NSF Additive Manufacturing Workshop

3D Printing, Additive Manufacturing, and Solid Freeform Fabrication: The Technologies of the Past, Present and Future

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Print me a Stradivarius
The manufacturing technology that will change the world

This violin was made using an EOS laser-sintering 3D printer (and it plays beautifully)
Solid Freeform Fabrication

Fabrication of complex freeform solid objects directly from a computer model of an object without part-specific tooling or human intervention.

Art to Part
Voxel Manufacturing - 1985

Layered Manufacturing
SFF Markets

Accuracy

Strength

Patterns

3D Printing – Concept Models

Prototypes

Machining Forms

Manufacturing

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Market Segments & Barriers

- Concept Models
  - Cost
  - Some performance
- Machining Forms
  - Cost & competition
- Patterns
  - Accuracy
  - Surface Finish
- Rapid Prototyping
  - Materials
- Manufacturing
  - Materials
  - Process Control
Additive manufacturing "makes it as cheap to create single items as it is to produce thousands... It may have as profound an impact on the world as the coming of the factory did."

Innovations in materials and processes are transforming rapid prototyping to rapid manufacturing

- Manufacturing near the point of use - enables rapid deployment
- "On demand" manufacturing - reduces inventories and wait times
- Replacement of metals with lightweight materials - enables new applications
History
Prehistory - Layered Additive Structures have been around for awhile

Dave Rosen

The oldest pyramid known is the Step Pyramid of King Zoser at Saqqara. It was built during the Third Dynasty (ca. 2800 B.C.)
Early Parts

Kodama

Herbert

Housholder
The Past

Françoise Willème’s Photosculpturing studio Paris about 1870

Admiral Farragut sits, late 1860’s, for photosculpture
UT Historical AM Contributions

1987: UT Develops 1st SLS Machine (Deckard & Beaman)
1988: UT Commercializes to DTM
1989: First Commercial SLS Parts Sold
1992: First SLS Machine Sold
1988: Ti SuperAlloy SLS Parts
1998: SiC Laser Sintered Parts (indirect)
2002: Custom Nylon Ankle-Foot Orthotics
2007: Flame Retardant Nanocomposites SLS Characterization
2010: Silicon Infiltrated Silicon Carbide Fuel Reformer
2011: 2nd Generation High Temperature Polymer SLS Testbed
2013: BAMBI
Processes
Selective Laser Sintering
Selective Laser Sintering (SLS)

Technology: Laser fused powders

Introduced: 1992
Stereolithography (SLA)

- **Technology:** Curable Liquid Resin
- **Introduced:** 1988
- **Major Vendor:** 3D Systems
Fused Deposition Modeling
Fused Deposition Modeling (FDM)

- **Technology**: Filament Extrusion
- **Introduced**: 1991
- **Major Vendor**: Stratasys
Ink Jet Systems

molten plastic

ink jet print head
Ink Jet Systems

- **Technology:** *Ink jet deposition*
- **Introduced:** 1994
- **Major Vendors:** Solidscape, Sanders Prototyping, 3D Systems
3D Printing

• Technology: Selective deposition of binders into powder
• Introduced: 1996
• Major Vendor: Zcorp
Additive Manufacturing
Cost versus Production Volume

- Injection Moulding
- Stereolithography (SLA 7000)
- Fused Deposition Modelling (FDM 2000)
- Laser Sintering (EOSP 360)

Loughborough University 2000
Direct Manufacture

(A) Conventional Duct fabricated from Vacuum Formed plastic
Part Count = 16 (plus glue)

(B) Component modified and consolidated for fabrication via Additive Rapid Direct Manufacture
Part Count = 1

Part Count = 1

Courtesy of 3D Systems / Boeing
Barriers to Additive Manufacturing

- Surface finish
- Production speed
- Cost
  - Machines
  - Materials
- Variation from part to part
  - Inadequate process control
- Materials availability
Direct Metals
Metal Components: EOS (Laser Sintering)
Metal Components: SLS Titanium

SLS processed AIM-9 Sidewinder missile guidance section housing (90% scale)
Metal Components: AeroMet

The AeroMet™ Laser Additive Manufacturing Process

- Deposition nozzle
- 18kW CO₂ laser
- Re-solidified titanium alloy
- Prior Passes
- Powder/laser interaction
- Molten titanium alloy puddle
- Pre-alloyed or mixed elemental powders

Process schematic

Actual machine

As built part

Finished part
Metal Components: POM

Process schematic
Metal Components: Optomec

Process schematic

Actual Machine

Wind tunnel prototype

Hip replacement implant

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Metal Components: Solidica (Ultrasonic consolidation)
Metal Components: ARCAM (e-beam sintering)
• The Future
Multiple Materials
M²SFF

Graded Tungsten Carbide / Cobalt

- Potential performance enhancement with use of FGM.
- Possess greater amounts of tungsten carbide near working surfaces to provide greater erosion
- Possess greater amounts of cobalt in regions of expected fracture to increase ductility.
A New Manufacturing Archetype

- Traditional Manufacturing:
- Regional Push-Button Manufacturing
Changing the Landscape of Design and Invention

- Elimination of Constraints:
  - Rather than
  - **DFM** → *Design for Manufacturing*

- Invert the process to
  - **MFD** → *Manufacture for Design*
Application Sectors

Military

Rehabilitation

Assistive Technologies

Consumer Products

Spectrum emphasizes strategic needs.
Complex Engineered System
3D-Fax - Demonstrated in 1992
We have seen this before

Willy Wonka and the Chocolate Factory
1971
Conclusion

- Additive Manufacturing is an exciting and emerging field
- Special thanks to NSF, ONR, DARPA