

NSF Additive Manufacturing Workshop

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

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**The
Economist**

FEBRUARY 12TH-18TH 2011

Economist.com

Europe loses the mobile-phone war

Africa's new wealth

Japan's tea party

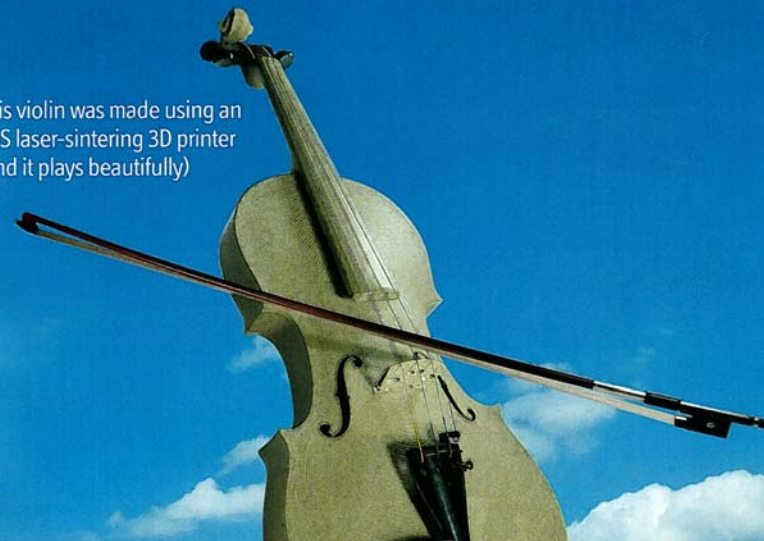
How to switch off the internet

The shoe-thrower's index

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)



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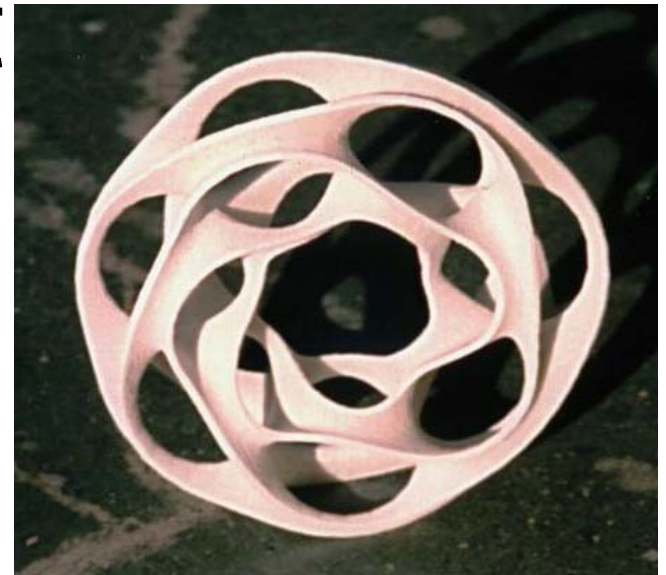


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Solid Freeform Fabrication

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

Art to Part

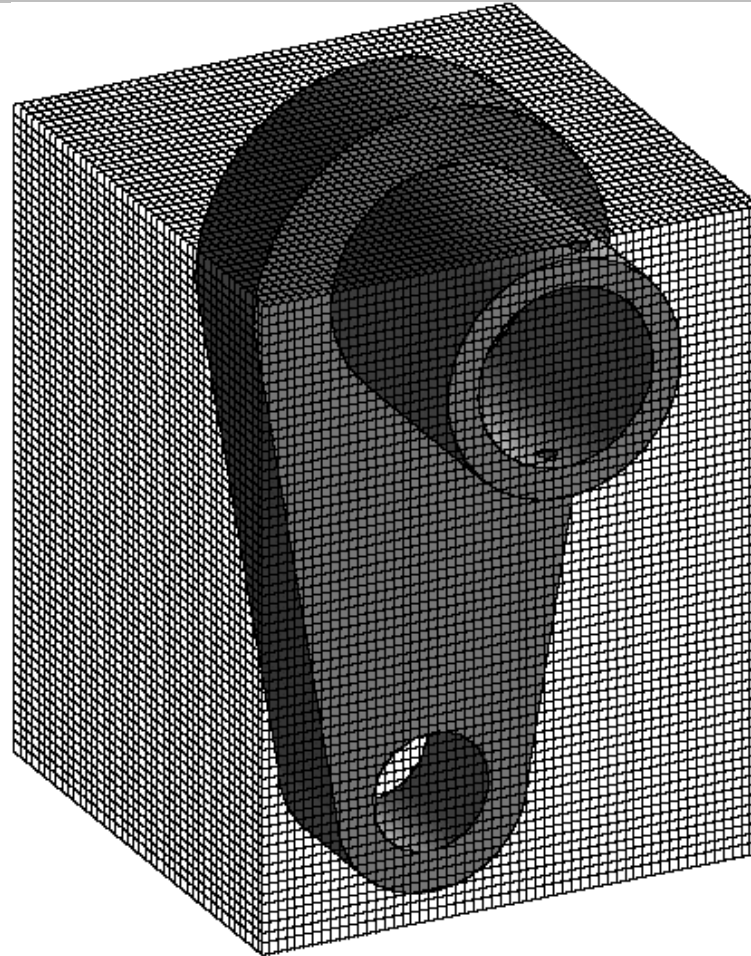


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Voxel Manufacturing - 1985



Layered
Manufacturing

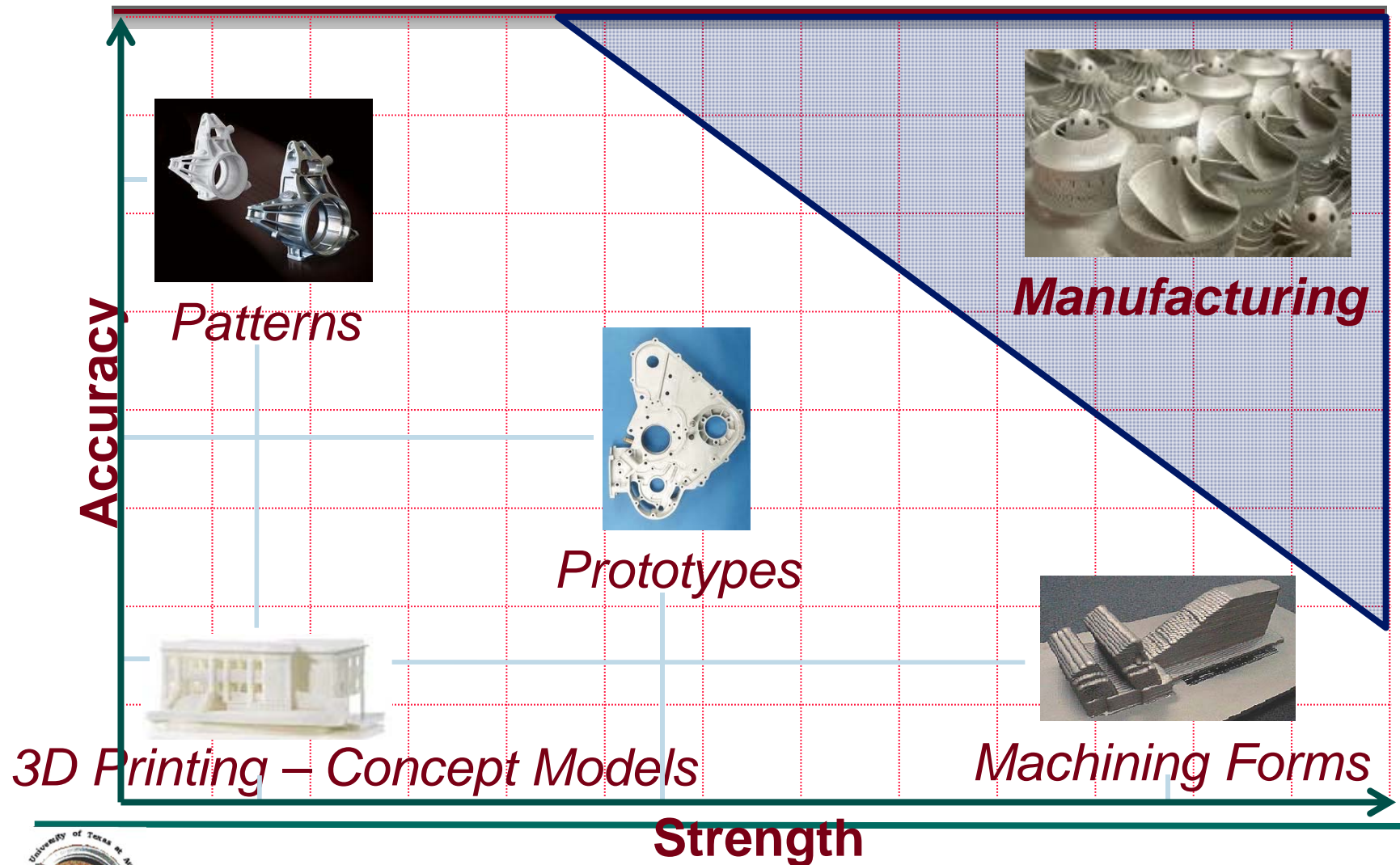


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SFF Markets



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Market Segments & Barriers

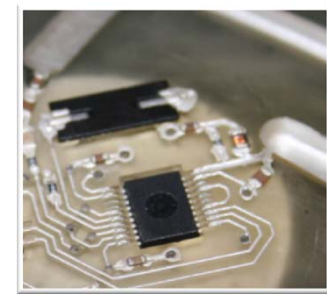
- Concept Models
 - Cost
 - Some performance
- Machining Forms
 - Cost & competition
- Patterns
 - Accuracy
 - Surface Finish
- Rapid Prototyping
 - Materials
- Manufacturing
 - Materials
 - Process Control



‘The Manufacturing Technology That Will Change the World’

The
Economist

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*



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History



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Prehistory - Layered Additive Structures have been around for awhile



Dave Rosen

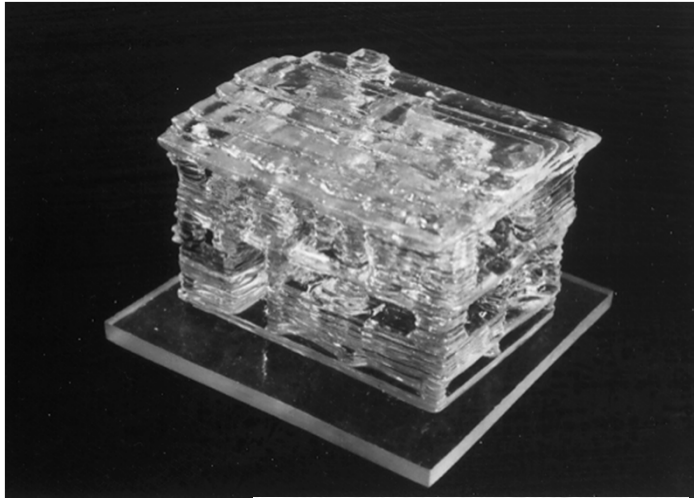
The oldest pyramid known is the Step Pyramid of King Zoser at Saqqara. It was built during the Third Dynasty (ca. 2800 B.C.)



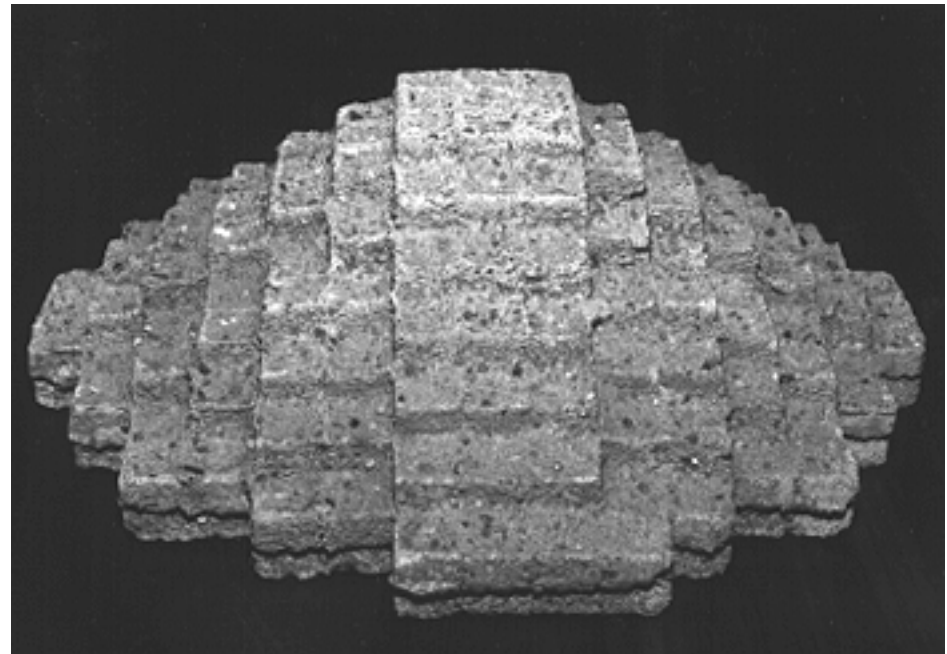
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Early Parts



Kodama



Housholder



Herbert



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The Past



Françoise Willème's
Photosculpturing studio
Paris about 1870

Admiral Farragut sits,
late 1860's, for
photosculpture

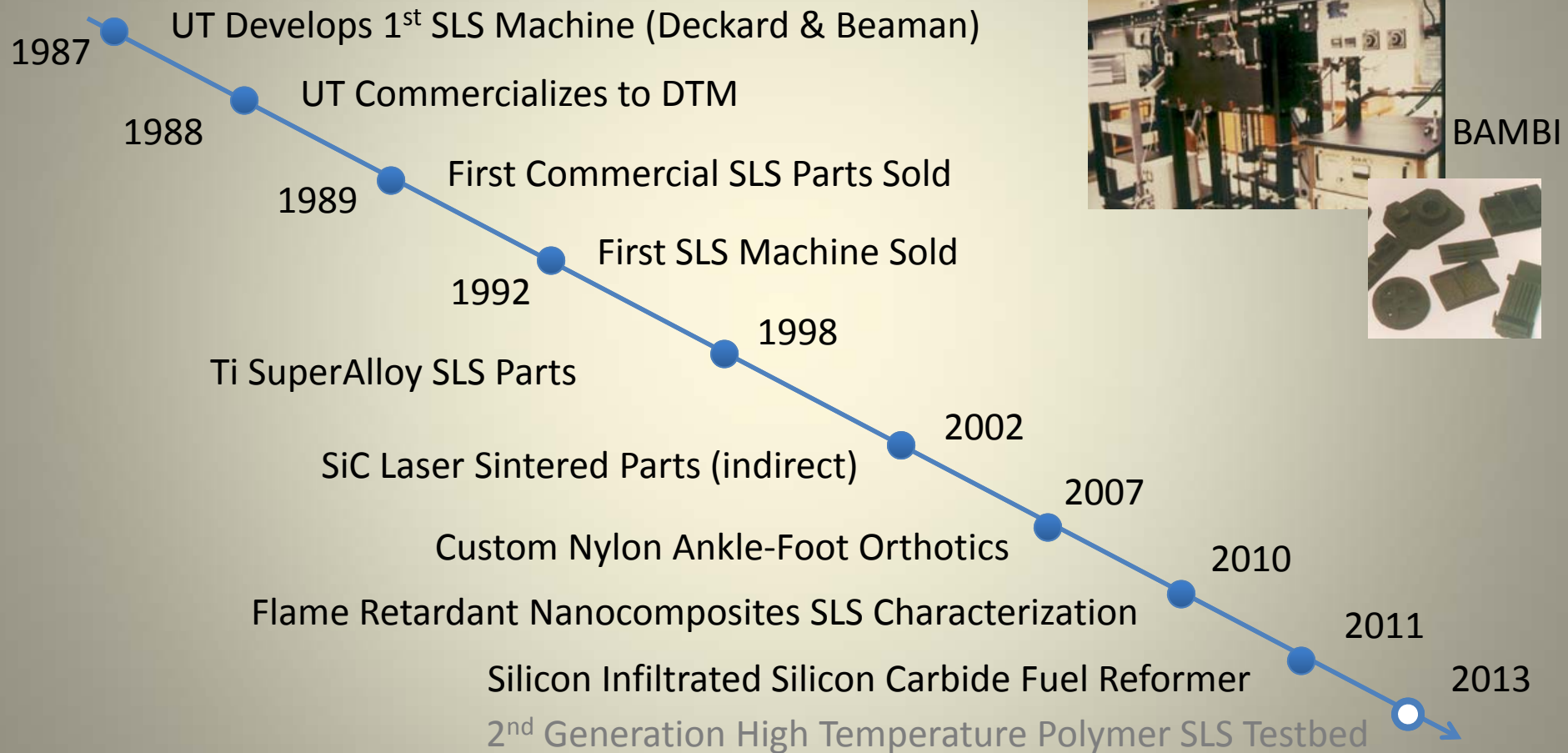


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UT Historical AM Contributions



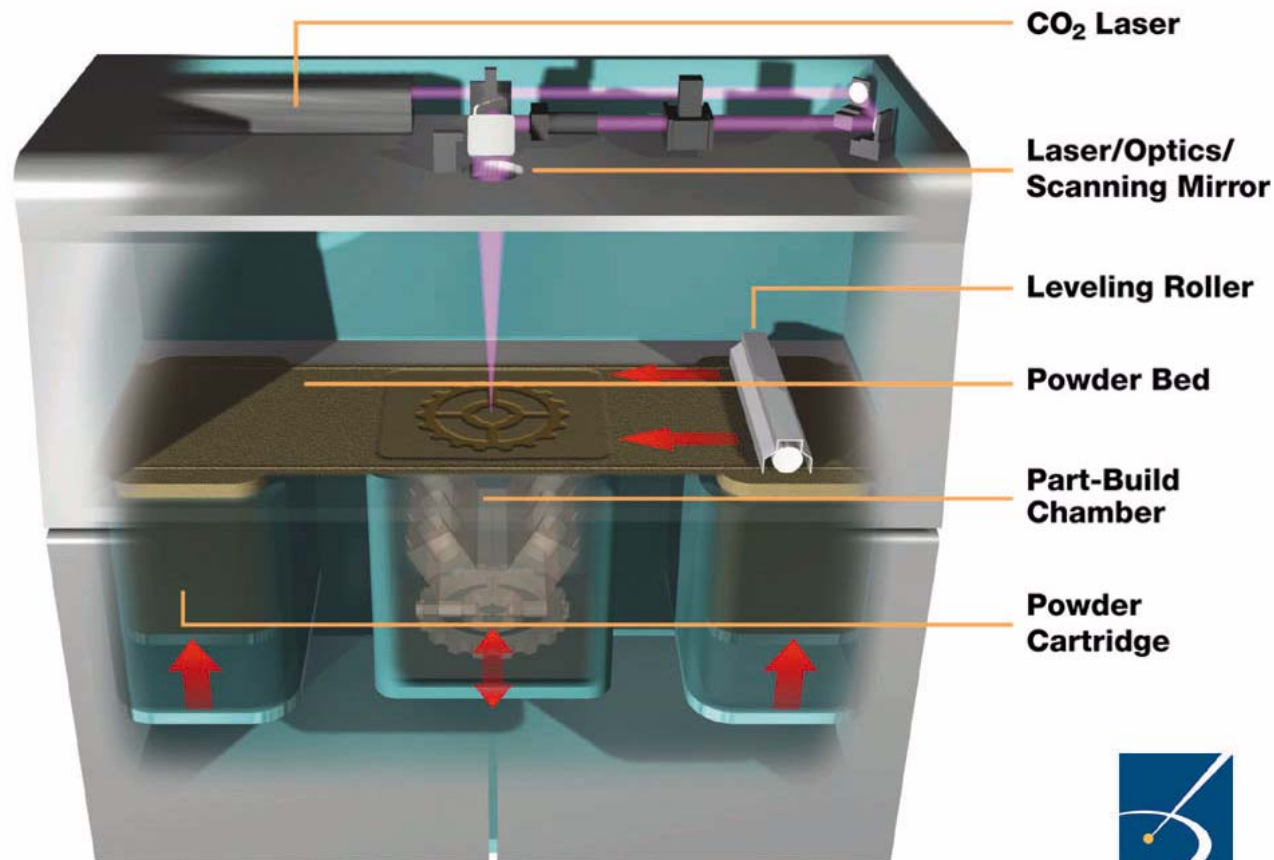
Processes



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Selective Laser Sintering



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Selective Laser Sintering (SLS)

Technology: *Laser fused
powders*

Introduced: 1992

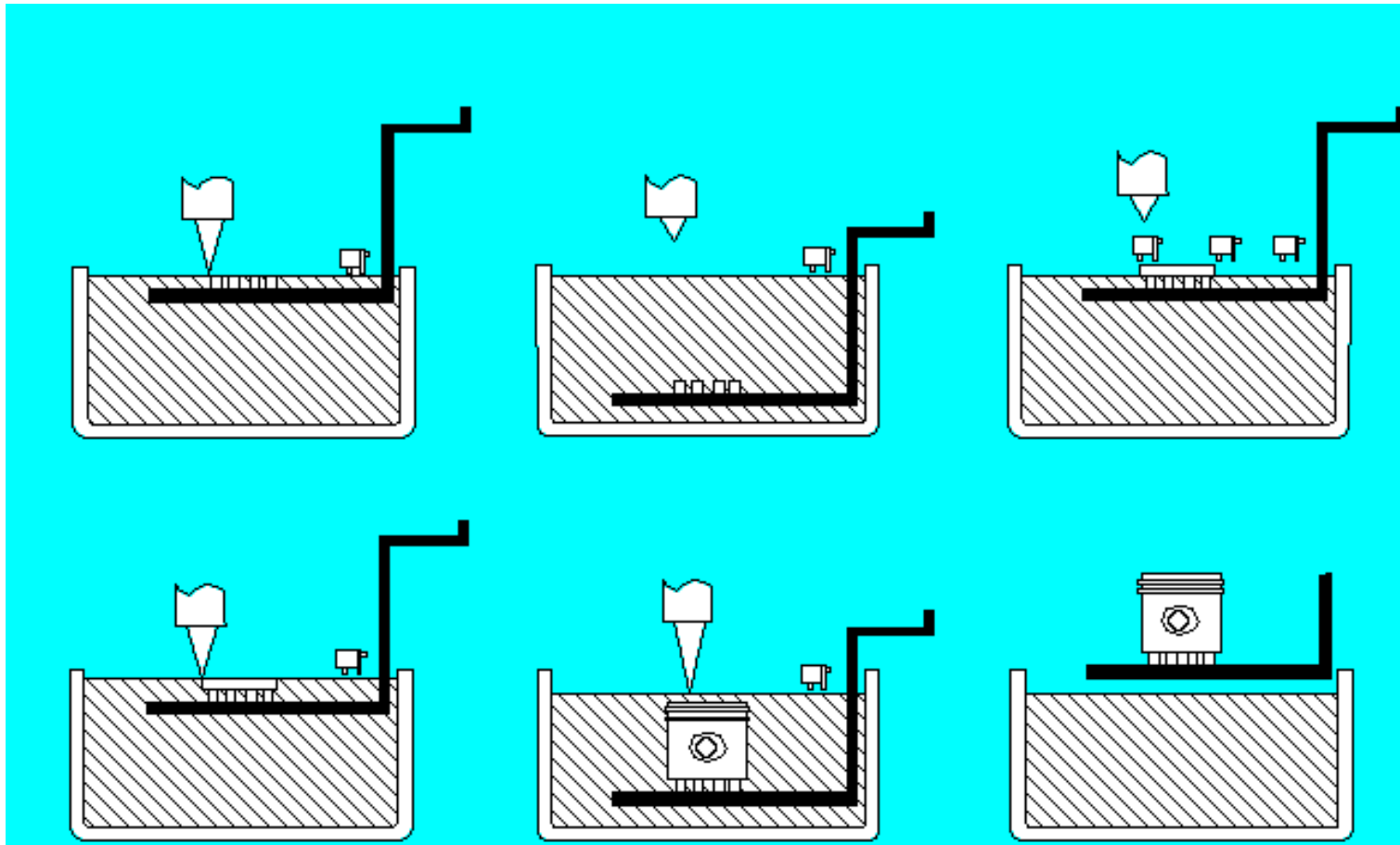


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Stereolithography



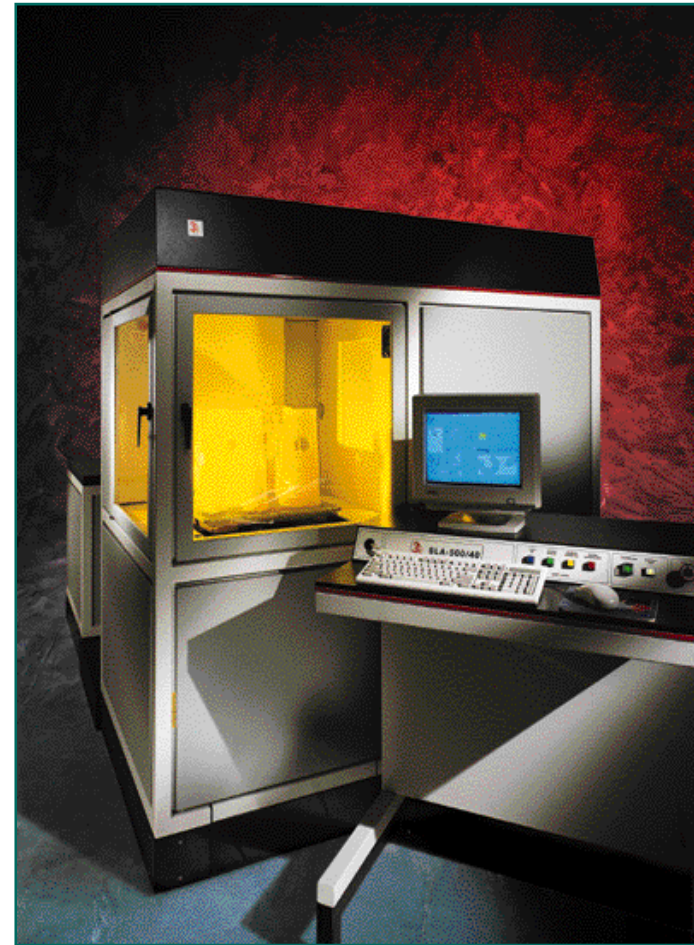
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Stereolithography (SLA)

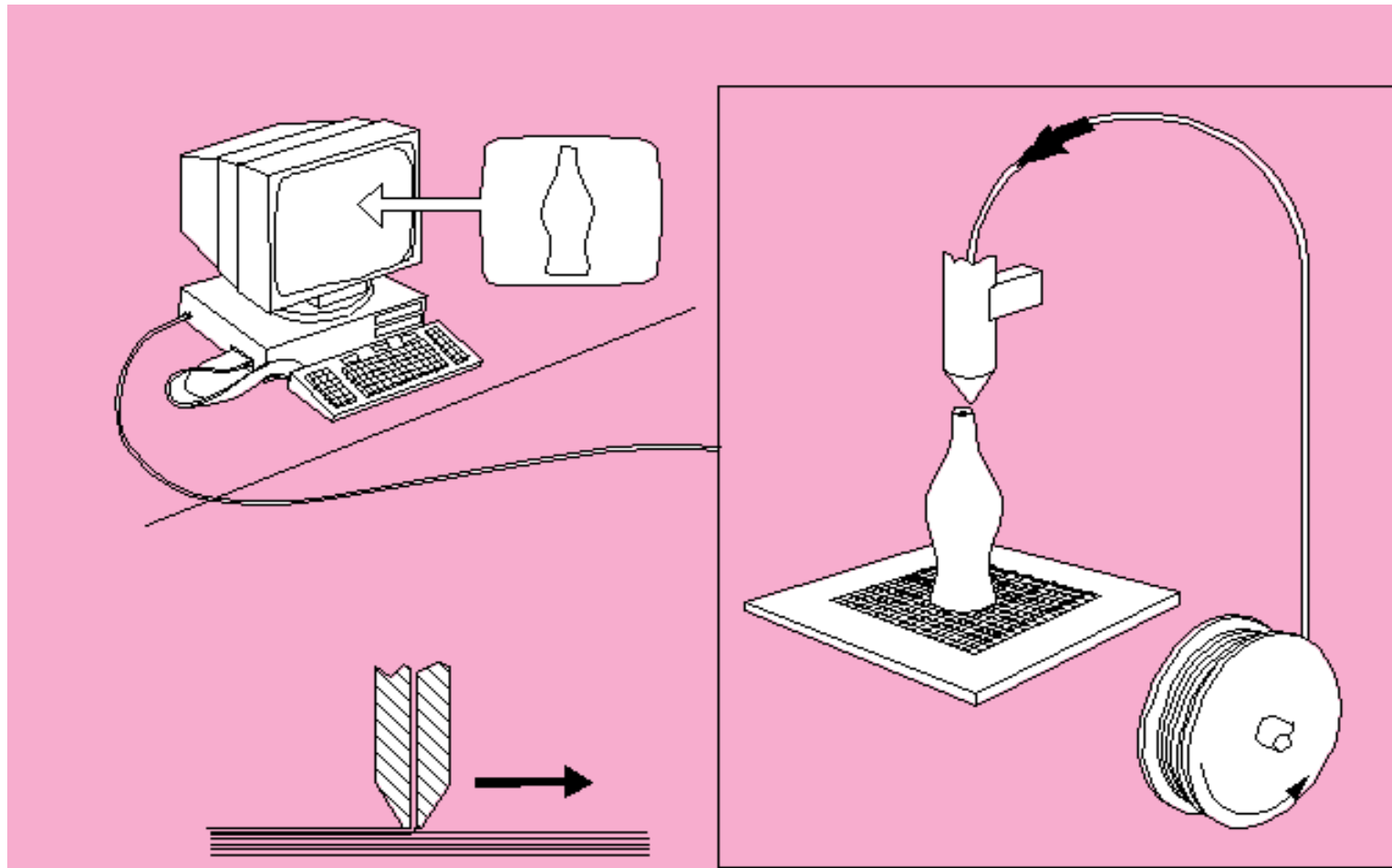
- ❖ **Technology:** *Curable Liquid Resin*
- ❖ **Introduced:** 1988
- ❖ **Major Vendor:** 3D Systems



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Fused Deposition Modeling



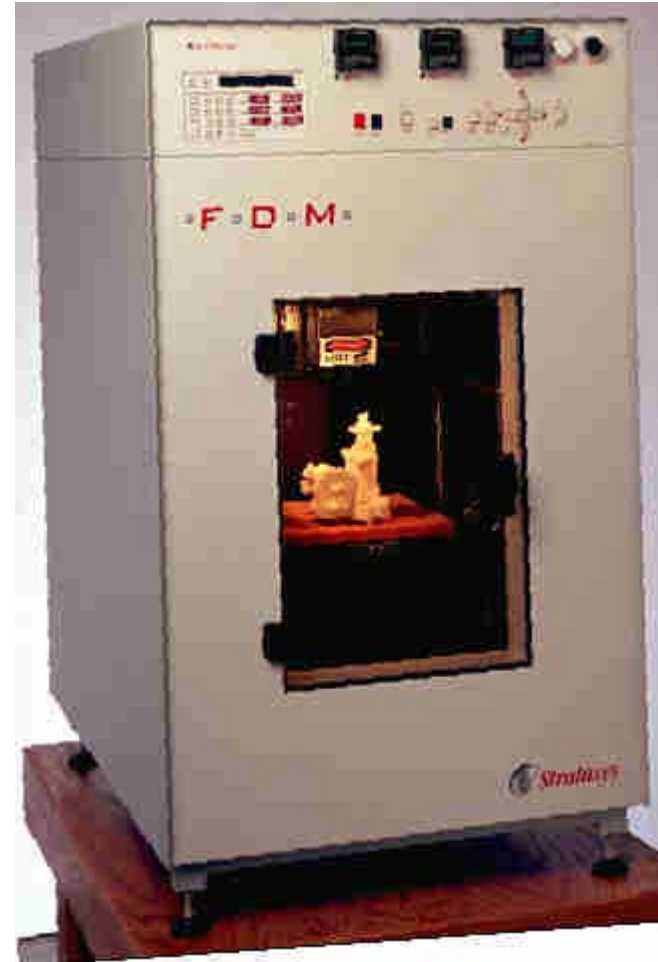
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Fused Deposition Modeling (FDM)

- ❖ Technology: *Filament Extrusion*
- ❖ Introduced: 1991
- ❖ Major Vendor: *Stratasys*

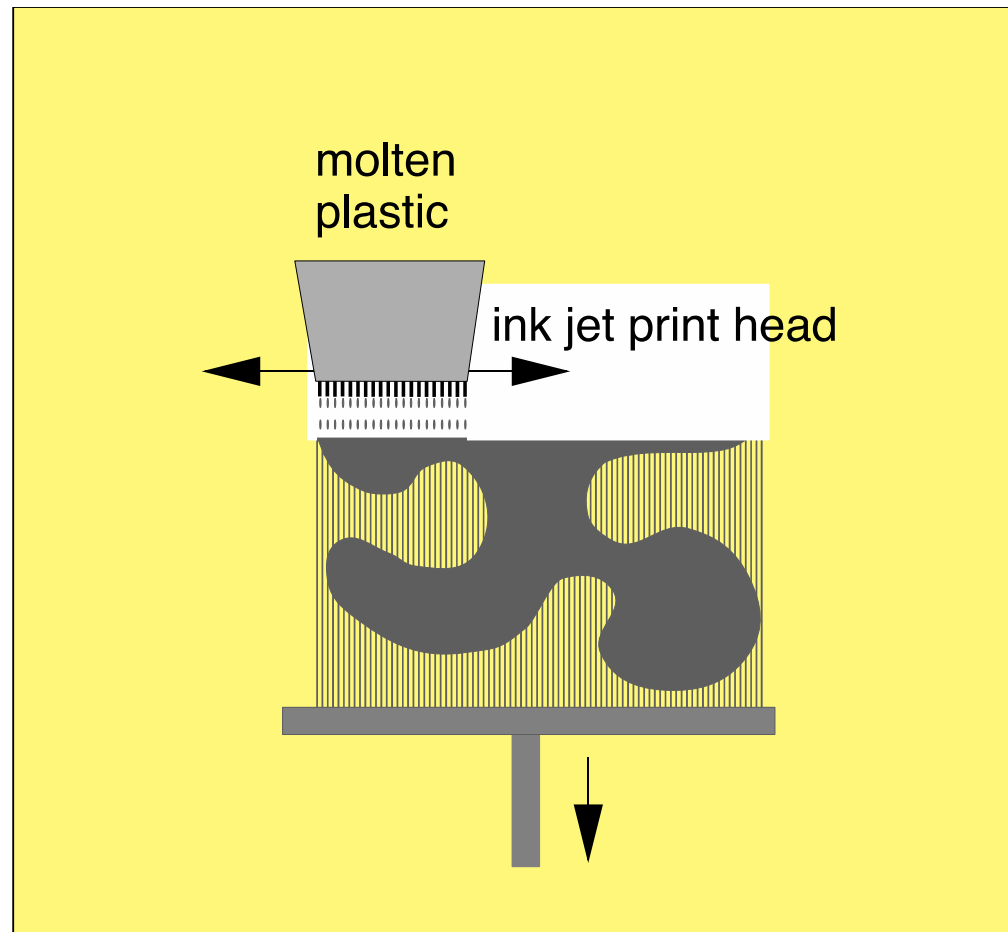


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Ink Jet Systems



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Ink Jet Systems

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



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3D Printing

- Technology:
*Selective deposition
of binders into
powder*
- Introduced: 1996
- Major Vendor: Zcorp



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Additive Manufacturing



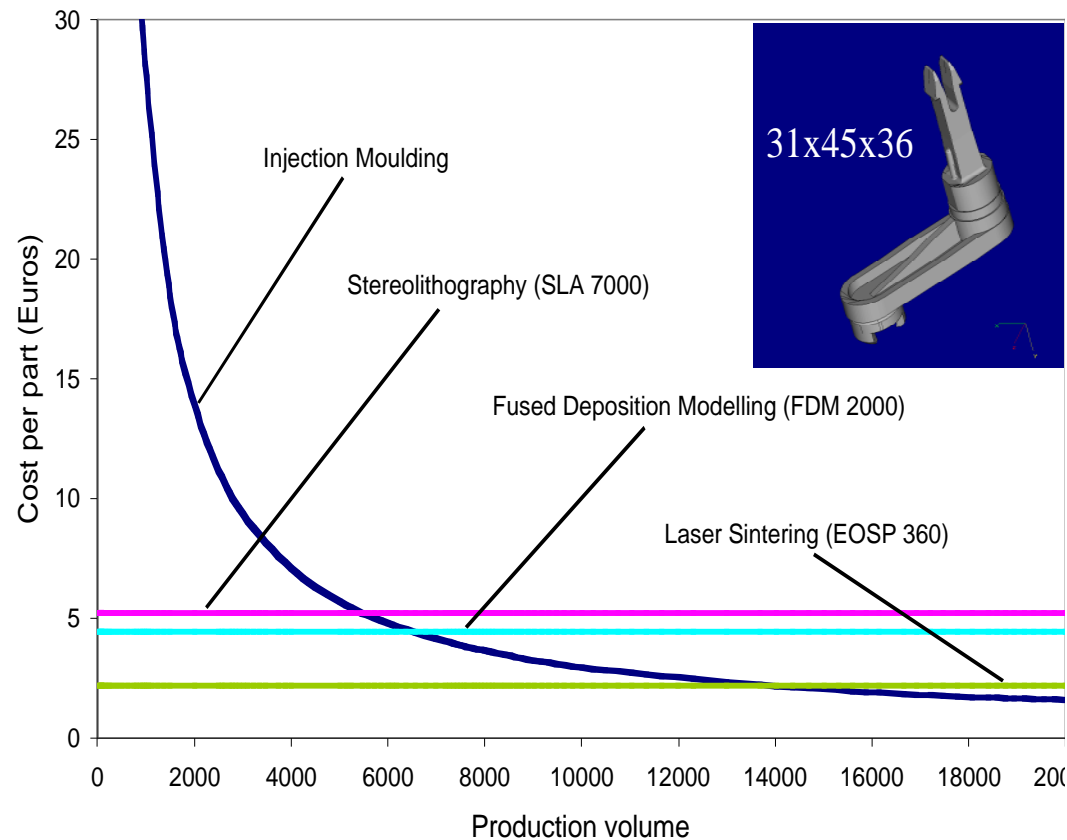
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Cost versus Production Volume



Loughborough University 2000



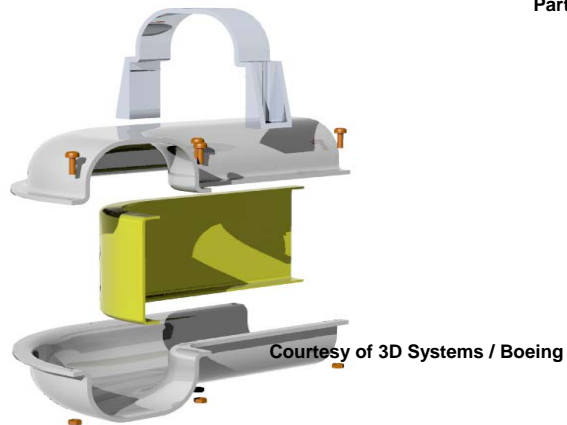
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Direct Manufacture

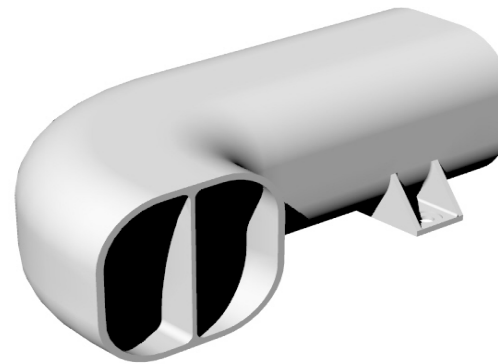
(A) Conventional Duct fabricated from Vac
Formed plastic
Part Count = 16 (plus glue)



(B) Component modified and consolidated for fabrication
via Additive Rapid Direct Manufacture

Part Count = 1

Part Count = 1



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Barriers to Additive Manufacturing

- Surface finish
- Production speed
- Cost
 - Machines
 - Materials
- Variation from part to part
 - Inadequate process control
- Materials availability



Direct Metals



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Metal Components: EOS (Laser Sintering)



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Metal Components: SLS Titanium

SLS processed AIM-9 Sidewinder missile guidance section housing (90% scale)

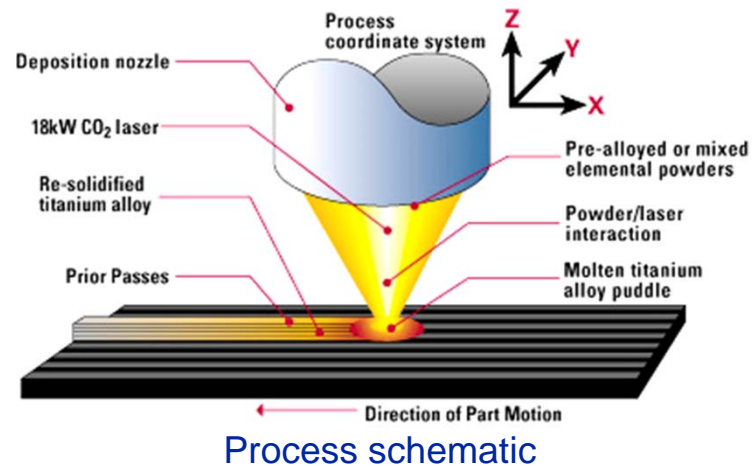


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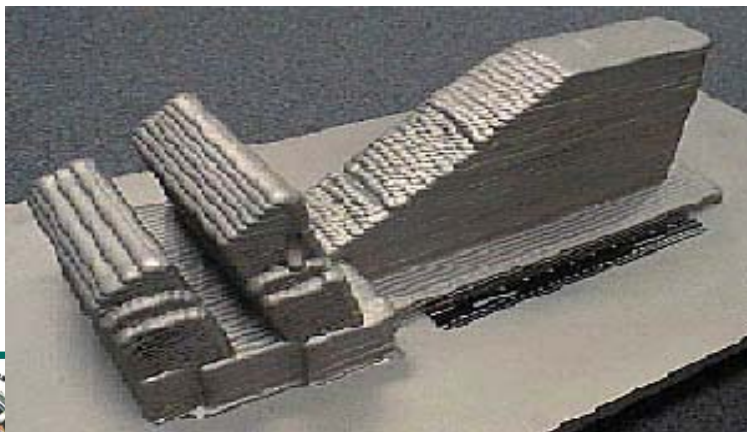
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Metal Components: AeroMet

The AeroMet™ Laser Additive Manufacturing Process



Actual machine



As built part



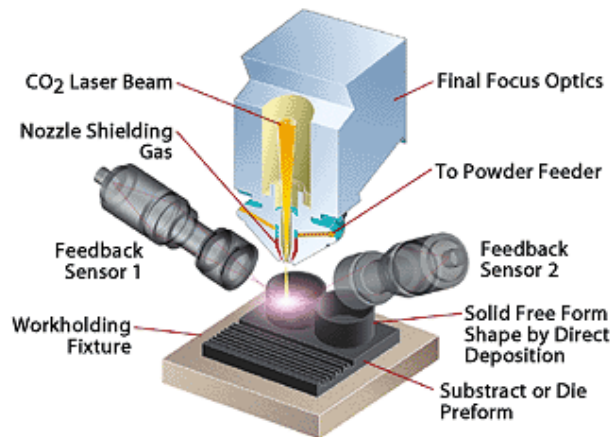
Finished part



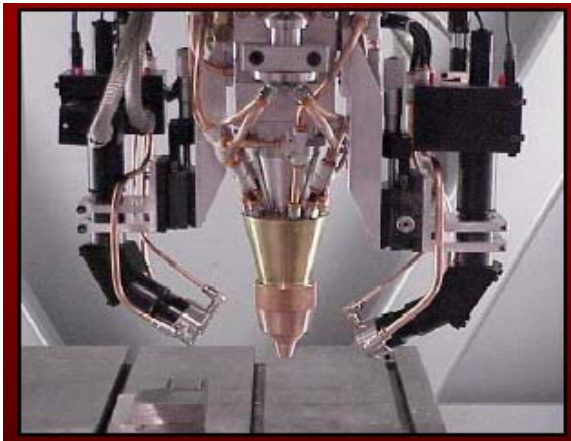
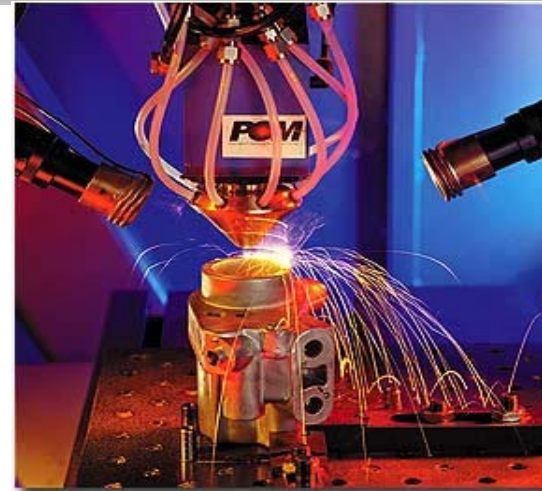
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Metal Components: POM



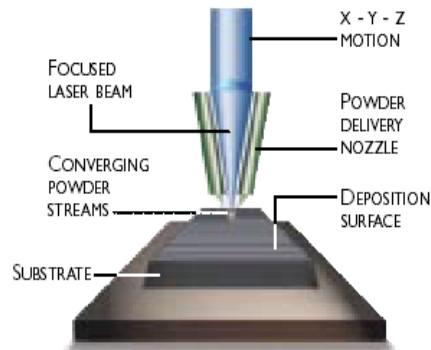
Process schematic



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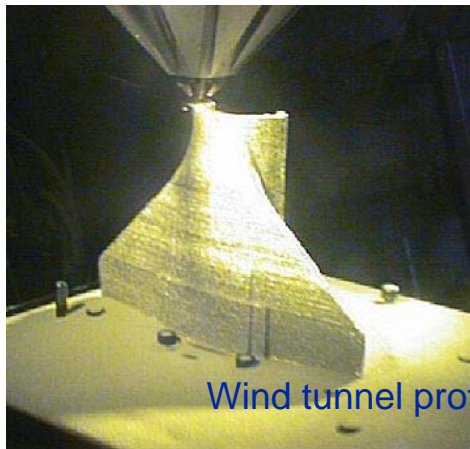
Metal Components: Optomec



Process schematic



Actual Machine



Wind tunnel prototype



Hip replacement implant

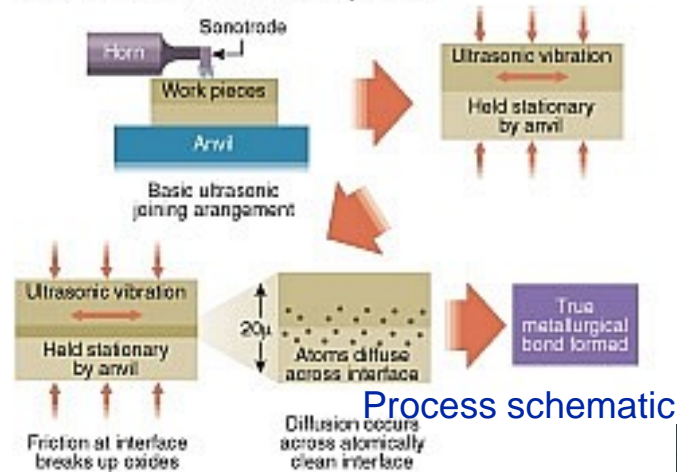


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Metal Components: Solidica (Ultrasonic consolidation)

The ultrasonic consolidation process

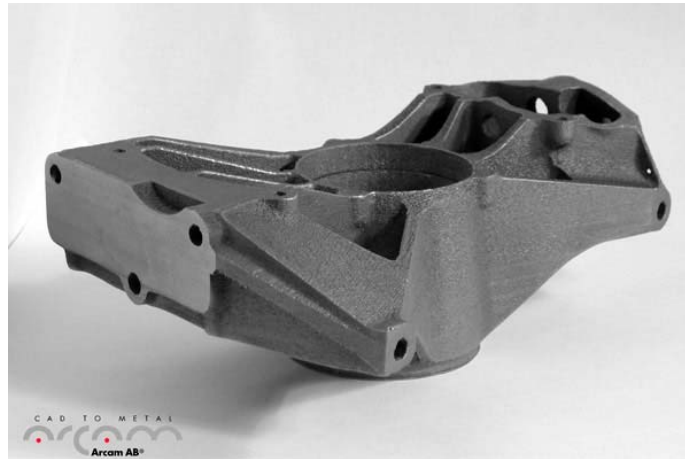


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Tooling for injection molding
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Metal Components: ARCAM (e-beam sintering)



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-
- The Future

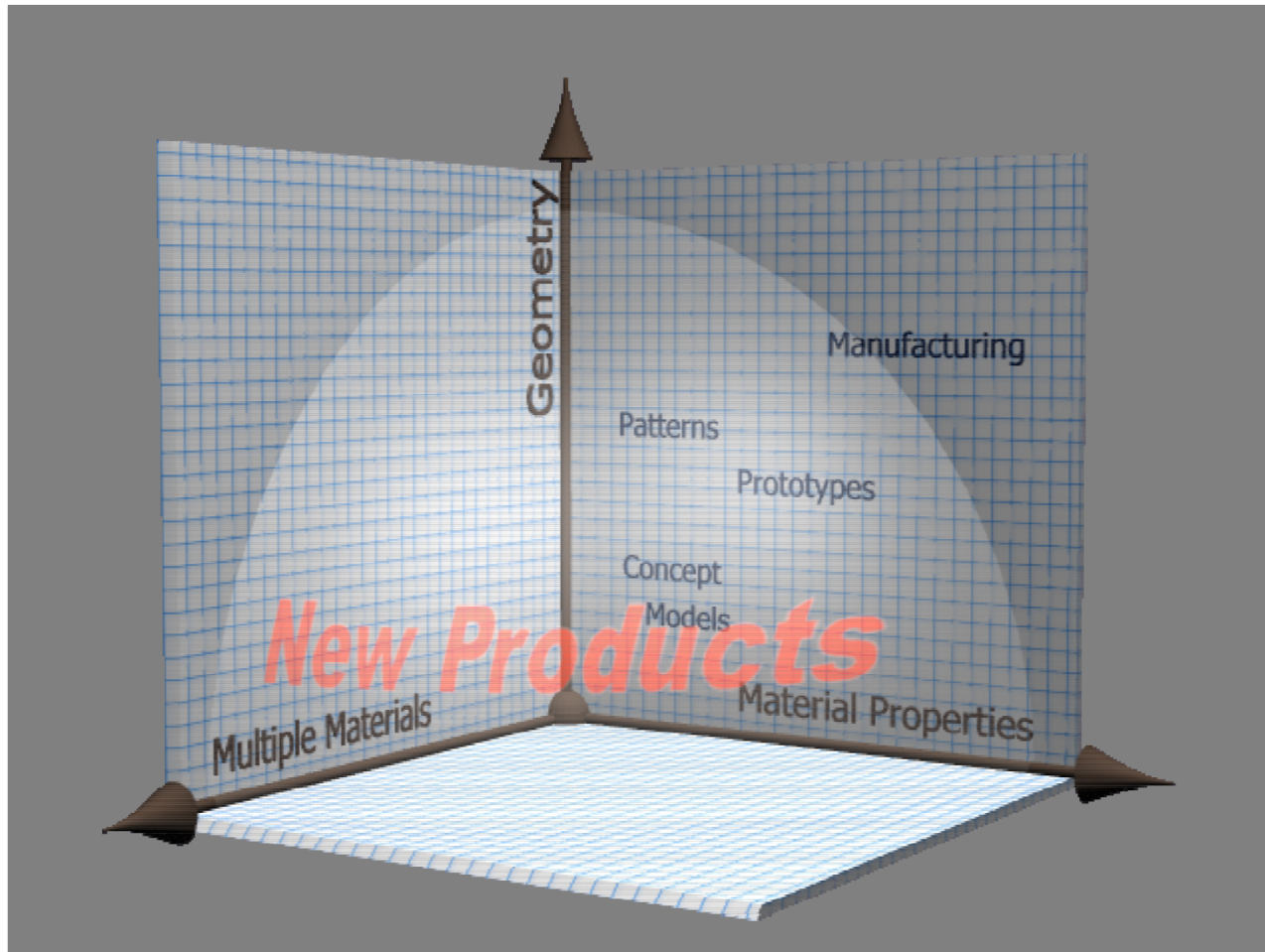


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Multiple Materials



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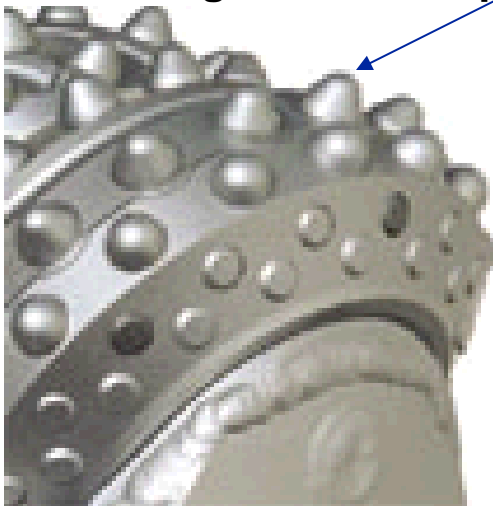


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M^2SFF

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.



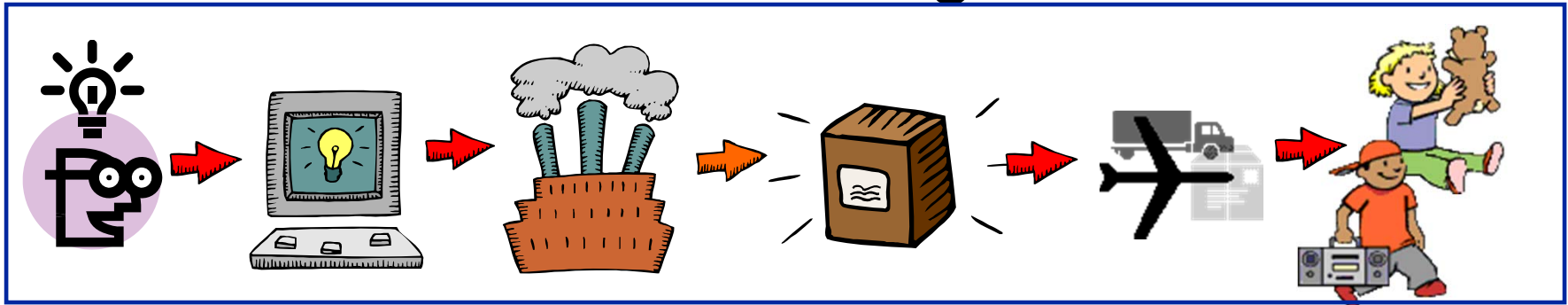
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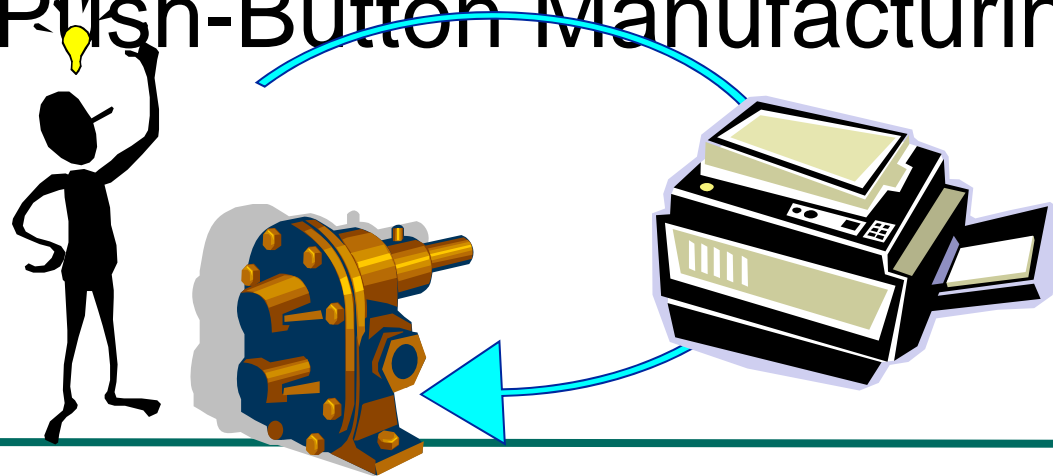
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A New Manufacturing Archetype

- Traditional Manufacturing:



- Regional Push-Button Manufacturing

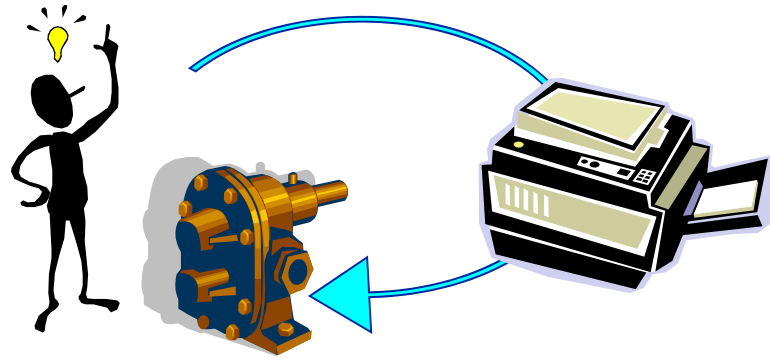
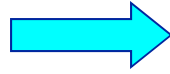


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Changing the Landscape of Design and Invention

- Elimination of Constraints:



- Rather than

- *DFM*  *Design for Manufacturing*

- Invert the process to

- *MFD*  *Manufacture for Design*

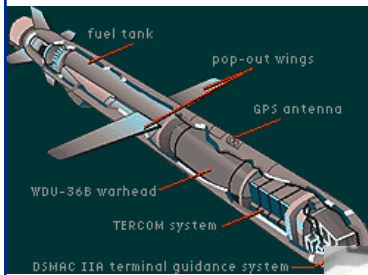


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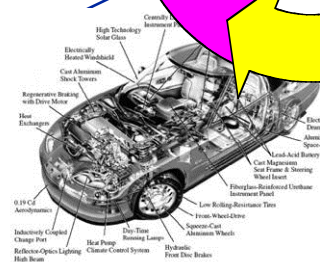
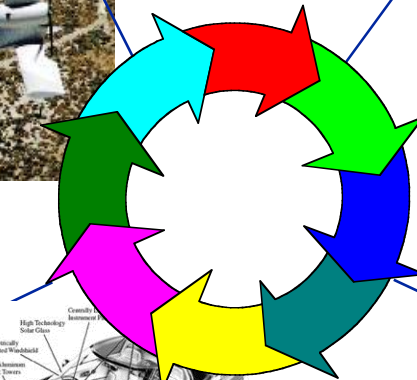
Application Sectors

Military



Consumer Products

Rehabilitation



Assistive Technologies



Spectrum emphasizes strategic needs.



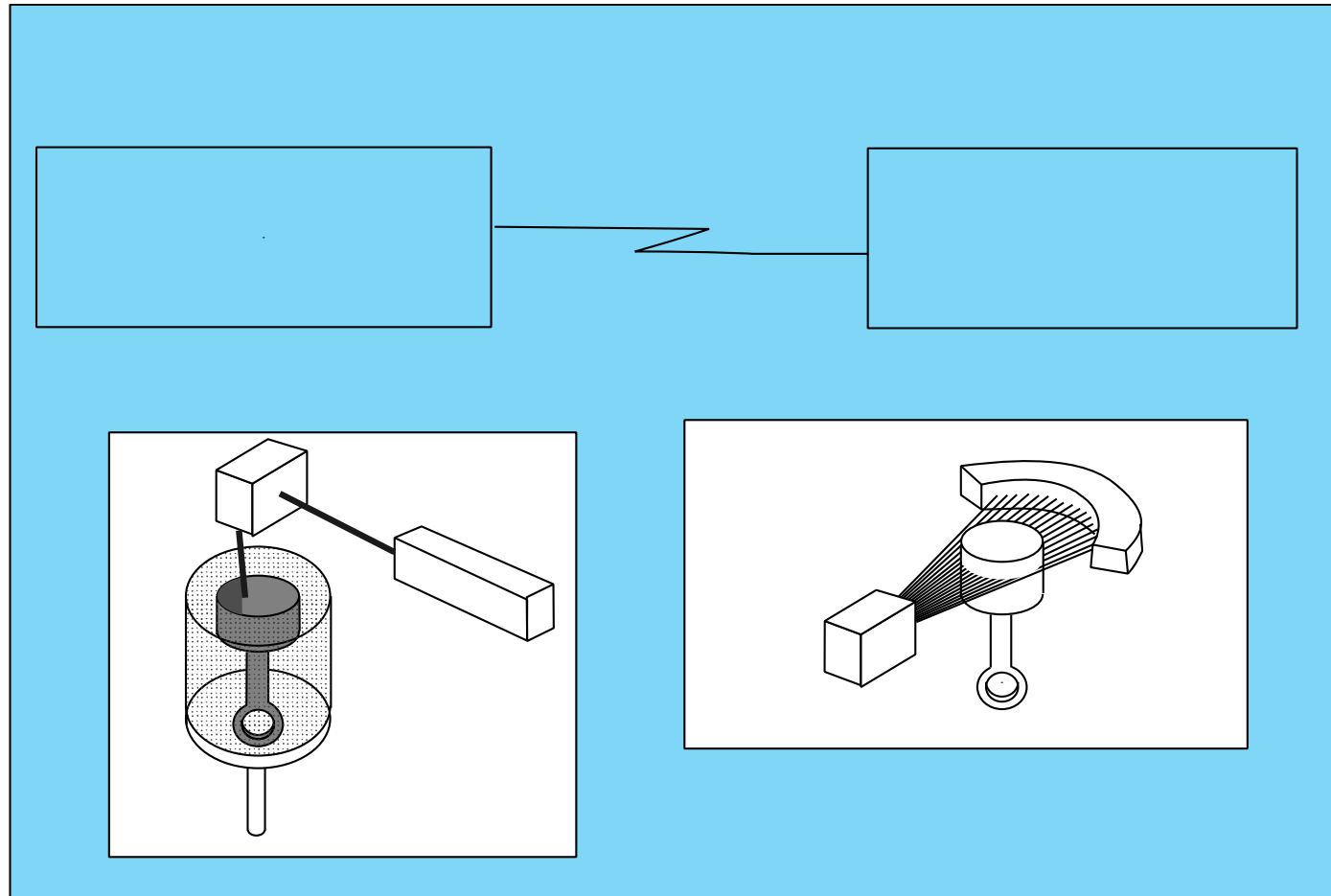
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Complex Engineered System

3D-Fax - Demonstrated in 1992



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We have seen this before

Willy Wonka
and the
Chocolate Factory
1971



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Conclusion

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



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