Additive Manufacturing (AM) 101

ASTM F-42 committee definition: a process of joining materials to make objects from three-dimensional (3D) model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.

AM enables a new design realm in which geometric complexity is not a constraint, and material can be deposited only where needed, and not where you don’t need it.
AM Pervasiveness

Aviation

Nutrition

Space

Automobile

Construction

Medical
• After 28 years, additive processes are reaching industrialization

• AM Growth:
  – Worldwide AM industry grew 25.9% to $5.165 billion in 2015
  – Growth of metal AM has average 59.2% over last three years

• Substantial AM investments:
  – GE: $1.5b
  – Alcoa: $60m R&D center
  – NY State: $125m public-private partnership
  – Stryker: $400m medical implant facility
  – Norsk Titanium: $25m expansion
  – DoE: $70m committed
  – America Makes: $97m project portfolio
Binder Jetting – a liquid bonding agent is selectively deposited to join powder materials

Directed Energy Deposition – focused thermal energy is used to fuse materials by melting as they are deposited

Material Extrusion – material is selectively dispensed through a nozzle or orifice

Material Jetting – droplets of build material are selectively deposited

Powder Bed Fusion – thermal energy selectively fuses regions of a powder bed

Sheet Lamination – sheets of material are bonded to form an object

Vat Photopolymerization – liquid photopolymer in a vat is selectively cured by light-activated polymerization
**Definition:** A liquid bonding agent is selectively deposited to join powder materials

**Materials:** Powder plastic, metal, ceramic, glass and sand

**OEMs:** ExOne, 3DSystems, Voxeljet

**Applications:** Full color prototypes, metal parts, sand molds

**Pros:**
- High resolution
- Range of materials/colors
- Sand molds allow legacy materials use

**Cons:**
- Not often suitable for structural parts
- Post-processing steps

Source: 3DHubs.com
**Definition:** focused thermal energy is used to fuse materials by melting as they are deposited

- **Materials:** Metal powder/wire
- **OEMs:** Optomec, Sciaky, Mazak, DMG Mori
- **Also called:** Laser Engineering Net Shape (LENS), Electron Beam Additive Manufacturing (EBAM), blown powder, Directed Metal Deposition (DMD)
- **Applications:** Repair, near shape manufacturing, large metal structures, hybrid manufacturing

- **Pros:**
  - Bi-metallic and functionally graded materials
  - Controllable grain structure
  - High deposition rates

- **Cons:**
  - Low resolution (~300 micron wall thickness)
  - No support material
**Definition:** material is selectively dispensed through a nozzle or orifice

**Materials:** Thermoplastics (PLA, ABS, Nylon, ULTEM, PETG, PC)

**OEMs:** Stratasys, Makerbot, 3DSystems, Cincinnati, Ultimaker, Lulzbot, Reprap (thousands)

**Also Called:** Fused Deposition Modeling (FDM), Fused Filament Fabrication (FFF)

**Applications:** Low resolution prototypes, tooling, low rate production, large parts

**Pros**
- Inexpensive and accessible
- Dissolvable support material
- Comparable strength to injection molded parts along build plane

**Cons**
- Relatively slow
- Rough surface finish and low resolution

Source: 3DHubs.com
**Material Jetting**

- **Definition:** *droplets of build material are selectively deposited*
- **Materials:** Multi-color, rigid, flexible, and clear polymers
- **OEMs:** Stratasys Objet
- **Also called:** Polyjet
- **Applications:** High resolution prototypes, tooling

- **Pros:**
  - Fast
  - Multi-color/material
  - High resolution/precision

- **Cons:**
  - Expensive
  - Long term material degradation

Source: 3DHubs.com
• **Definition:** thermal energy selectively fuses regions of a powder bed

• **Materials:** Powder metals/polymers

• **OEMs:** EOS, 3DSystems, SLM, ARCAM, Concept Laser, Renishaw, etc.

• **Also called:** Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Direct Metal Laser Melting (DMLM), Electron Beam Melting (EBM)

• **Applications:** Fully dense aerospace parts, medical implants, tooling, prototypes

• **Pros:**
  – High resolution
  – No support structures (polymers)
  – Internal features
  – Integrated assemblies
  – High strength

• **Cons:**
  – Expensive
  – Powder removal
  – Post-processing (metals)
  – Qualification
**Definition:** *liquid photopolymer in a vat is selectively cured by light-activated polymerization*

**Materials:** Photopolymers

**OEMs:** 3DSystems, Formlabs, Carbon3D, B9Creator

**Also called:** Stereolithography (SLA), Digital Light Processing (DLP), Continuous Layer Interface Printing (CLIP)

**Applications:** High resolution prototypes, casting/molding, medical drill guides, dental, small end use parts

**Pros:**
- Details down to 25 microns
- Smooth surface finishes

**Cons:**
- Resins are messy
- Limited, brittle materials (for now)
- Single material with no support

Source: 3DHubs.com
Manage the hype! AM is diverse and each process has appropriate application.
## Pros

**Freedom of design** – produce an object of virtually any shape, even those not producible by conventional processes

**Complexity for free (sort of)** – increasing object complexity will increase production costs only marginally

**Elimination of tooling** – direct production without costly and time-consuming tooling

**Lightweight design** – weight reduction via topological optimization

**Part consolidation** – reduce assembly requirements by consolidating parts into a single component or assembly

**Elimination of production steps** – complex objects manufactured in one process step

## Cons

**Slow build rates** – various process inefficiencies resulting from rapid prototyping heritage

**High production costs** – resulting from slow build rate and high cost of metal powder

**Design difficulties** – design software not readily available

**Setting process parameters** – complex set of material and process parameters

**Manufacturing process** – component anisotropy, surface finish and dimensional accuracy may be inferior, requires post-processing

**Limited component size** – size of producible components is limited by build chamber size

**Qualification** – Standards and processes are not established for airworthiness certification

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**Source:** Dave Pierson, Manufacturing Advocacy & Growth Network (MAGNET)
Develop an additive manufacturing body of knowledge by:

- Executing aviation and missile centric S&T efforts
- Collaborating with Army labs, other DoD and DOE agencies, industry, and academia
- Educating the workforce, customer base, and community of the capabilities and limitations of AM
- Procuring/sustaining equipment capability across the various AM processes

Responsive and cost-effective AM research, development and life-cycle engineering solutions
Pillar: Rapid Enabling and Prototyping

- Casting molds and cores
- Fixtures and jigs
- Tooling for injection molding
- Prototyping / cycle time reductions
- Conceptual model development
- Manufacturing demonstration

AM Facilitates Rapid Response and Cost Savings
• Material performance (capturing pedigree material data to inform design and engineering of AM parts)
• Machine performance (identifying, improving and documenting key build parameters)
• Topology optimization
• Embedded functional structures (structural health monitoring, embedded electronics, conformal antennas)

Engage Aviation and Missile Centric AM Research
• Largest barrier to implementation within the aviation community
  – Lack of material allowables and standards
  – Inspection difficulties
• Army’s airworthiness authority (AED) engaging commercial and government partners to determine best practices and write Aeronautical Design Standard (ADS)

AM Benefits Outweigh Aviation Qualification Challenges

147 Parts reduced to 25 parts
926 Manufacturing steps eliminated
Cost Savings Projected
• Worn part repair (including parts that cannot be repaired currently)
• Diminishing manufacturing sources and material shortages (DMSMS) parts
• Part replacement (reduce cycle time for long lead items)
• Digital Thread (leverage DMDII National Institute)

Additive Repair of High Value Aviation Assets

Worn Seal Teeth  Material Added  Repaired Part

AM Increases System Readiness and Supply Chain Resiliency
• Team Redstone AM IPT
• RDECOM AM Community of Practice
• Huntsville City Schools Education Partnership Agreement (EPA)
• Government Organization (GO) on Additive Manufacturing
• Joint Army Navy NASA Air Force (JANNAF)
• Participation in Army roadmapping efforts

Government Organizations
  • DoD
  • NASA
  • DoE

Academia
  • Universities
  • Community Colleges
  • High schools

Industry
  • Aviation and Missile OEMS
  • Machine manufactures
  • Powder suppliers

Nonprofits
  • America Makes
  • DMDII
  • Standards Organizations
• General Awareness AM Training for AMRDEC workforce:
  – Three day course featuring hands-on printer exercises
  – Over 120 employees trained to date
  – Third session planned for this summer
• Embedding AMRDEC personnel at NASA MSFC and ORNL
• Educating customers on the capabilities and limitations of AM

Smart Adoption of AM Requires Cultural Change and Education
AM Adoption Challenges

Current Research

New Part Production

Worn Part Refurbishment

AM Enablers

- Industry standards/specifications
- Non-destructive evaluation
- Increased throughput
- Improved surface finishes
- In-situ sensing/monitoring

- Multi-material structures
- Alloy development
- Smart support structures
- Material databases
- Approved vendors
- Cultural change

Designed for Additive

Qualified Processes

Future Systems
• Department of Defense AM Roadmap: [https://www.americamakes.us/dod-amroadmap](https://www.americamakes.us/dod-amroadmap)
• America Makes: [https://www.americamakes.us/index.php](https://www.americamakes.us/index.php)
• ASTM F42: [https://www.astm.org/COMMITTEE/F42.htm](https://www.astm.org/COMMITTEE/F42.htm)
• Reprap: [http://www.reprap.org/](http://www.reprap.org/)
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