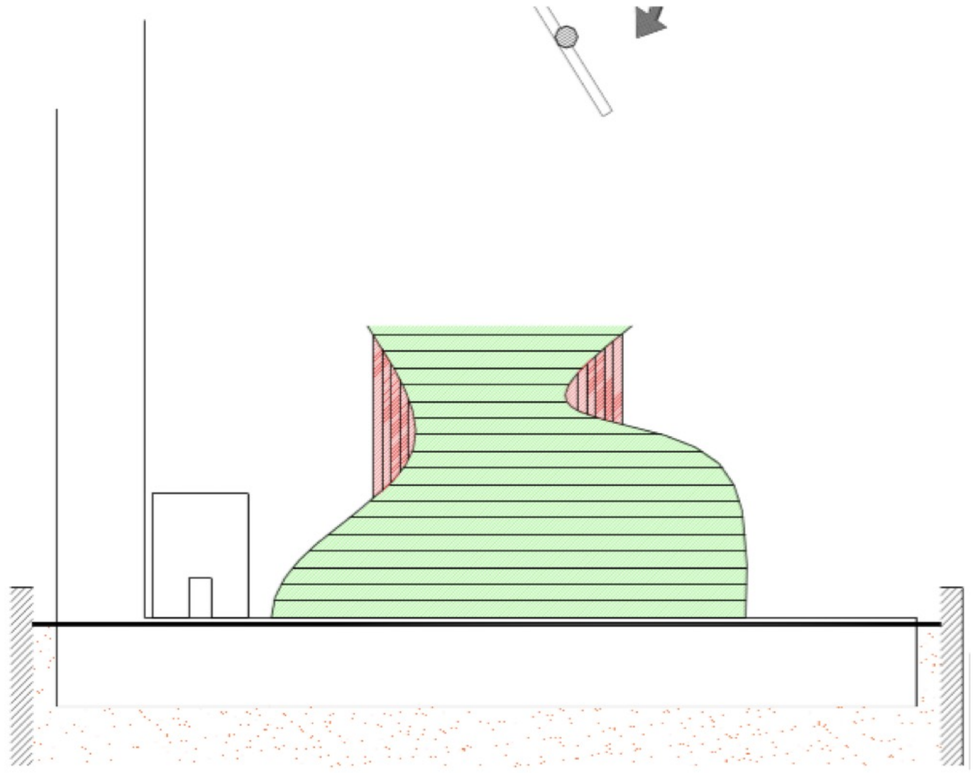
Optical Region



Platform is submerged one layer depth



Curing a layer with the laser

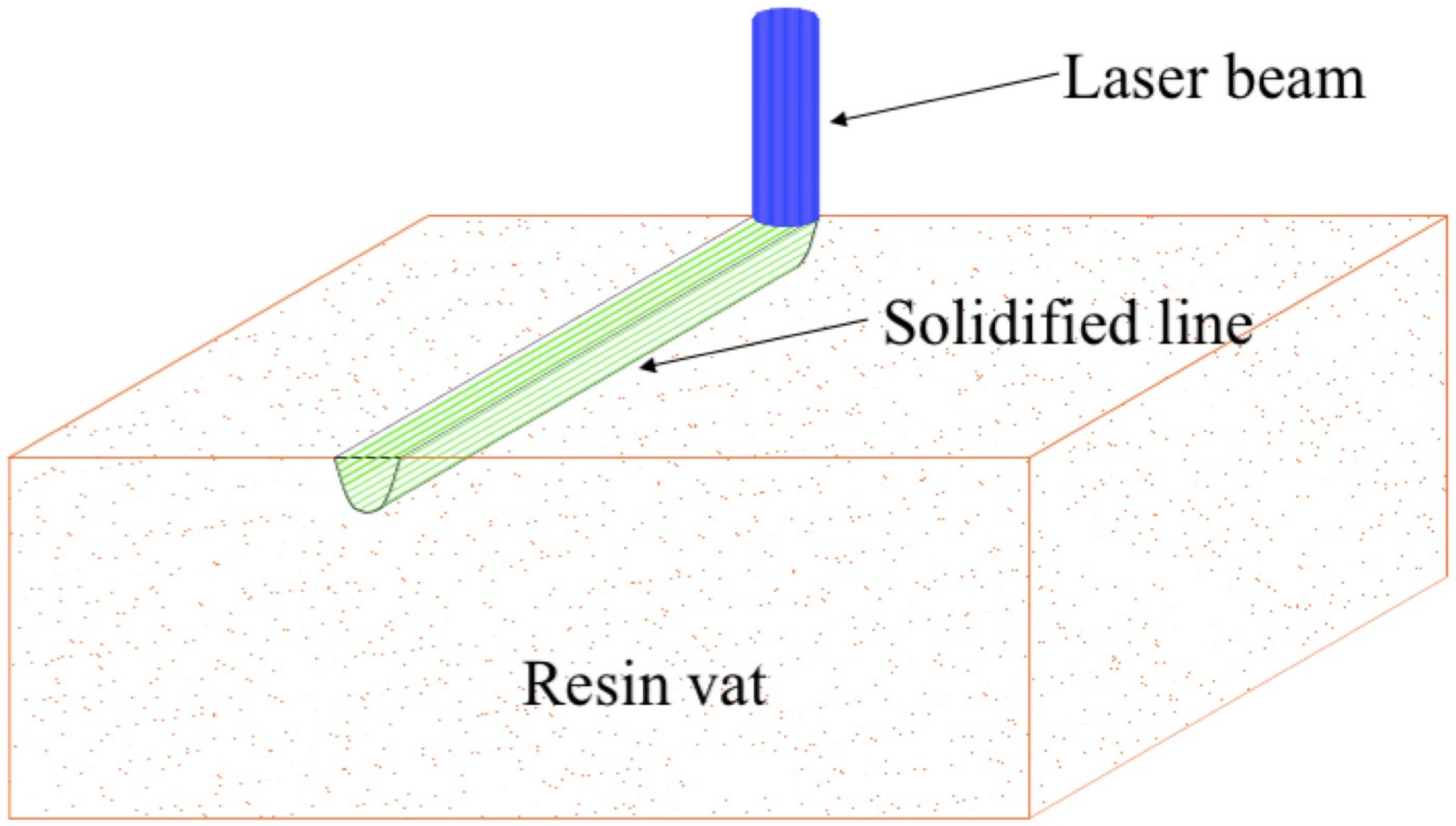


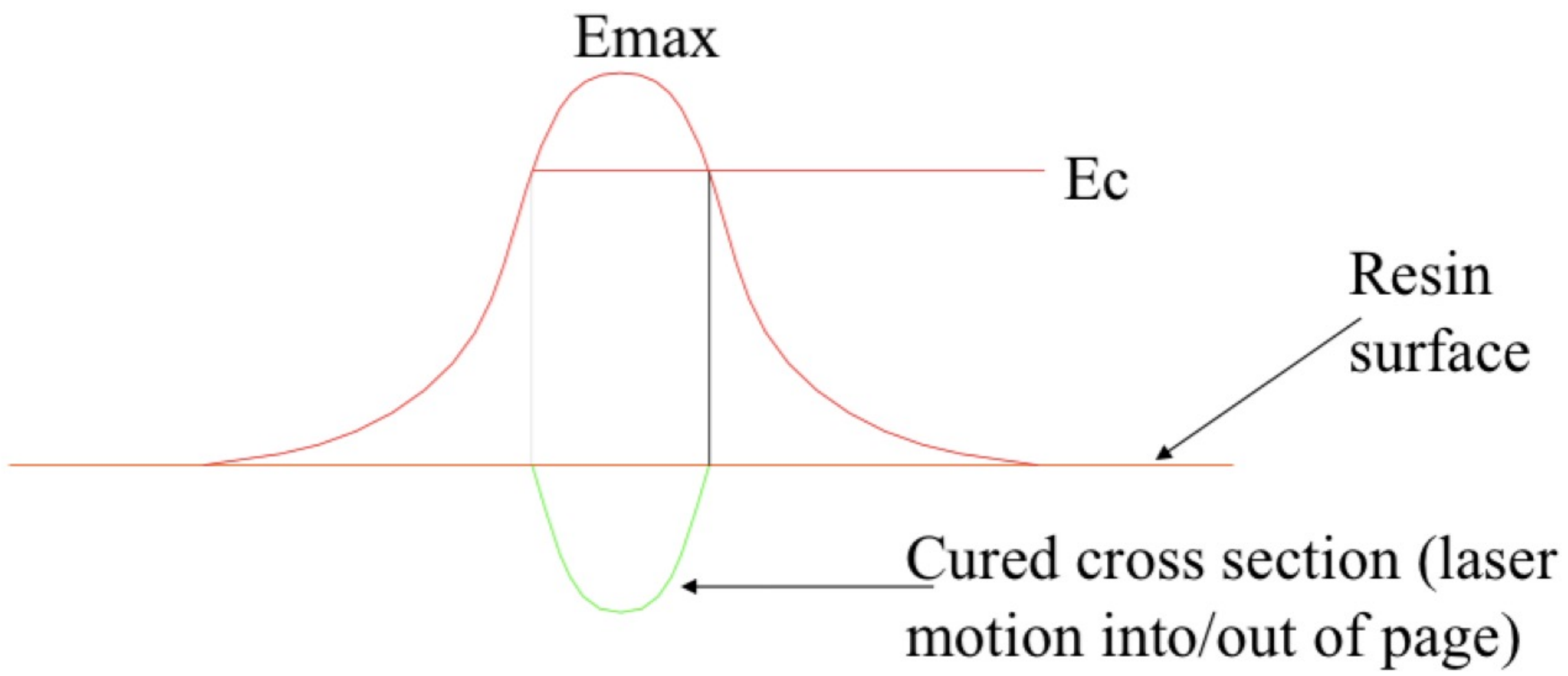
Model is Raised from the Vat

SLA: Laser Solidified Shape Considerations

- In addition to the material considerations the system must be able to accurately focus the UV light (where accuracy may depend on the users needs)

- Laser spot diameter (0.010in - 0.030in) or (0.254mm - 0.762mm) for borders and interior filling, respectively (as available)





Exposure of the laser energy to the resin

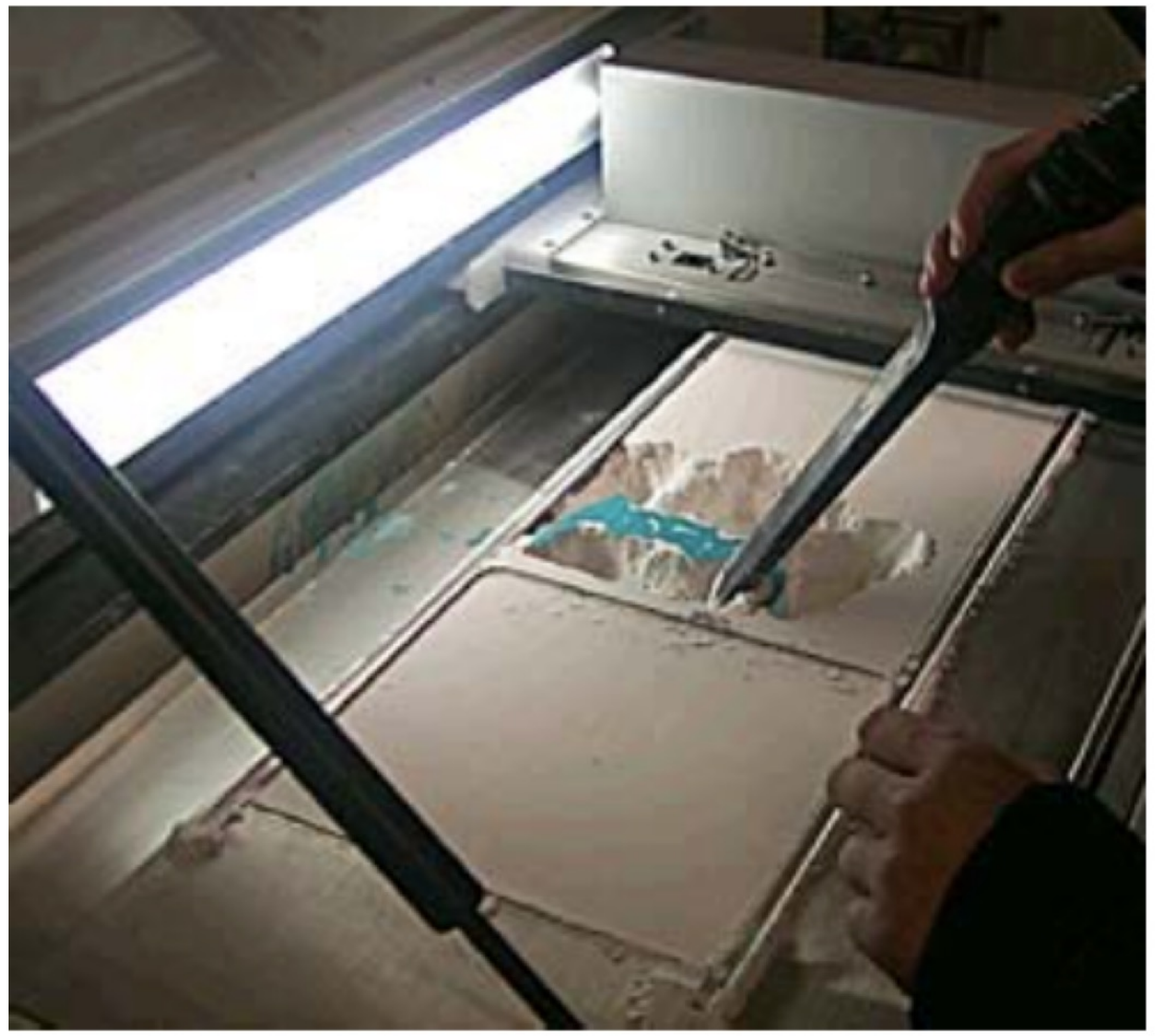
Ec: Critical Exposure, below which polymerization does not occur

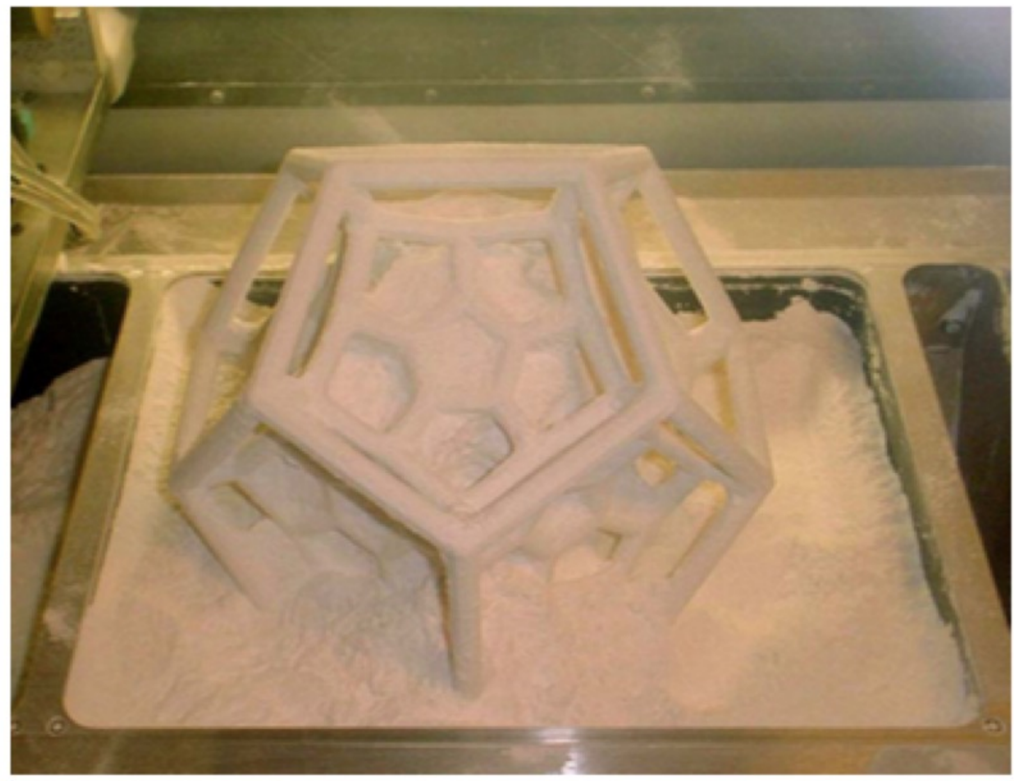
Post Processing, Maintenance, & Quality Assurance

- ***"I'm melting"***: water soluble supports
- ***"I'm not melting but I am feeling a bit hygroscopic"***: help control the wet filament population, have your filament stored and adsorbed
- ***"I think I'm melting"***: FDM vs. FFF (why your extruder is probably clogged)
- ***"I wish I was melting"***: you can't "print metal" but you can sinter it
- ***"I overcooked it"***: laser power and angle of incidence in a heated build chamber
- ***"I wasn't roughhousing"***: post-processing steps non-AM quality assurance inspection standards applied to AM parts
- ***"I'm not done with it, but it printed"***: the often forgotten but beneficial post-processing steps
- ***"I'm for sure melting"***: how to make fully dense metal parts using AM processes/techniques

Post Processing: 3D Printers

- Inkjet binder is not very strong
- Infiltration with other liquids
  - Wax 100% infiltration, not very strong, improves surface
  - Cyanoacrylate, lower quality but better strength than wax, < 1/8” penetration depth
  - Elastomeric Urethane, higher strength and flexibility, < 1⁄2” penetration depth
  - Epoxy, best strength, may be machinable, < 1⁄2” penetration depth
- Infiltration by
  - Dipping (wax)
  - Spraying, Brushing, Dripping





Post Processing: SLA

1. Remove the build platform

2. Put the build platform on the jig

3. Use the removal tool to remove print

4. Agitate part in IPA

5. Repeat with a second rinse

5. Remove the supports

Post Processing: FDM

- Traditionally Polyvinyl Acetate (PVA)
- Stratasys: “Water Works” PVA for ABS
- 3D Systems: Infinity Rinse Away

- Support Materials
  - Plastics
  - Water Soluble (“WaterWorks” option)
    - Can be removed in soapy water bath
    - Automated with Ultrasonic excitation
    - Not available for all materials as of yet