CHAPTER 1

The Impact of Additive Manufacturing on the Supply Chain

Aerospace & Defense

Research Support Service

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PreScouter

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Executive Summary

The Aerospace & Defense industry has benefitted from decades of using additive manufacturing (AM) technology to create increasingly complex parts in a cost-effective way. AM technologies bring several advantages to the A&D industry, namely the ability to produce parts with complex structures. As a result, these parts, with consolidated functions, can reduce the total number of parts needed in a specific system. In addition, due to their complex structures, these parts can be built with lighter weight and higher strength. From an economic perspective, AM makes possible lean production systems with reduced raw material waste and faster response due to shortened lead times.

Because of these advantages, many companies are exploring AM and novel products are emerging in the market; examples include 3D-printed fuel nozzles, fuel injectors, engine skulls and blades. Moreover, new AM technologies are being developed that provide a wide range of advantages to the A&D industry. The supply chain, in particular, will benefit greatly from these developments, increasing in efficiency and in its ability to dynamically respond to shifting needs..

AM IN AEROSPACE & DEFENSE
OVERVIEW

Additive manufacturing for aerospace and defense (A&D) applications first began in the mid- to late-1980s. During that time, AM was mainly used to prototype new designs and produce tools. Since then, (1) the flexibility in manufacturing complex parts, (2) the ability to produce lightweight parts, and (3) a reduction in lead time caused by adopting AM, has allowed the A&D industry to expand and mature its use of AM. Today, due to the upscaled productivity and consequently reduced production costs, AM is finding even more opportunities in the A&D market.

The A&D industry is one of the largest markets for AM technology today and has been using AM successfully in its operations for several decades.

in 2012

Global revenue for the A&D sector reached **$0.2B**

Representing **10%** of AM's total revenue

by 2023

AM in the A&D sector is poised to become a **$4.8B**

with a CAGR of **23%**

The key driver of this growth is the significant reduction in product maintenance and production costs, making AM a natural fit for A&D.

References:

1. https://www2.deloitte.com/content/dam/insights/us/articles/additive-manufacturing-3d-opportunity-in-aerospace/DUP_706-3D-Opportunity-Aerospace-Defense_MASTER2.pdf
2. https://www.defensenews.com/industry/2018/03/13/aerospace-and-defense-3-d-printing-market-to-surpass-4b-by-2023-report-says/

AM technologies fit with A&D industry for two main reasons:

1) AM creates unique parts:

- AM allows for the creation of complex part geometries. Traditional manufacturing processes have limited methods to remove undesired portions of the material to fabricate a product, such as drilling holes, filing surfaces, etc. In comparison, AM can freely select where to deposit or solidify the material in three dimensions. More complex parts consolidate functions from different parts, reducing the number of parts needed while improving the strength of the produced parts.
- AM can create lightweight parts with weight reduction compared to traditional manufacturing methods approaching 64%. As a result of being able to create complex structures, AM can create parts with internal cavities or lattices. These internal cavities cannot be produced with traditional methods. Lightweight parts will save fuel and energy when operating aircraft, satellites and other such trends.

Figure 2: *Conventional (a) and AM (b) design for a hinge used in aircrafts (Knofius et al. 2017)*

References:

1. https://www2.deloitte.com/content/dam/insights/us/articles/additive-manufacturing-3d-opportunity-in-aerospace/DUP_706-3D-Opportunity-Aerospace-Defense_MASTER2.pdf
2. https://www2.deloitte.com/insights/us/en/focus/3d-opportunity/additive-manufacturing-3d-printing-supply-chain-transformation.html
3. https://www.ey.com/en_gl/aerospace-defense/why-supply-chain-management-is-important-in-aerospace-and-defense
4. https://www.researchgate.net/publication/317616596_Improving_effectiveness_of_spare_part_supply_by_additive_manufacturing_as_dual_sourcing_option

2) **AM changes the production economy:**

- AM allows for a lean production with less material input: driving part costs down as much as 50%. In contrast to traditional production methods, which remove undesired parts, AM recycles unused metal powders, reducing the raw materials input. Because high-cost alloys are widely used in the A&D industry, lean production can drastically reduce costs.
- AM can increase flexibility to customize/prototype productions: leading to a buy-to-fly ratio of 1:1. To ensure the quick acquisition of spare parts, a large amount of spare parts are produced and stocked in inventory, resulting in an excess of parts that will not be used. With AM, due to the reduced manufacturing lead times, a spare part can be produced when needed, avoiding excess inventory levels and reducing maintenance costs.
- AM decentralizes production, and optimizes supply chains: bringing time-to-market down by 64%. In the traditional manufacturing model, different parts will be produced in an order and then be assembled. This requires multi-level production in the supply chain, increasing the amount of time for a part to reach the market. With AM, the consolidated function of complex parts can avoid multi-level production, reducing the total manufacturing time and increasing the responsiveness to the market.

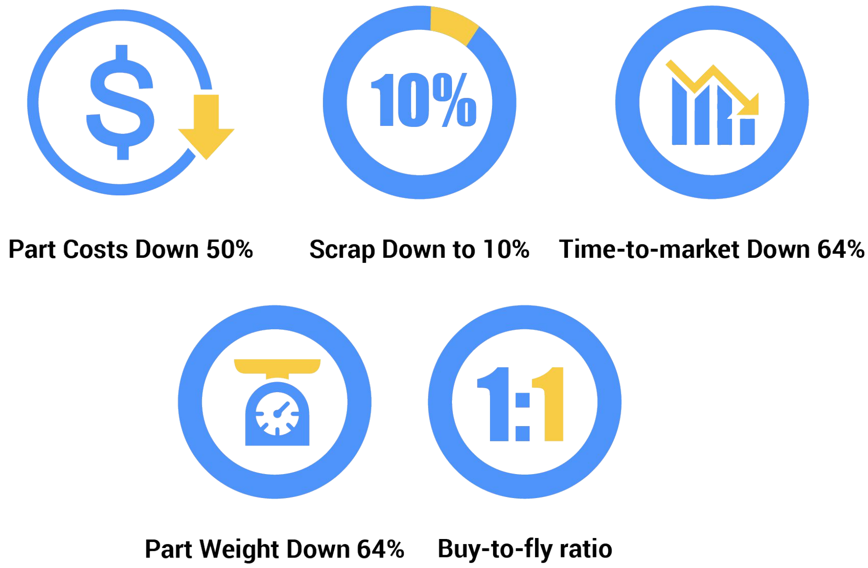


Figure 2: How AM can benefit the A&D production economy

There are five main technology families that are widely applied in the A&D market today.

- Among them, powder bed fusion (PBF) and directed energy deposition (DED) are the most expensive technologies while providing the most durable parts. These two technologies are a good fit for building highly complex repair and replacement parts.

- Binder jetting (BJ), material jetting and material extrusion are of lower cost and higher fabrication speed, which means they are a better fit for producing small, nonstructural parts with large volume demand.

The representing technologies under each family are summarized in the table below.

Type	Powder Bed Fusion (PBF)	Directed Energy Deposition (DED)	Binder Jetting	Material Jetting	Material Extrusion
Description	Powdered materials are selectively exposed to laser/electron beams that generate heat and are solidified through fusion	Depositing powdered materials onto the melting area of a surface to join the parts	Chemical bonding agents are selectively applied onto powdered materials to “glue” them together	Droplets of molten materials or photocurable materials are deposited into carrier liquid or layer to form parts	Materials are dispensed through a nozzle to join the parts through thermal plastic reactions
Advantages	High complexity, wide range of materials	High flexibility, effective for repairing parts, enables multiple materials	Wide range of materials, high productivity	High accuracy, enables multiple materials in one part	Low cost, can be used in office environment, good part structural properties
Part Durability	++++	++++	++	+++	++
Speed	Low	Low	High	Medium	Medium
Cost	$$$$	$$$	$	$	$
Technologies	Selective Laser Melting (SLM), Electron Beam Melting (EBM)	Laser Engineering Net Shape (LENS), Electron Beam Additive Manufacturing (EBAM)	Binder Jetting (BJ)	Nanoparticle Jetting (NPJ), Drop on Demand (DOD)	Fused Deposition Modelng (FDM)

Highly engineered complexity, high buy-to-fly ratio and low volume production are three major common features for AM parts in A&D sectors. Due to the nature of AM, 3D printing of complex parts can reduce production costs and improve efficiency by removing traditional cutting processes.

The high buy-to-fly ratio is another index that is related to cost. By reducing the material wastage compared with subtractive manufacturing, the production cost is further reduced.

> Typical buy-to-fly material ratios of 4:1 (input material to final component) are common using traditional 5-axis milling processes, with some components having a ratio as high as 20:1. The EU FP7 MERLIN project sought to address this environmental impact through the application of AM technologies in civil air transportation. The project involved a number of leading European aerospace organisations, including Rolls-Royce, Turbomeca and MTU, as well as researchers at the Fraunhofer ILT. One of the results of this project was an improved AM process, Laser Material Deposition (LMD), for the manufacture of bladed disks (‘blisks’) used in aero engines.
>
> *Additive manufacturing and sustainability: an exploratory study of the advantages and challenges. S Ford, M Despeisse. Journal of Cleaner Production 137: 1573-87.*

Finally, low-volume production fits AM’s flexibility. It is easy to ramp up production with highly customized designs.

General Electric Aviation introduced its GE9X commercial aircraft engine, which is produced with significant additive content. This engine will be installed on Boeing's new 777X twin-engine jet.

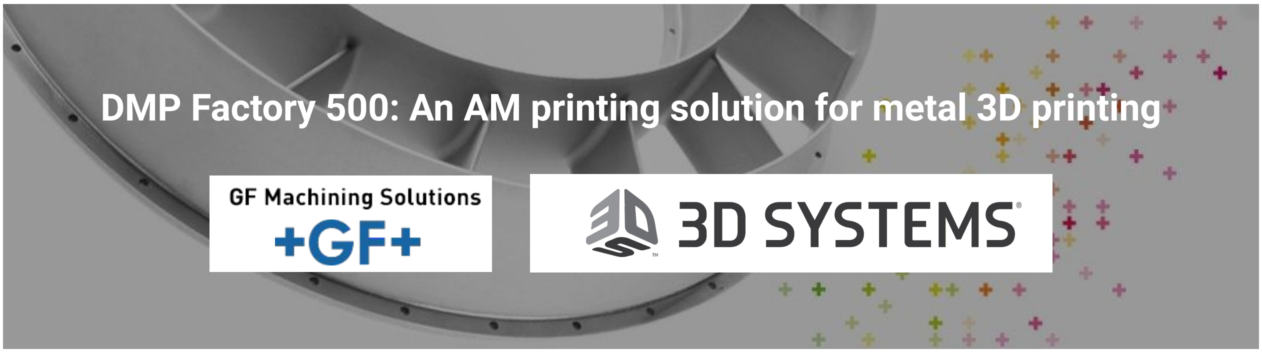
With **seven components** and **204 parts** being additively manufactured, GE9X represents the first commercial engine made with AM technologies. GE is able to combine different materials in their AM process.

The engine is expected to receive final Federal Aviation Administration (FAA) certification this year.

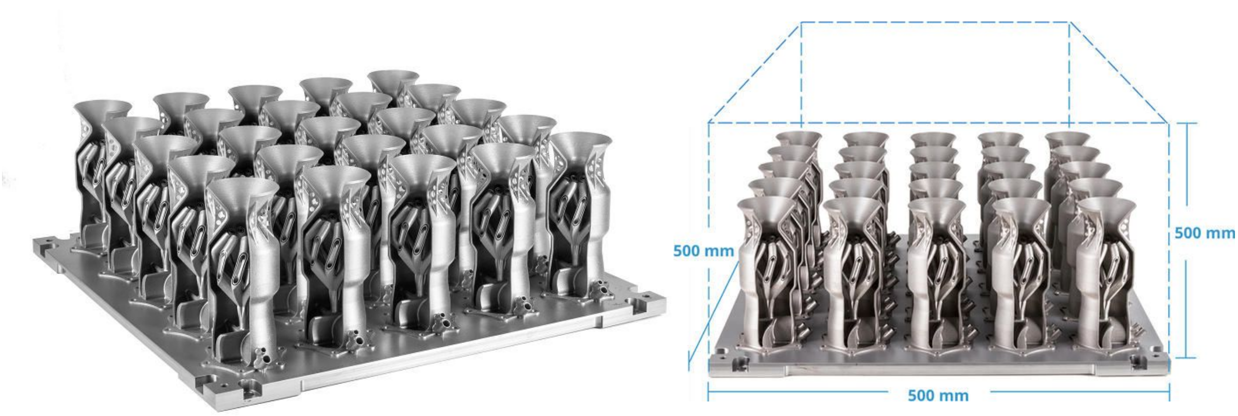
GE9X engine's low-pressure turbine (LTP) blades. The 3D-printed titanium aluminide blade has higher strength-to-weight ratio than traditional nickel alloys. Photo: GE Aviation

References:

1. https://www.additivemanufacturing.media/news/ge-announces-additive-manufacturing-breakthrough-in-commercial-aviation
2. https://www.geaviation.com/commercial/engines/ge9x-commercial-aircraft-engine



DMP Factory 500 is a workflow-optimized metal AM printing solution. It is designed by GF Machining Solution and 3D Systems to provide a metal 3D-printing solution that optimizes the quality of large parts with lower total cost of ownership (TCO) for original aerospace equipment manufacturers (OEMs) and their suppliers.



Engine fuel nozzles built by DMP Factory 500. Source: 3D Systems

References:

1. https://www.gfms.com/com/en/Products/advanced-manufacturing/additive-manufacturing-family/dmp-500-factory.html
2. https://www.3dsystems.com/3d-printers/dmp-factory-500
3. https://www.additivemanufacturing.media/products/dmp-factory-500-offers-workflow-optimized-metal-3d-printing

3D Systems and German Aerospace Center (DLR) partnered to develop 3D-printed reusable rocket engines. This engine is a part of the EU project SMILE (Small Innovative Launcher for Europe), which aims to design a small satellite launch vehicle.

The engine is composed of a 3D-printed injector and a ceramic combustion chamber. The ceramic chamber is primarily developed at DLR. Using AM, engineers can independently optimize the thermal, mass and hydraulic performances of the engine, a feat not possible using traditional manufacturing processes. In addition, the 3D-printed injector is highly integrated, avoiding production and assembly steps.

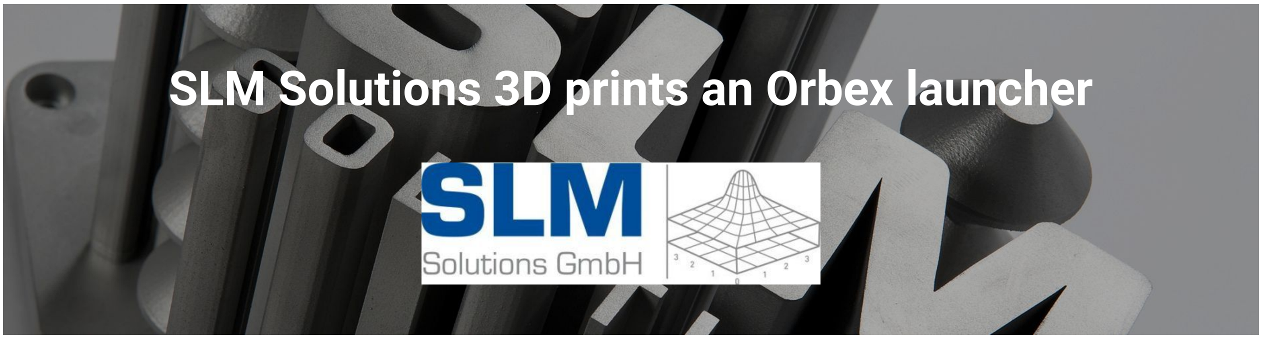
This engine passed an initial hot firing test in 2018.

The 3D-printed injector and ceramic combustion chamber for rocket engines. The combustion chamber is made of special high performance material

References:

1. https://www.additivemanufacturing.media/blog/post/additive-technology-delivers-small-satellites-to-space

SLM Solutions 3D prints an Orbex launcher

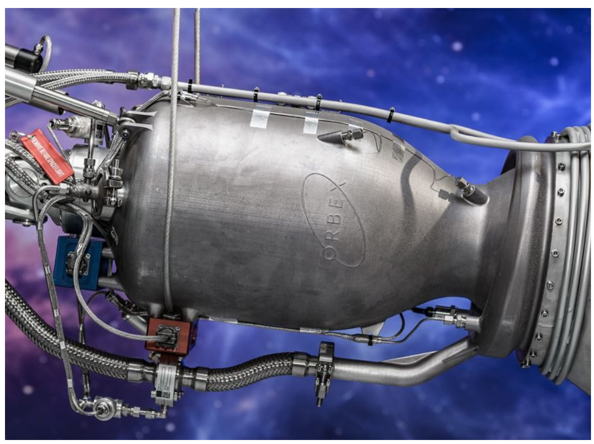


Orbex unveiled its single-piece 3D-printed metal rocket engine, which is the world's largest 3D-printed rocket engine. It is produced by SLM Solutions 800. Orbex is a UK-based spaceflight company that develops small satellite launch vehicles and environmentally-friendly rockets.The 3D-printed Orbex launcher is made using selective laser melting (SLM). It uses 100% renewable fuel to cut carbon emissions by 90% and it will leave no orbital debris after its lifetime.

The engine part meets the porosity level and distribution quality acceptance criteria. It is also reported that the SLM process saved 90% of the turnaround time and over 50% of the cost compared to standard manufacturing.

This 3D-printed engine is 30% lighter and 20% more efficient than other launch vehicles of its kind.

The engine for the Orbex launcher that is built by SLM 800 using a special nickel alloy



References:

1. https://www.additivemanufacturing.media/news/slm-solutions-3d-prints-orbex-launcher
2. https://www.slm-solutions.com/

RUAG Space is going to send the first 3D-printed engine mount to the moon. Made of aluminum, this engine mount is part of a lunar lander by SpaceIL, a private Israeli company.

Using 3D-printing technology, the engine mount is lighter than traditionally made ones. “Every kilogram less saves money, since less energy is needed for sending the satellite into orbit,” says Guggenbach, the CEO of RUAG Space.

Lunar Lander of the Israeli company SpaceIL. Copyright: SpaceIL.

The 3D-printed aluminum engine mount built by SpaceIL. This would be the first 3D-printed part to land on the moon. Copyright: RUAG Space, SpaceIL.

References:

1. https://www.additivemanufacturing.media/news/engine-mount-set-to-be-first-3d-printed-part-on-the-moon
2. https://www.ruag.com/en/news/ruag-space-first-3d-printed-part-going-moon

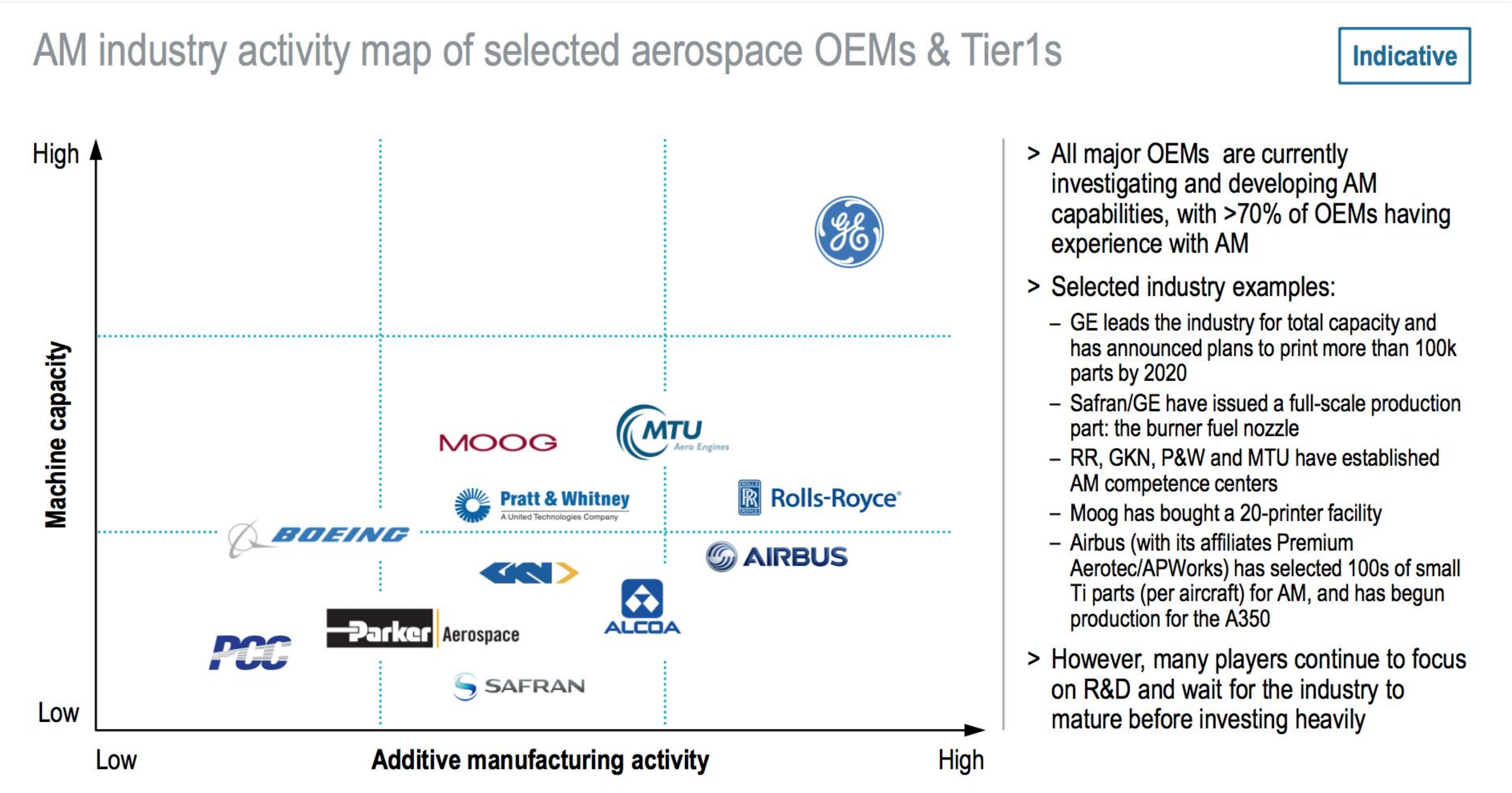
According to a Roland Berger's industry research in 2017, all major OEMs are currently investigating AM capabilities. **Seventy percent** of them already have experience with AM production. Recent examples include:

- General Electric announced the production of more than 100k printed units in 2020;
- Safran and GE have printed a full-scale burner fuel nozzle;
- Rolls-Royce, GKN, Pratt & Whitney, and MTU have built AM competence centers;
- Moog bought a 20-printer facility;
- Airbus started to print hundreds of small Ti parts for A350 aircraft production.

All OEMs are investigating and developing AM capacities. However, most players are focusing on R&D and waiting for the industry to mature.

As can be seen in the figure on page 17, manufacturers with higher machine capacity generally tend to be more active in embracing AM production, indicating the pioneers in this market.

This figure shows that more manufacturers are likely to explore AM capabilities despite their machine capacities being low, such as Rolls-Royce and Airbus, indicating that these companies may be looking for AM to revolutionize their production.



Source: Roland Berger

Commercial Aerospace & Defense

Current Applications

- Concept modeling and prototyping
- Printing low-volume complex aerospace parts
- Printing replacement parts
- Printing complex engine parts

Potential Applications

- Printing electronics directly on parts
- Printing aircraft wings
- Printing repair parts on the battlefield

Space Exploration

Current Applications

- Printing specialized parts for space exploration
- Printing structures using lightweight, high-strength materials
- Printing parts with minimal waste

Potential Applications

- Printing on-demand parts/spares in space
- Printing large structures directly in space to reduce vehicle's launching cost

How do AM technologies solve current supply chain issues?

The A&D supply chain includes many players, including OEMs, Maintenance, Repair and Overhaul (MRO) providers, and Service Locations (SLs). Geographical differences and complicated information exchanges between all players makes the entire supply chain management challenging.

Especially in the A&D industry, urgency in the repair and maintenance of aircrafts will drastically impact the company's economic situation. Thus, efficient supply chain management will increase companies' operational efficiencies, reduce costs, improve their safety profile and afford greater value to customers. According to Deloitte, there are four main current issues to be solved in A&D supply chain management:

1. Sourcing of raw materials
2. Mitigating supply disruption risks
3. Coping with modernization and technologies
4. Shortage of skilled workers

How AM can help solve these issues is presented on page 20.

The current challenges to be solved in A&D supply chain management:

1. **Sourcing of raw materials:** Raw materials sourcing is challenging because companies have to determine what material they need and how much to inventory. Additionally, since raw material providers are located globally, an early and accurate plan is crucial.

2. **Mitigating supply disruption risks:** Due to natural disasters and other geo-environmental issues, there are risks that affect the availability and pricing of materials and parts. That means companies need to mitigate this risk by doing short-term prediction and long-term prediction to avoid price inflation.

3. **Coping with modernization and technologies:** Technologies develop quickly, and companies need to keep up with these emerging technologies. One example of the failure to do so was that, due to software glitches, the newly designed engine for A320 started slower than expected.

4. **Shortage of skilled workers:** As technology grows, people also need to be properly trained.

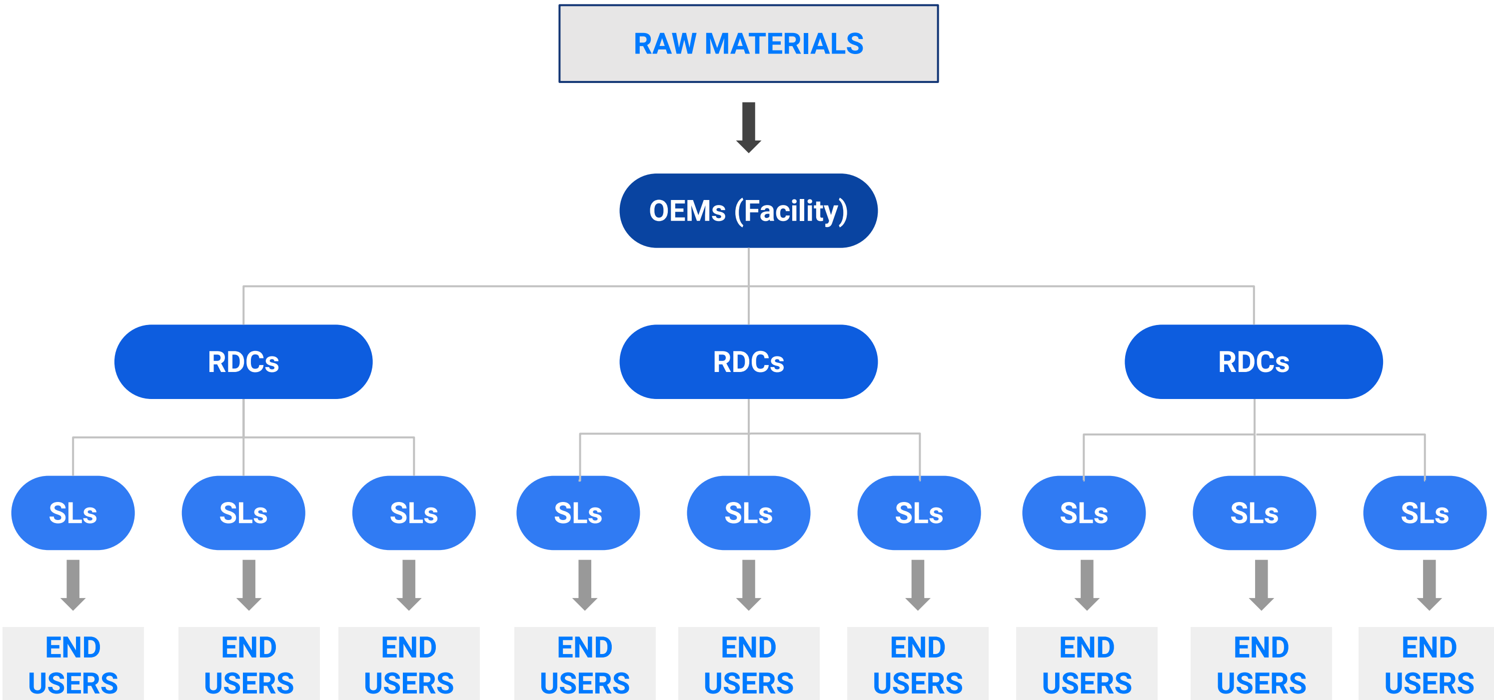
IMPACT ON SUPPLY CHAIN

Additive manufacturing technologies can impact the supply chain by solving these four issues as presented below.

SOURCING OF RAW MATERIALS	Because AM is a data-heavy technology, it will benefit raw material sourcing by creating more accurate data tracking and historical data.
MITIGATING SUPPLY CHAIN RISKS	Because AM is a data-heavy technology, it will benefit raw material sourcing by creating more accurate data tracking and historical data.
SHORTAGE OF SKILLED WORKERS	As a highly automated process, the training processes would be simplified.
COPING WITH MODERNIZATION AND TECHNOLOGIES	Due to AM's flexibility in processing different materials, its upgrade and modification is relatively easy.

How does AM change the supply chain structure?

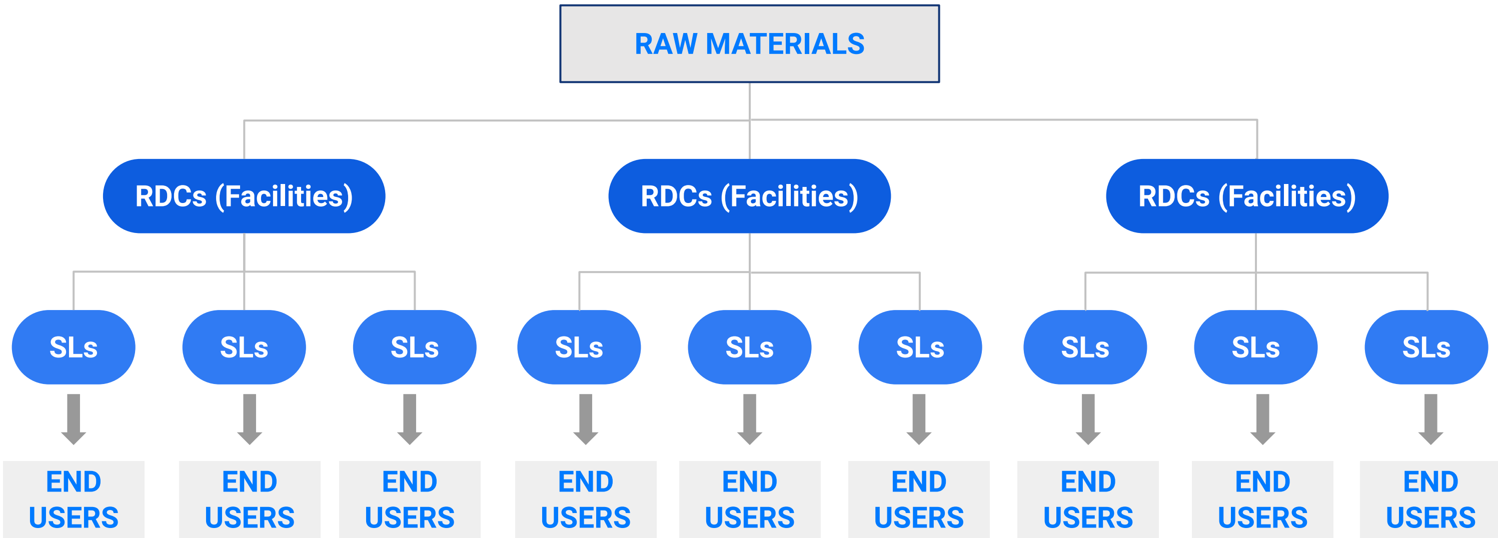
In the current (as-is) structure, raw materials are sent to OEMs, OEMs produce aircraft parts and then deliver them to regional distribution centers (RDCs), then to service locations (SLs), hierarchically.



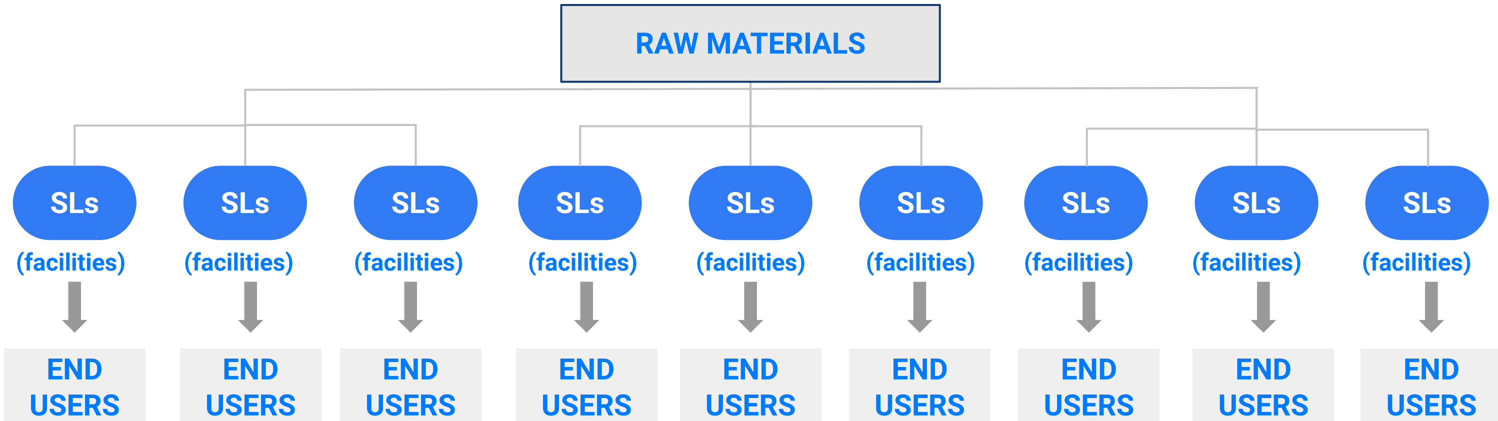
The current structure of the supply chain structure

AM can change the supply chain structure in two scenarios.

In a centralized scenario (seen below), raw materials are sent to RDCs and parts are built in the RDCs. Since RDCs are much closer to end users, the production lead time and logistics lead time are decreased. As a result, the inventory cost can be reduced.



In a distributed scenario (seen below), raw materials are sent to SLs, and parts are built in the SLs. Since SLs are even closer to end users, the lead time would be further decreased.



So, what's the impact of AM on supply chains?

A supply chain operations reference (SCOR) model was used to quantify the impact of AM in the supply chain. The SCOR model was developed to help large companies assess different practices by analyzing five major steps (plan, source, make, deliver and return) in three level depths (defining scope as level 1, type of supply chain as level 2 and implementation details as level 3). This model is widely used in the industry.

The SCOR Model Analyzes 5 Major Steps in 3 Depth Levels:

1. PLAN
2. SOURCE
3. MAKE
4. DELIVER
5. RETURN

1. DEFINING SCOPE
2. TYPE OF SUPPLY CHAIN
3. IMPLEMENTATION DETAILS

By putting different players together, such as OEMs, RDCs and SLs, the inventory level is modeled by researchers. Figure 13 below, is a representative result. The x axis represents six different parts used in aircrafts that are studied in this model: intercase, simple duct flange 1, simple duct flange 2, complex duct flange 1, complex duct flange 2 and large blisk. The inventory level (y axis) is modeled under three different supply-chain scenarios. As shown in the figure, the safety inventory level of centralized AM and distributed AM are generally lower than the as-is supply chain configuration by roughly 20-60%, signifying that inventory costs are reduced by applying AM technology.

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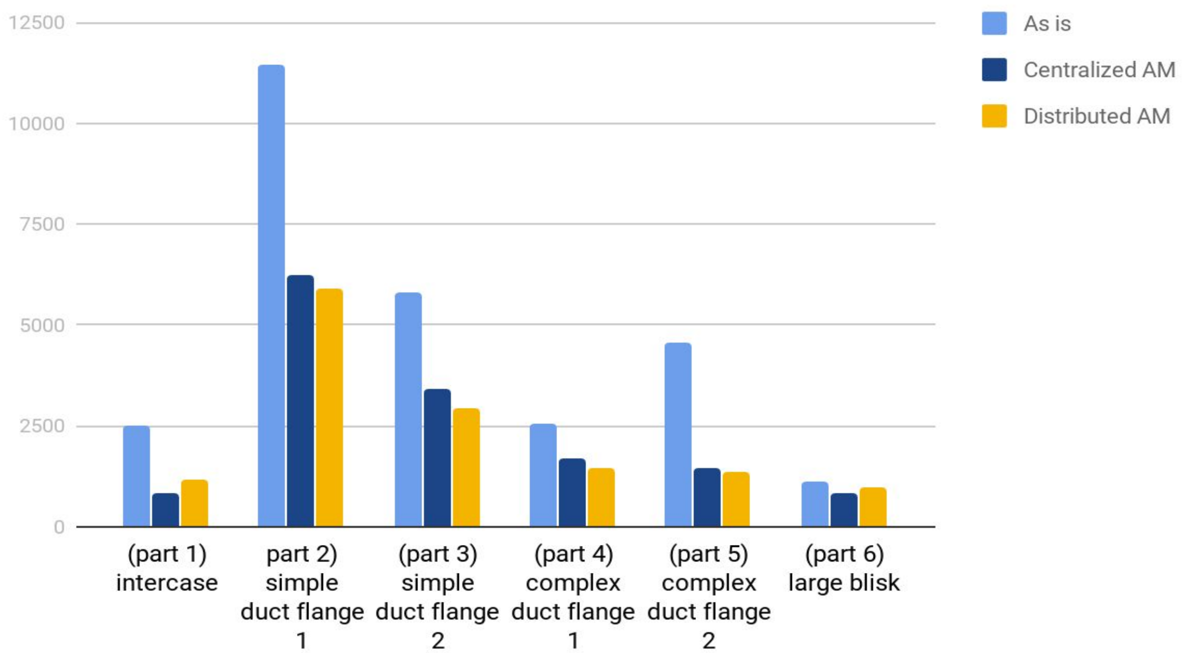


Supply chain-safety inventory under different scenarios

CONCLUSION

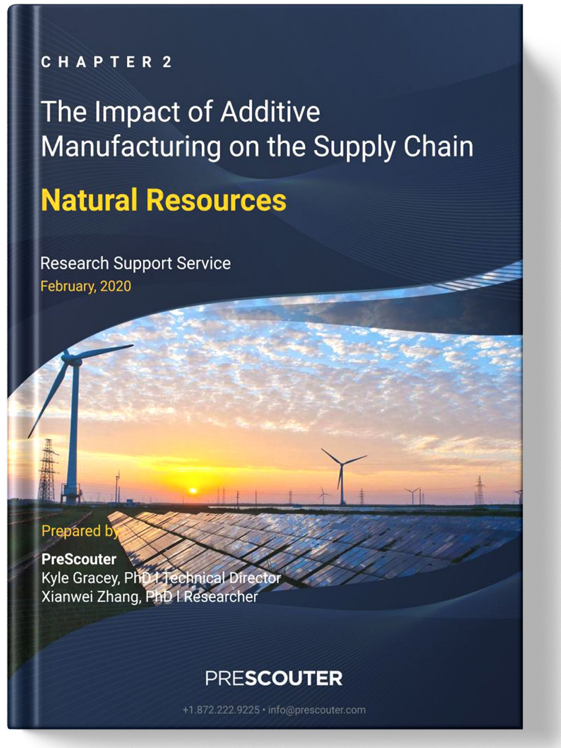
Today, Additive Manufacturing benefits from a rich experience in the Aerospace and Defense sector. The use of this approach for manufacturing parts in the sector will continue to be adopted by players in this space, driven by advancements in technology and the need to remain competitive in the industry. Additional benefits to the supply chain will further accelerate AM's adoption in this sector.

AM can solve four issues in the supply chain: namely **(1) improve reliability in raw materials planning, (2) reduce potential production disruption, (3) offer high flexibility for production upgrades, and (4) simplify the training process.** In addition, AM will change the supply chain structure by decentralizing production and removing multi-level production chains, thus reducing inventory cost by 20%-60% as well as dramatically lowering distribution costs.

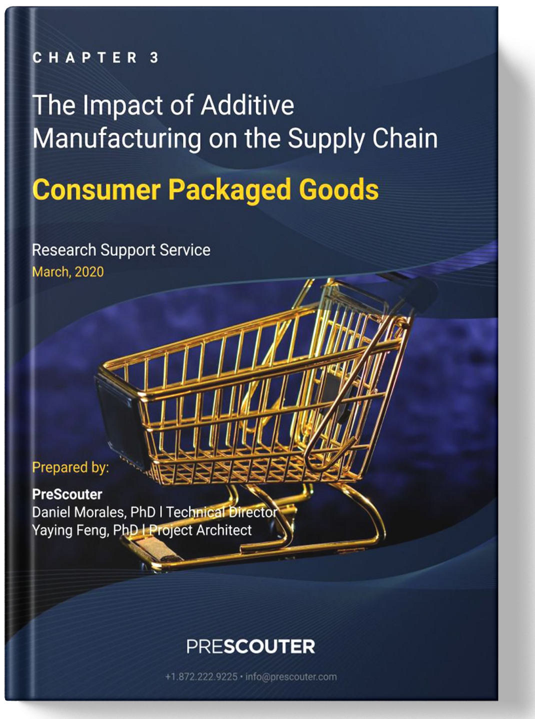
Although AM manufacturing itself is more expensive because it involves more complex equipment and requires more high-skilled technicians, the net impact of embracing AM to the supply chain will reduce the overall operating costs. As a result, AM is a great candidate for next-generation manufacturing in the A&D industry.

At PreScouter, many clients are increasingly learning about the benefits of this technology and how it can be integrated into their own operations in to optimize their businesses and remain competitive.

AM IN THE SUPPLY CHAIN
UPCOMING REPORTS



02 Natural Resources



03 Consumer Packaged Goods

04 High Tech

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Technical Director, High Tech / Aerospace & Defense Practice

Sofiane leads the high-tech, aerospace and defense and finance verticals at PreScouter. Sofiane earned his B.S. in Materials Science and Engineering from The University of Illinois at Urbana-Champaign, and his Ph.D. in Materials Science and Engineering from the Georgia Institute of Technology, where his research focused on nanotechnology and energy storage. Since graduating from Georgia Tech, he has worked as an emerging technology and business strategy consultant at several firms and for his own clients.

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Project Architect

Yaying earned his Ph.D. in Materials Science and M.S. in Electrical and Computer Engineering from Duke University. Before that, he earned his B.S. in Materials Physics from University of Science and Technology Beijing in China. During Yaying's Ph.D. tenure, he built expertise in nanomaterial synthesis, energy devices, advanced manufacturing, and telecommunication. At PreScouter, Yaying leads projects in the energy industry.

NEXT STEPS

SOME POSSIBILITIES THAT PRESCOUTER CAN OFFER FOR CONTINUATION OF OUR RELATIONSHIP

- COMPETITIVE INTELLIGENCE
- TECHNOLOGY & PATENT LANDSCAPING
- TECHNOLOGY ROADMAPPING
- MARKET RESEARCH & ANALYSIS

- TRENDS MAPPING
- ACQUIRE NON-PUBLIC INFORMATION
- PATENT COMMERCIALIZATION STRATEGY
- DATA ANALYSIS & RECOMMENDATIONS

- REVIEW BEST PRACTICES
- SUPPLIER OUTREACH & ANALYSIS
- CONSULT WITH INDUSTRY SUBJECT MATTER EXPERTS
- INTERVIEWING COMPANIES & EXPERTS

WE CAN ALSO DO THE FOLLOWING

- **CONFERENCE SUPPORT:** Attend conferences of interest on your behalf.
- **WRITING ARTICLES:** Write technical or more public facing articles on your behalf.
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