





ADDITIVE MANUFACTURING IN AEROSPACE & DEFENSE

How does it fit & does it affect you?

FAIRMONT
CONSULTING GROUP

MARCH 2017

Fairmont Consulting Group At A Glance









WHAT DOES FAIRMONT DO?

STRATEGY

We help clients understand evolving markets and changing competitive environments in order to decide where and how to invest time and capital in support of profitable long-term growth

OPERATIONS

We help clients organize for maximum effectiveness and execute on their strategic roadmap, driving more productive operations, more successful business development, and more targeted innovation

TRANSACTIONS

We provide critical market & competitive diligence in support of the acquisition and sale of businesses; detailed, objective independent financial forecasts and critical transaction support

WHO RELIES ON FAIRMONT AND WHY?

CLIENTS

Aerospace & defense primes

Tier 2 and Tier 3 suppliers

Global private equity investors and hedge funds

PE portfolio companies

EXPERIENCE

Advisors to CEOs, boards, and leading investors in A&D

100+ strategy engagements

100+ transactions worth $10B+ in total enterprise value

100+ collective person-years of A&D experience

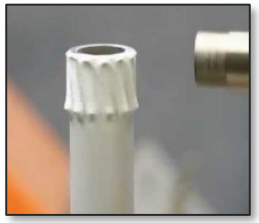
CAPABILITIES

Deep domain knowledge across A&D and all subsectors

Global network of SME's in operations, finance, technology, government

Technology-enabled, data-driven analytical techniques

Additive Manufacturing
Implications For The Aerospace Market And Supply Chain



Additive Manufacturing (AM) is a disruptive manufacturing technology, but with all of its hype it can be difficult to ascertain what is really important

The following AM technology review by ***Fairmont Consulting Group*** goes in depth on this technology and discusses the most critical information for potential investors and traditional suppliers. The focus of the analysis is on metallic processes used in the aerospace market.

Areas of discussion include:

- What has been the ***evolution of this technology***?
- Which ***processes are causing disruptions***?
- What ***part types are most vulnerable*** and when might AM affect your parts?
- What ***complementary technologies and market risks*** exist for AM?
- How will AM ***impact the aerospace supply chain***?
- How can suppliers or investors ***capitalize on AM or mitigate risk*** from AM?

This report will provide aerospace suppliers and investors with an understanding of the risks & opportunities associated with additive manufacturing

Is The Hype True?
AM Will Disruptively Impact A&D Industry; Acceleration Of Production Uses Likely Post 2025 With New Platforms & Operational Data

- ***What's the Hype?*** Most market analysts agree that AM will become pervasive throughout the aerospace & defense world

  "The aerospace industry, with its stringent certifications, testing, and safety approvals, relies on 3D printing, making a strong case for 3D printing to become a critical part of manufacturing's future for the rest of us."
  - Ed Yuh, Project Engineering Manager, Stratasys Direct Manufacturing

- ***Why?*** Simply put, 3D printing enables components to be ***simpler*** (fewer parts), ***lighter*** (complex geometries), and ***faster to market*** (reduced total manufacturing time)

- ***Fairmont's Take?*** Fairmont Consulting Group believes AM will dramatically impact the manufacturing landscape, ***particularly beyond 2025 at which point penetration will accelerate greatly in commercial aero applications***
  - 'Entry Points' and flight experience are two major impediments to AM's penetration into production use
    - The next wave of clean sheet designs, engine & airframe, is not likely until middle of next decade – Fairmont expects a large increase in AM at this point
    - OEMs are gaining critical flight experience with recent AM parts; data on survivability, maintainability, reparability, and failure prediction calibration is critical to AM's continued growth in the industry
  - Other part specific challenges exist that will limit the adoption rate of this technology *(further investigated in the review)*

Benefits & Limitations of AM

Today's Process Benefits

- ***Design Flexibility***
  - Shape
  - Materials
- ***Reduces Buy-To-Fly Ratios***
- ***Speed (Design To Use)***
- ***Tooling Cost***
  - Reduced tooling costs

Today's Process Limitations

- ***Capacity***
  - Slow manufacturing time
  - Machine size
- ***Applicable Component Size***
- ***Material Options***
- ***Production Part Cost***
- ***Printing Resolution***

Sources: Fairmont Analysis; 3D Printing Industry, Open Source Materials

Additive Manufacturing History
AM Development Following Traditional Path; Usage Is Accelerating

- Additive Manufacturing (AM)or 3D Printing has ***transitioned from a lab technology to a production manufacturing process*** in the heavily regulated Aerospace and Defense (A&D) industry
- During the first decade of AM, inventors and pioneers developed process parameters and machine mechanics ***improving consistency, quality, and cost***
- Industry began in earnest to explore the technology post 2000; ***first priorities were to understand the value, and test and standardize the technology***

The First Comprehensive Attempt At A Regulatory Guideline & Standardization Document For AM Processes
ANSI; March 1, 2017

SLA Process Patent*
Chuck Hull (3D Systems)
1986

FDM Process Patent*
Scott Crump
(Stratasys)
1989

First Solid State SLA System Introduced
(3D Systems)
1996

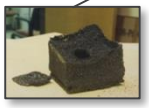
Boeing's First Use Of Metal AM On F-15 Aluminum Pylon
(Boeing)
2001

Thor - World's First 3D Printed Plane; 46lb Drone
(Airbus)
2011

The First Entry-into-service Jet Engine Using AM For Production Parts
Geared Turbo Fan (P&W)
2015

Largest 3D Printed Part Tested In Flight
Trent XWB-97 (RR)
2015

1980 *1990* *2000* *2010* *Today*



SLS Process Patent*
Carl Deckard, Univ. Of Texas
1987

DMLS Introduced*
Hans Langer
(EOS)
1989

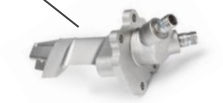
STEREOS Series Introduced
(EOS)
1990's

First 3D Printer <$30K Introduced
(Stratasys)
2002

Prototype Parts For Osprey
(Bell Helicopters)
2005

'Print The Fleet' Initiative Kicked Off
(US Navy)
2014

GAO Recommended DoD Systematically Track AM Efforts
2015



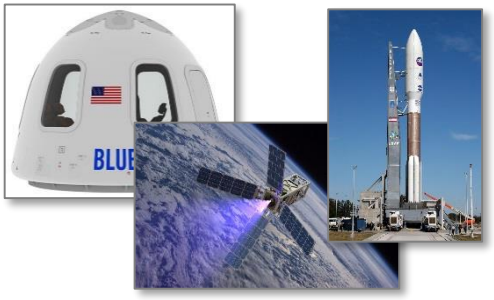
The First FAA Cleared 3D Printed Part For A Commercial Jet Engine Compressor Inlet Temp Sensor: GE90-94B (GE)
2015

Process Invention ***Machine Development*** ***Industry Exploration*** ***Process Development & Standardization***

Sources: University of Texas, 3D Printing Industry, OEM Public Announcements, International Materials Review, Open Source Materials
**Process Acronyms Defined Later In Presentation*

AM Has Wide Applicability Across A&D

AM Addresses Similar Challenges Across A&D Sectors; Market Differences Will Drive Unique Applications And Penetration Rates



Across the Aerospace & Defense industry, markets deal with a number of similar issues: improving system performance & quality while decreasing system weight, complexity, & cost. Regulation and certification is a common trait throughout the the A&D industry

Despite the challenges, Fairmont believes AM will significantly impact all sectors of A&D over the next decade

Industry Unique Characteristics

Defense (Non Aero)

- ***Timeliness*** is a critical factor in defense supplies; real time production is long term goal
- ***Hyper-local*** having the ability to produce components on an aircraft carrier, at a FOB, or in the back of a JLTV opens up incredible opportunity
- ***Aged assets*** demand replacement parts that are out of production & very expensive to restart; AM enables part creation without tooling

Aerospace

- Commercial and military aerospace is a natural fit for additive manufacturing within the A&D market because of the balance between ***safety and efficiency***
- Aircraft have ***regular & controllable maintenance visits*** where new technologies can be monitored
- ***Volumes are relatively low*** which makes cost trade-off reasonable vs. traditional machining processes

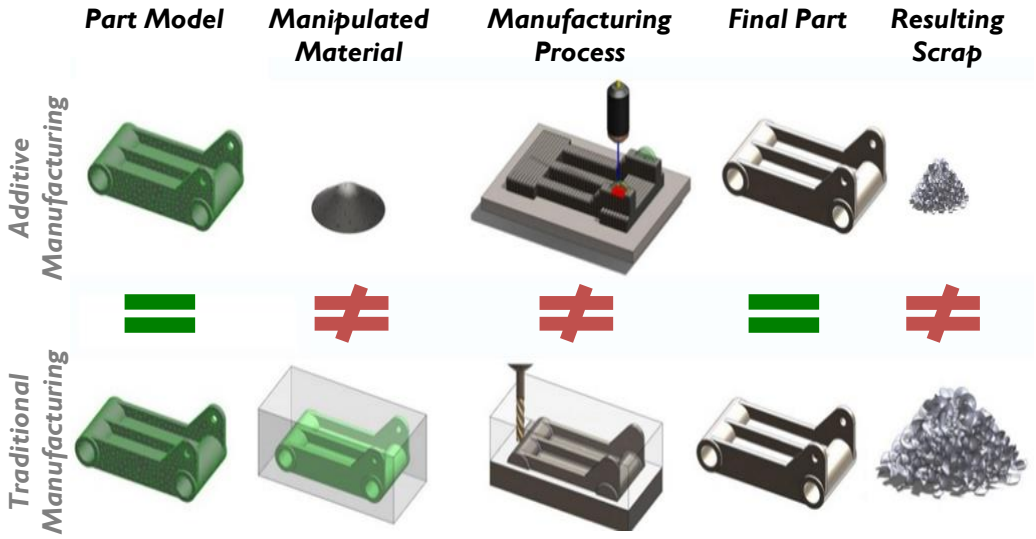
Space

- ***Risk aversion*** is the greatest in the Space community and will push against unproven technologies
- ***Flight experience***, or 'heritage', is critical, but the inability to inspect space vehicles after use will work against AM's use for critical parts
- ***Production volumes*** are the lowest in the Space industry which supports AM's use for parts with expensive traditional manufacturing methods

Additive Processes Comparison
AM Offers A Paradigm Shift For Component Manufacturing

- Additive manufacturing is a paradigm shift in the manufacturing industry
- By building material layer-by-layer vs. removing material subtractively, AM enables designers and part manufacturers to address challenges in novel ways
- ***As a result of the process, AM enables organic & complex design shapes, internal structures & cavities, and reduces resulting scrap material***

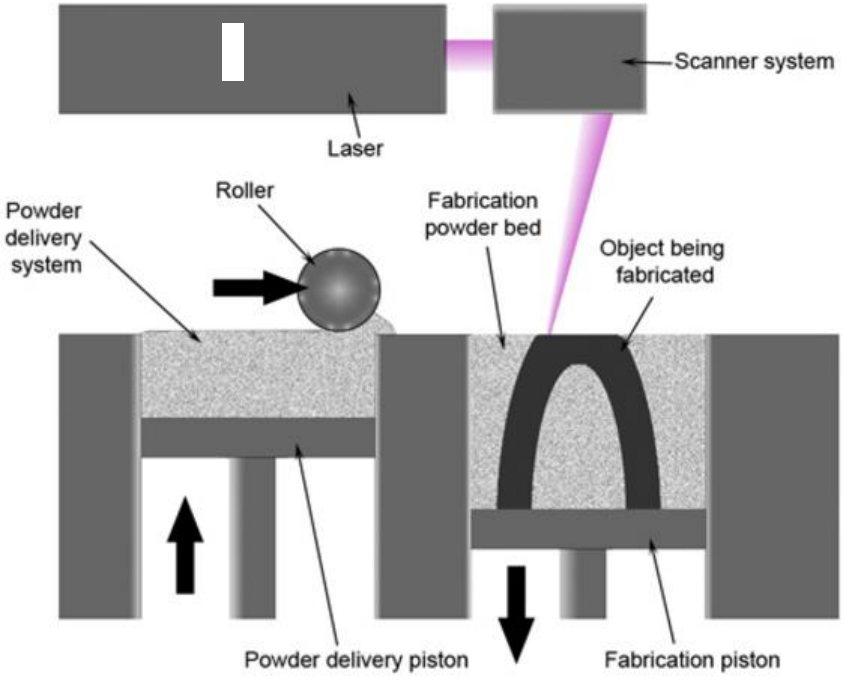
Manufacturing Process Comparison: *Additive vs. Traditional*



AM relies on powder materials vs. solid material 'blocks' and the additive nature of the process naturally results in significantly less material waste, or scrap, upon part completion

Manufacturing Process Comparison; source: CSIRO Manufacturing; Fairmont Analysis

Additive Manufacturing Process Example



DMLS Process; source: Inside 3D Printing

Sources: Fairmont Analysis; Metal AM, Inside 3D Printing, Open Source Materials

Additive Processes Landscape
Powder Bed Processes Vying For Production Quality Aerospace Uses

A number of AM process groups have emerged with aerospace relevancy each with their particular uses; multiple processes have developed within each category competing on market space (cost, speed, quality)

AM Process Landscape
(Process Group / Specific Process Names)

Key: Metal, Polymer, Other — Material Applications; Significant Aero Application

	Typical Uses	Group Characteristics & Benefits	
Powder Bed • *Selective Laser Melting (SLM)* • *Selective Laser Sintering (SLS)* • *Direct Metal Laster Sintering (DMLS)* • *Electron Beam Melting (EBM)*	***Production Parts***	*Powder Bed Fusion (PBF) processes all use a heat source (laser or electron beam) to melt alloy powder. PBF is currently the* **most investigated for aero uses**. *Multiple processes patented, none has yet to emerge as universally superior.*	Relative Benefits: • Inexpensive for metal apps • Many material options • Quality
Other Additive Processes • *Cold Spray Technology* • *Laser Cladding* • *Friction Stir Welding* • *Directed Energy Deposition*	***Part Repairs & Part Feature Creation***	*A number of additive processes have been developed to build new material on top of existing components. These processes are particularly useful for* **repair processes or feature creation** *to reduce buy-to-fly ratios*	Relative Benefits: • Scalable technology • Can control material sub-structure
Material Extrusion • *Fused Deposition Modeling (FDM)* • *Fused Filament Fabrication* • *Composite Filament Fabrication*	***Polymer Production Parts***	*Rather than using powder as the substrate material extrusion adds solid material through a nozzle continuously under pressure. It is only used for polymer and soft metal applications.*	Relative Benefits: • Inexpensive polymer process
Light Polymerized • *Stereolithography (SLA)* • *Digital Light Processing (DLP)*	***Prototyping***	*These processes solidify liquid photopolymers with US light layer-by-layer. Heavily used for prototyping.*	Relative Benefits: • Relatively fast • High accuracy • Smooth finish

Impact On Aerospace Market

Sources: Loughborough University, Inside 3D Printing, Fairmont Analysis

What Challenges Exist To AM Penetration?
AM's Greatest Value Is Challenging To Unlock; Novel Solutions & Time Needed To Address *Flight Critical, Large, & High Volume Parts*

Implementation Challenges: *Specific Challenges For Critical, Large, & High Volume Parts*

Challenges To Flight Critical Parts

- ***Process capability & repeatability***
- ***Material definition***
- ***OEM & regulator confidence*** (demonstrated experience)
- Printing resolution
- Inspection method maturity


Turbine Blade

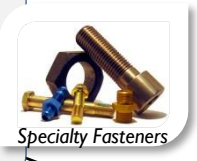
Challenges To Large Parts

- ***Printing machine envelope***
- Higher axes printing capabilities; unconstrained envelope processes
- Machine cost


Aircraft Wing

Challenges To High Volume Parts

- ***Machine speed***
- ***Process control*** within & between machine
- Supplier capacity / machine install base size


Specialty Fasteners

Criticality / ***Size*** / ***Quantity*** — ***Part Characteristics***

General Challenges

- ***Entry points*** *(new platforms)*
- In service ***data collection / experience***
- ***Design process exposure***
- Production & testing ***standards***
- Inspection development
- Current supplier contract expiration
- Traditional manufacturing advancements (cost & quality)
- Material advancements

Solutions accelerate implementation across part categories

- A host of challenges exist which will slow AM's penetration rate
- ***Part Specific*** challenges exist based on their *criticality* to the system, *size*, and production *quantity*
- ***General*** challenges exist that will delay AM overall in A&D
  - Specific to the aerospace industry, ***entry points*** or new product introduction (either engine or aircraft) are critical to the penetration of AM
  - Fairmont expects the next wave of clean sheet aircraft design (beginning ~2025) to be a major growth point of the technology
  - Regulation drives the A&D industry to be highly ***empirical*** (operational experience & data) which takes time for new innovations to develop

Sources: Fairmont Analysis; Aerospace OEM Announcements, Open Source Materials

What Parts Are Likely To Be Impacted?
Safety Concerns & Financial Returns Will Drive Timing Of AM Impact

- AM is likely to penetrate specific part categories in a predictable way based on the previously described challenges
  - Boeing produced a production trim & drill tool for the 777X in 2016 (a first of its kind); Leo Christodoulou, a Boeing director, suggested "AM will dominate tooling" citing AM reduced the tool's build time from weeks to days and reduced cost by up to 70%
- Ultimately ***safety concerns & the business case will dictate the penetration rate*** of this technology in the industry
- While the next big AM wave is expected post 2025, OEMs will continue to slowly integrate AM into their product lines with targeted uses

	Features & Repair	***Tooling***	***Non Flight Critical Components***	***Specialty Trials***	***Legacy Parts***	***Flight Critical Parts***
Targeted Application						
	Large ***feature rich parts***	***Difficult to machine tools***	Relatively ***expensive & heavy parts***	***'One-off'*** parts and trials	***'Out of production' or low volume*** parts	***Critical parts*** are likely last to be AM produced
	Most Vulnerable		***Relative Part Vulnerability / AM Impact Timing***			***Least Vulnerable***
Supplier Impact	Producing features with processes like laser cladding, cold spray reduce price	Tools can take a significant amount of time to produce and are extremely costly	AM can drastically reduce weight or complexity by reducing part count	Tests & experiments drive demand for unique parts, which are at high margins	Suppliers make high margins on legacy parts where tooling 'locks' in their position	When AM processes are approved for critical parts, the industry will be disrupted
	Part Price Impact	***Market Disruption***	***Market Disruption***	***Supplier Margin Impact***	***Supplier Margin Impact***	***Market Disruption***

Sources: Fairmont Analysis, 3D Printing Industry, Industrial Laser Solutions

Adjacent Opportunities & Market Risks
Complementary Technologies Likely To Ride / Enable The AM Wave; Market Risks Exist That Could Drive Penetration Set Backs

Beyond the direct technology development, there are a number of enablers and limiters to this technology which can come in the form of complementary technologies, market events, or industry behaviors

Enablers

Complementary technologies & events that accelerate penetration

- ***Alloy Development***
  - *Material development is going to be a primary enabler of AM to address many applications, particularly in aero engines*
- ***Computing Techniques***
  - *AM enables organic designs that are difficult for today's designers to create; new computing techniques and automated design software will grow to compliment human design*
- ***Quality Inspections***
  - *Many AM designs are hollow or lattice type designs which will require significantly different inspection methods*
- ***3D Inspections***
  - *The combination of 3D inspection and 3D printing create dynamic re-engineering opportunities*

VS.

Limiters

Events or industry behaviors that will limit penetration rate

- ***Regulation***
  - *The FAA is concerned about the lack of standards which will limit their ability to approve AM processes*

"Studies have identified over 150 variables that may need to be controlled for a given AM machine to produce stable and repeatable parts, demonstrating an increased risk to the aerospace industry due to the lack of adequate standards" FAA Policy Notice N 8900.391

- ***In-Flight Failure***
  - *Should a public failure occur due to an AM part early in the technology roll out, look for a significant impact to penetration*
- ***Military Risk Reduction***
  - *The military is continue to drive down costs by requiring mature technologies on new platforms; a lower risk tolerance may slow AM penetration in certain defense market areas*

Supply Chain Impacts
2nd And 3rd Tier Are Most At Risk; Part Vulnerability Review And Mitigation Plans Should Be Considered

- AM processes will have very significant impacts on today's A&D supply chains
- ***Mid-Tier suppliers will be most impacted*** based on product portfolio
  - ***Market analyses and customer interaction are recommended*** for these suppliers to identify risk areas early
- Mitigation actions exist for all supplier levels and should be evaluated based on current and forecasted position

Major Sub-System Integrators

MITSUBISHI HEAVY INDUSTRIES, LTD.
Honeywell Aerospace
MTU Aero Engines

Lowest Near Term Impact

Top tier system providers are likely to be following the lead of OEMs and making their own evaluation of how to best utilize AM

Major integrators and risk sharing partners are likely to be urged by their partner OEMs to reduce costs, weight, and time to produce via AM processes; ***integrators that can not build AM competency or an AM supplier base will be at risk*** for future opportunities on next generation platforms

Component Manufacturers

Senior Aerospace
EDAC TECHNOLOGIES
Parker
lisi

Highest Near Term Impact

Mid to lower tier component suppliers are more likely in the cross hairs of the market disruption; ***new processes will mean re-evaluation of make v buy decisions & supplier selection***

Parker Aerospace proactively worked with GE through a joint venture (Advanced Atomization Technologies) to use AM to produce fuel nozzles; this technology enabled Parker to maintain this product line and serves as an example for traditional suppliers on how to mitigate the risk of parts being transferred or in-sourced

Material Providers

PCC
ALCOA
DONCASTERS
ATI

Medium Near Term Impact

Ultimately there will be a ***slow transition away from tradition material sources to powder materials due to AM process***

The impact will initially be relatively small compared to the size of these consolidated material providers, but will begin to erode their revenue base if no actions are taken to penetrate the powder material market – many of the largest material providers have already made organic developments or acquisitions to build capabilities with AM powder metallurgy

Sources: Fairmont Analysis; Aerospace OEM Announcements, Open Source Materials

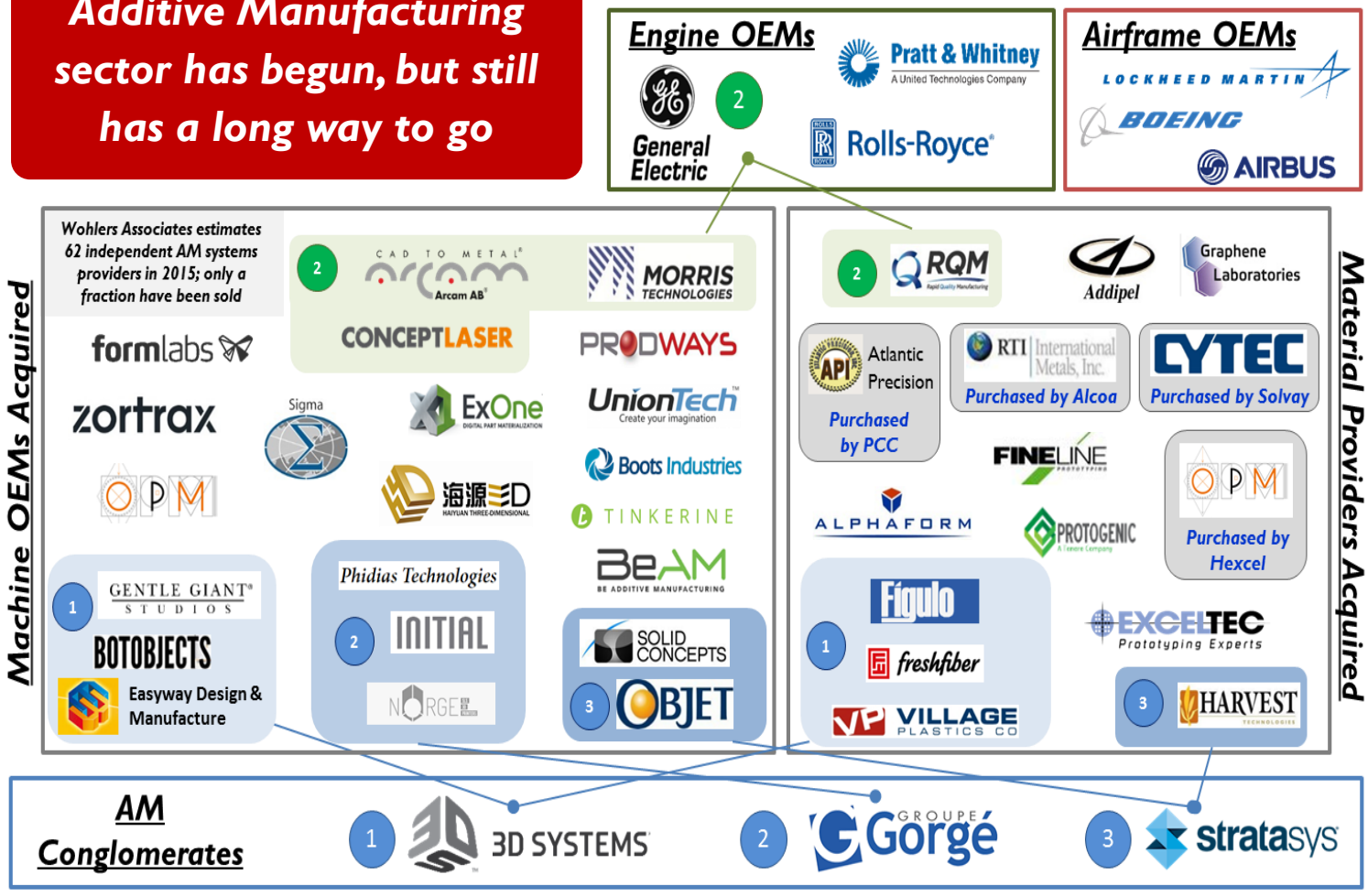
Merger & Acquisition Activity (Machine & Material Providers)

Significant M&A Activity Within The AM Industry; GE Stands Alone As An OEM Acquirer While Others Developing Capabilities Organically

Consolidation in the Additive Manufacturing sector has begun, but still has a long way to go

Acquired AM Companies Since 2012

Buyers Noted For Aero OEMs & Emerging AM Conglomerates



- ***At least 43 acquisitions*** have occurred in the AM industry since 2012 *(36 highlighted below with buyer noted for key deals)*
  - A total deal value of ~$9.5B (publicly announced on 21 deals)
  - EV ranging from 1.2X-12.1X on Revenue & 8.9X-20.5X for EBITDA
- ***GE has emerged as an AM industry*** leader via M&A
  - Other noted aerospace OEMs discuss developing technologies organically and have not made large acquisitions for AM capabilities
- ***Traditional material providers are establishing AM footholds***

Sources: Fairmont Analysis; DACIS, Wohlers Associates, Open Source Materials

Implications & Actions For Investors & Suppliers
Prudent Actions Exist To Mitigate Risk And Exploit Opportunities

- Additive Manufacturing will continue to develop and find new aerospace applications over the next 5 years; there will be another market shift in early to mid 2020's as new aero platforms enter the design phase

- AM enables major market trends in both commercial and military aerospace industries
  - Cost is a primary concern commercially: AM enables improved performance (fuel efficiency) while increasing speed to market
  - Performance remains a critical parameter for military applications: AM enables new design techniques to significantly reduce weight

Implications & Suggest Actions For Investors

1. Acquisitions will remain competitive with a limited number of well positioned assets that are in high demand by aerospace primes
2. Traditional aero suppliers still remain in demand; a critical review of their AM risk exposure is required
3. Look to capitalize on less visible complementary markets that are likely to follow the AM trends
4. Prepare AM risk mitigation plans for current or targeted assets

Implications & Suggest Actions For Suppliers

1. Understand your OEM's intentions for AM
2. Assess AM risk exposure
   - Feature-rich parts, legacy parts, & high count assemblies are most at risk in the near term
3. Consider investment in AM machine to develop capability or establish relationship with AM service provider
   - Investigate opportunity for cost sharing with customers to reduce cost, improve quality, and advance technology

AM Will Disruptively Change A&D Manufacturing; Companies Should Proactively Identify Risks & Develop Strategic Plans

1. AM will become pervasive in the A&D industry, but its penetration will be metered by 'Entry Points' and operational experience

2. AM process will likely impact components / suppliers in a logical order based on financial return and component characteristics
   - Timing of Part Impact: Part Features → Tooling → Non-flight Critical → 'One-off' → Legacy Parts → Flight Critical

3. 2nd & 3rd Tier suppliers will face the greatest risk from technology disruption; mitigation actions exist and should be addressed

4. OEMs are all developing AM capabilities; most developing organic capabilities
   - GE is clearly taking an industry lead and growing capabilities quickly via M&A

Fairmont has deep experience with advanced material, manufacturing, and design technologies and is here to help you evaluate investments and develop strategies for long-term success

Unique Domain Experience Allows Fairmont To Deliver Client Value In Strategy & Diligence Engagements

- Fairmont Consulting Group provides ***strategy consulting and due diligence*** to clients in the ***aerospace, defense and government services markets***
- Fairmont's mission is to ***help our clients measure value, mitigate risk, and drive value creation***
- We bring ***domain focus, business expertise, and proven experience*** to bear on behalf of our clients
- **ABOUT THE AUTHOR:**
  - As a former project engineer, working with one of the ***major engine OEMs***, Max led cross functional teams through all phases of the jet engine life cycle
  - His roles ***directly exposed him to Additive Manufacturing*** where he was instrumental in the component design, tradeoff studies, source selection, component & system testing, and certification for engine components that utilized this technology
  - Also, with nearly a decade of OEM experience, Max has ***unique insight into OEMs' views regarding AM*** and how the technology is likely to impact the industry since these companies are the primary technology drivers

Author

Max Asterlin
Manager

masterlin@fairmontcg.com
Office: (857) 265-3400
Mobile: (574) 274-0690









FAIRMONT
CONSULTING GROUP












Jay Wynn
Founder, Managing Director

Ben Harper
Co-Founder, Partner

Jack Cronin
Partner

Dr. Annalisa Weigel
Director

Fairmont Consulting Group LLC – 160 State Street, 4th Floor, Boston, MA 02109
Phone: (857) 265-3400 – Fax: (617) 939-0262 – www.FairmontCG.com