KEYWORDS additive manufacturing project management supply chain management agile 3D printing

IS 3D PRINTING TRANSFORMING THE PROJECT MANAGEMENT FUNCTION in the aerospace industry?

Alejandro Romero-Torres
School of Management (École de gestion - ESG)
University of Québec in Montréal
romero-torres.alejandro@uqam.ca

Darli Rodrigues Vieira
School of Management
University of Québec in Trois-Rivières
darli.vieira@uqtr.ca

ABSTRACT

Traditional manufacturing techniques fade into the background, while manufacturing systems require using additive technologies for rapid adaptation to current demand and reduction of production cycle duration. Many large mechanical and aircraft engineering companies have already adopted additive manufacturing technologies in their future production strategy. The general concept of 3D printers on the basis of e-manufacturing principles is aimed at the integration of computer models of physical objects and processes. This change requires a big transformation of the enterprise business model, affecting either core or support activities. For instance, additive manufacturing could also change project management practices. This paper aims to identify how additive manifacturing could transform the project management function for the aerospace industry. Results show that projects could improve their performance by integrating additive manufacturing; however, project managers could adapt their approach to a new paradigm for lifecycle management and for leaner supply chain management in aerospace industry.

1. Introduction

Aerospace is a highly competitive industry where actors look for being the first adopters to lead the market, if not, they should follow adopters to survive. With a decreasing market size, aerospace manufacturers are competing more than ever to obtain new contracts. Customers, such as airlines, private and public organizations or civilians, are looking to spend less money and get the best products possible *(Franke & John, 2011)*. These factors create an enormous challenge for aerospace actors to manufacture products with high performance, short production cycle time, low cost and fierce competition *(Witick et al., 2012)*. Within technology evolution, major manufacturing firms invest hundreds of millions of dollars in introducing new innovations to improve their products or services to overtake their competitors.

Additive manufacturing *(AM)* seems to be the next hype technology driver for the aerospace industry to improve manufacturing operations *(Smartech Markets, 2014)*. AM, commonly known as 3D printing, could be adopted to manage aircraft production, characterized by low manufacturing volumes, personalization, complex geometries and optimal balance between mechanical resistance of parts and weight *(Hopkinson et al., 2006)*. McKinsey Global Institute *(2013)* estimates AM will generate annually up to 550,000 million of savings by 2025.

AM is considered to be the real cornerstone of the industrial future for the most developed countries *(Gebhardt, 2012)*. AM is often presented as an industrial revolution, based on innovative technologies, challenging traditional manufacturing models and upsetting the relationship between actors *(Hopkinson et al., 2006)*. However, this transformation cannot be reduced to the production activities, it could also require operational optimization for the entire enterprise business model, including support functions such as supply chain management, product lifecycle management and project management. This paper aims to provide information about this transformation.

The objective of this paper is to assess how the introduction of AM into aerospace projects is transforming project management. How could project managers make decisions while using AM systems? How could project managers be more agile while employing 3D printing? In the following section, we first discuss the employment of AM and the trends in manufacturing. We then outline the basic features of aerospace sector and its AM applications. In the next section, we describe key transformations for project management practices and project manager role. Finally, in the concluding section, we state some implications of our study as well as directions for future research.

2. Additive Manufacturing

2.1 The third industrial revolution

In the last three decades, industries have experienced a transition to digital. This evolution can be illustrated by technological changes, such as: offices have moved from paper hand-drawn design plans to parametric files, first in two dimensions *(2D computer-aided design software CAD)* and then in three dimensions *(3D CAD)*; communications have gone from sending postal mail to the first appearance of the fax and then email. Manufacturers are not immune to this phenomenon. Traditional manufacturing techniques fade into the background, manufacturing systems require using additive technologies for rapid adaptation to current demand and reduction of production cycle duration *(Fogliatto, 2010)*. Indeed, several researchers consider this transition as the third industrial revolution *(Berman, 2012; Rifkin, 2012)*.

Digital capabilities allow high-speed processing of data, overcoming unknown limits such as reliability and accuracy. For manufacturing industries, digital technologies could improve operation by introducing data and control technologies such as computer-aided-design *(CAD)*, computer-aided-manufacturing *(CAM)* or computer-aided-engineering *(CAE)*. However, manufacturing processes remain basically the same: first digital design, then piece production by material removal, cold or heat forming, casting or injection, and finally, surface finishing *(Tiwary & Harding, 2011)*. The above processes face several limits such as high cost of tooling and machinery for complex geometries, long and complex supply chain to lower tooling costs *(Berman, 2013)*, high "time to market" for new designs, loss of flexibility in decision-making due to tooling cost and development time *(Gebhardt, 2012)*; tooling collisions when complex geometries are involved, curved cutting edges and drafting angle constraints, design and manufacturing tools designed to use Design for Manufacture and Assembly *(DFMA)*, thus generating constraints for product design and, although not necessary for geometries, use of solid pieces *(Grimm, 2004)*.

Furthermore, this manufacturing model is based on mass production *(Fogliatto, 2010)*. Standardized parts and processes made economies of scale achievable, but limited design flexibility and personification. These limitations could block manufacturers' creativity and constitute a barrier for developing new products with high added value or new functionalities *(Fogliatto, 2010)*.

E-manufacturing or "smart production", the use of advanced and emerging information technologies to provide automated data-driven productivity optimization, takes advantage of all knowledge developed in the digital age to overcome the above traditional manufacturing limitations *(Nyanga et al., 2012)*. At the heart of this new industrial revolution is additive manufacturing AM, which enables manufacturing complex geometries for several industries such as aerospace, electrical power and healthcare.

2.2 Additive manufacturing definition

AM, more commonly known as 3D printing, is a process of creating a three-dimensional object or 3D-model from a digital model. Using an AM machine, or printer, successive layers of material are laid down precisely in arranged patterns and lines in accordance with the digital design. Wohlers and Caffrey *(2013)* defined AM as the direct manufacturing of finished products with additive construction processes through a bottom-to-top approach by combining materials without any traditional tool or equipment. AM is used to produce models, prototypes, patterns, components, and parts using a variety of materials including plastic, metal, ceramics, glass, and composites *(Lyons, 2014)*.

In traditional manufacturing processes, a complex geometry requires a more sophisticated manufacturing process, which results in an additional cost *(Gibson et al., 2010)*. For AM, an elaborated geometry does not generate complexity for the manufacturing process; it enables material savings and time reductions. In addition, some complex items require joining several pieces to form the final product *(Campbell et al., 2011)*. These elements are separately manufactured and they are integrated at the end of the manufacturing process. Fortunately, AM allows manufacturing these complex items in a single process, thus enabling integration during design process *(Wohlers and Caffrey, 2013)*.

2.3 Additive manufacturing processes

Although there is a variety of different additive manufacturing techniques, they all follow the same pattern. As shown in **Figure 1**, AM processes could be divided into three fixed phases, namely digital, manufacturing and post-process.

Digital phase: This phase includes two main activities:

- **Computer-aided design CAD:** Object design is performed to get its 3D digital design (Grimm, 2004). CAD takes a series of digital images of a design or object and sends descriptions of them to an AM industrial machine. 3D design enables the improvement of improving quality and reduction in overall developmental time and costs by creating a model that is precise, easily replicated, and easily conceptualized (Schindler, 2010).
- **Standard Tessellation Language STL:** CAD software generates process files for AM machines in STL format. These files should be verified to avoid errors that may affect the total quality of the end product (Grimm, 2004). Errors are identified and corrected by the STL repair program or returning the file back to the design stage.

Manufacturing phase: This phase included two main activities:

- **Machine setup:** STL files are transferred to the AM machine and raw materials for object production are loaded.
- **Production part:** This is the process whereby the AM machine uses the STL files to create the item by adding material, layer-upon-layer. Layers, which are measured in microns, are added until a three-dimensional object emerges. AM machines could operate 24 hours a day without human intervention (Campbell et al., 2011). The only labour involved is the machine set-up, build launch, and the removal of the prototypes or object upon completion. This phase can be last if the part does not require a withdrawal of supports or, better than that, offered by the machine surface finish (Schindler, 2010).

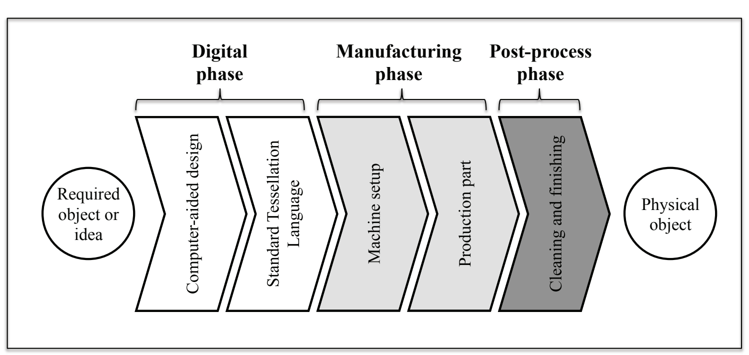

FIGURE 1. *Additive manufacturing processes*

Post-process phase: The part is then removed from the AM machine for post-processing such as removal of sacrificial supports for any overhanging edges. Cleaning and finishing of the object is the most manual, labour-intensive portion of the AM process *(Grimm, 2004)*. Sometimes, objects should go though other manufacturing procedures such as thermal operations or copper empty for improving their properties.

2.4 Additive manufacturing applications

AM is industrially used for three main types of application: developing prototypes known as rapid prototyping, manufacturing tooling known as rapid tooling and for manufacturing functional mechanical parts known as direct manufacturing or rapid manufacturing.

- **Rapid prototyping** is the main application for AM (Bibb et al., 2015). Prototypes require no dedicated tools and are produced in small series, generating high costs for industries. AM enables developing, in a short time, prototypes with relatively low costs and using different type of materials. Furthermore, a rapid prototype can be used either for visual or functionality validation for final product, reducing its development time.
- **Rapid tooling** provides a significant increase in speed and reduction in cost for complex tools (Campbell et al., 2011). This application allows replacing conventional steel tooling by soft material such as epoxy-based composites with aluminum particles, silicone rubber or low-melting-point alloys (Noble et al., 2014).
- **Direct manufacturing** is the latest application developed using AM processes. It accounts for a very small part of the market (Wohlers & Caffrey, 2012). It is used for low-volume products for the aerospace, automotive or medical sectors. However, direct manufacturing will also have implications for medium- to high-volume production as the AM technologies improve (Hague et al., 2003).

2.5 Additive manufacturing benefits

Berman *(2012)* drew an analogy between AM effects and those observed during the emergence of digital printing 20 years ago. Digital printing has completely transformed the industry in a few years, since businesses change their business model to integrate digital competencies. Based on 2D printing effects, we can anticipate what will happen with AM in the world of manufacturing:

- **Design benefits:** AM technologies bring creativity and flexibility for product design. AM machines can produce parts with almost any shape or complexity and without geometric limitations, as with the conventional manufacturing processes. In traditional manufacturing processes, there is a direct connection between complexity and manufacturing costs (Wohlers & Caffrey, 2012). A relationship tying cost to complexity does not exist in AM. Furthermore, AM technologies allows the manufacturing of objects of any shape or branching for circulation channels or with internal cavities (Campbell et al., 2011).
- **Manufacturing benefits:** AM does not require any type of tooling, as do conventional manufacturing processes. From this feature, two advantages could be identified. First, investment in tooling for manufacturing parts is not necessary (Lyons, 2014). Second, there are no manufacturing geometric constraints arising from the use of tools, such as collision of pieces during machining or draft angles during part injection (Lyons, 2014). In addition, AM enables tools or pieces with 100% density (in the case of metal technology). These objects have no residual porosity generating excellent mechanical properties, unlike conventional powder metallurgical processes (Hopekinson, 2006).
- **Material benefits:** AM permits maximum saving of material. The material is selectively added and not subtracted from a block. For some applications, wastes produced from raw material, especially in the metal sector, are reduced up to 40% when additive manufacturing technologies are used instead of subtractive technologies (machining). Thomas et al. (2014) showed AM permits the reduction objects' weight by 21%. In addition, between 95% and 98% of the material used can be totally recycled (Reeves et al., 2011).
- **Time benefits:** AM enables the reduction of time required for placing custom products on the market (time-to-market). The introduction of new products is less risky than before, due to the elimination of costly production tooling and the development of prototypes (Hopekinson, 2006). This has a strong impact on the post-processing of existing products. Changes in the design can be published on the market even faster. Thomas et al. (2014) studied AM impact on small innovative enterprises and they showed that organizations could save 24 days in production time.

AM has a low production speed, therefore, it is not used for large production volumes. Therefore, AM should be considered for use where its application is an advantage and not for integral manufacturing *(Reeves et al., 2011)*. In the last case, AM may be a complement to with traditional manufacturing processes.

3. Additive manufacturing in the aerospace sector

Many large mechanical and aircraft engineering companies have incorporated or are incorporating these technologies into their daily operations. AM is used mainly for military and civil applications, accounting for approximately 12.1% of AM investment in the U.S.A *(Ford, 2014)*. For instance, Boeing uses 3D printings to produce 200 pieces that are installed into 10 different aircrafts *(Harris & Director, 2011)*. An F-18 aircraft contains more than 90 3D-printed-components such as air ducts and light pieces *(Gibson et al., 2010)*. As well, Boeing has included 32 different components for its 787 Dreamliner planes *(Freedman, 2012)*.

AM holds significant potential for driving down costs in the aerospace sector by enabling manufacturing objects which are lightweight, strong, and geometrically complex and typically produced in small quantities *(Smelov, 2014)*. Given that aerospace products are mainly manufactured using expensive raw materials such as titanium, plastic, and other lightweight materials, AM could decrease production cost by keeping material amounts used to a minimum. For instance, Airbus is assessing 90 separate cases where AM could be adopted to produce tools and pieces with less raw materials *(10% less compared to the traditional manufacturing) (Wood, 2009)*. In addition, Airbus is developing prototypes to manufacture most of its aircraft parts from ducts to turbine blades with AM technologies *(Gebhardt, 2012)*.

Cost economies could also be observed for complex geometries. Manufacturing cost increases within pieces' complexity for conventional methods. In contrast for AM technologies, there is no related complexity cost, resulting in a low cost strategy with higher added value. For instance, Turbomeca is employing AM technologies to manufacturing fuel injectors and combustion chamber turbines for helicopter engines, resulting in cost economies.

AM is also a driver to build a "greener" aircraft by reducing components' weight. A reduction of one kilogram in the weight of an aircraft could reduces carbon emissions and save $3,000 US in fuel per year *(Ford, 2014)*. For instance, GE is manufacturing 20% of its turbojet components for commercial aircraft using AM. These components are 25% lighter and as much as five times more durable than the existing model *(Zaleski, 2015)*. GE has also announced a $50-million investment to implement AM infrastructure in its factory in Alabama *(Zaleski, 2015)*. Like GE, Pratt and Whitney has produced more than a dozen pieces of its PW1500G engine which is used in the new Bombardier C-Series aircraft with AM.

Aerospace manufacturers and service providers could take advantage of AM technologies to reduce their lead-time for either new or replacement parts. Smartech Markets *(2014)* stated that lead-time for a part could by reduced by 80%, compared with conventional manufacturing methods." For instance, Kelly Manufacturing Company, the world's largest manufacturer of general aerospace instruments, has reduced their production time "for 500 housing components from three to four weeks to just three days, using AM technologies" *(Smartech Market 2014)*.

4. Additive manufacturing impacts for project management

Many large manufacturers and aerospace suppliers state that aircrafts' configuration frequently changed, generating complexity for project management. In particular, this complexity could vary in function in either customer's requirements or internal/external factors. Project managers should navigate beyond this complexity to avoid any delayed delivery, over budget or quality problems. Furthermore, aerospace organizations operate in a highly reactive environment not favourable to supporting strategic planning. Thus, these companies sometimes fail to improve their product, to manage their research and development initiatives and their supplier's coordination.

4.1. Project managent in the aerospace industry

Actual characteristics and needs trigger the complexity for aerospace projects. First, project managers should focus on the intrinsic characteristics of aerospace products: i) the time required for technology maturity *(between 10 to 20 years)*, ii) the time required for development *(between 5 to 7 years)*, resulting in difficulties to be more agile and obtain get investments and human resources, ii) the time required for production *(between 15 to 20 years)* and the lifetime of its product *(between 30 to 50 years)*. Second, organizations are exposed to increasing pressures from emerging countries which are, at the same time, buyers and competitors such as Brazil, Russia, China. Therefore, project management should adopt innovative practices to develop better products with less ressources. Third, they must invest an important amount of money to design their products in function of market needs and capacities. Fourth, several problems are related to the actual supply chain management which result in increasing costs. This industry must manage different providers *(see* **Figure 2***)*, different aircraft pieces and deal with the variability of pieces and nomenclature. Airbus, for instance, requires more than 100,000 wires for its A380 aircraft. Finally, with the pressure to increase the pace of production, aeronautical organizations should be capable of identifying needs more quickly based on the establishment of a collaborative relationship with their suppliers *(ranks 1 and 2)*. This collaboration permits to engage providers into the design and production from the first steps and encourage them to respect the levels of quality and cost. These characteristics show the importance of implementing an effective document management and configuration system for tracking the progress of each piece from conception and production to its final disposal *(modifications, repairs, new approvals, etc.)*.

Given this complexity, project managers should focus on two main approaches to conduct aerospace projects, namely product lifecycle management *(PLM)* and supply chain management *(SCM)*. The PLM approach enables to better control product development complexity while SCM permits a better monitoring of suppliers.

4.1.1. PLM and AM

PLM, much more than a technology solution, is a strategy that contributes to sharing product data within the organization and throughout its value chain. The PLM goal is to effectively and efficiently innovate, manage products and their related services from upstream to downstream of their lifecycle *(see topside* **Figure 3***)*, and finally, optimize production processes. PLM also facilitates the continuous involvement and communication of internal and external stakeholders. The aerospace industry, by investing in PLM, seeks to master for mastering the full aircraft lifecycle, improving information and decision traceability, facilitating information communication among stakeholders and developing an optimal process flow.

AM could strengthen PLM competencies by enabling advances to improve aircraft performance, such as innovation capacity, frequency and time-to-market, quality assurance and development costs and materials control. As shown in **Figure 3**, AM could be used for rapid prototyping, rapid manufacturing and rapid tooling:

Rapid prototyping enables the improvement of mainly two aircraft lifecycle phases, pre-feasibility/feasibility and design. In this case, AM accelerates product development cycles from its design. In addition, 3D printers could be a way of accelerating time-to-market, as prototypes can be launched in a short time to assess its performance or customers' satisfaction.

Rapid manufacturing could be adopted for three main phases: part and system production, assembly and maintenance, repairing and overhaul MRO. AM has the potential to reduce the costs of storing, moving, and distributing raw materials, mid-process parts, and end-usable parts. The ability to produce parts on demand without the need for tooling and setup could decrease production and MRO cycle times, as well as their related cost.

Rapid tooling could be implemented for three phases, namely aircraft assembly, MRO and final disposal. AM enables building tools when they are required. This could create bring several benefits for MRO and final disposal where service suppliers manage several types of aircrafts requiring different type of tools for disassembling, repairing and assembling aircraft systems, parts or pieces.

AM greatly changes the PLM paradigm since aerospace organizations could focus on designing products with higher performance or functionality, without considering assembly or manufactory constraints. Design for Assembly and Design for manufacturing methodologies aim to making products easier to manufacture and assemble based on the characteristics of current manufacturing methods. However these characteristics no longer apply when taking into account AM capabilities. Furthermore, piece design is improved with AM since aerospace professionals can exchange their vision for the proposed solution into an easy, common and visual language, accelerating analysis time and a decision-making. A design paradigm shift is needed in order to "bring designers and manufacturers to stop thinking in terms of limitations, but to think in terms of possibilities" *(Rosenberg, 2008)*.

Finally, aircraft product cycles are characterized by long periods of time for technology maturity *(between 10 to 20 years)*, for aircraft development *(between 5 to 7 years)*, for aircraft production *(between 15 to 20 months)* and for MRO aircraft *(between 2 days to 2 months)*. For commercial planes whose average life expectancy is almost 30 to 40 years, circumventing the need to maintain and replace old tooling is a notable inventory cost advantage for manufacturers. Airbus believes that AM holds the potential to keep the turnaround for test or replacement parts as low as two weeks. These parts can be rapidly shipped to and installed in a broken-down plane to help get the plane back into the air and making money for the airline.

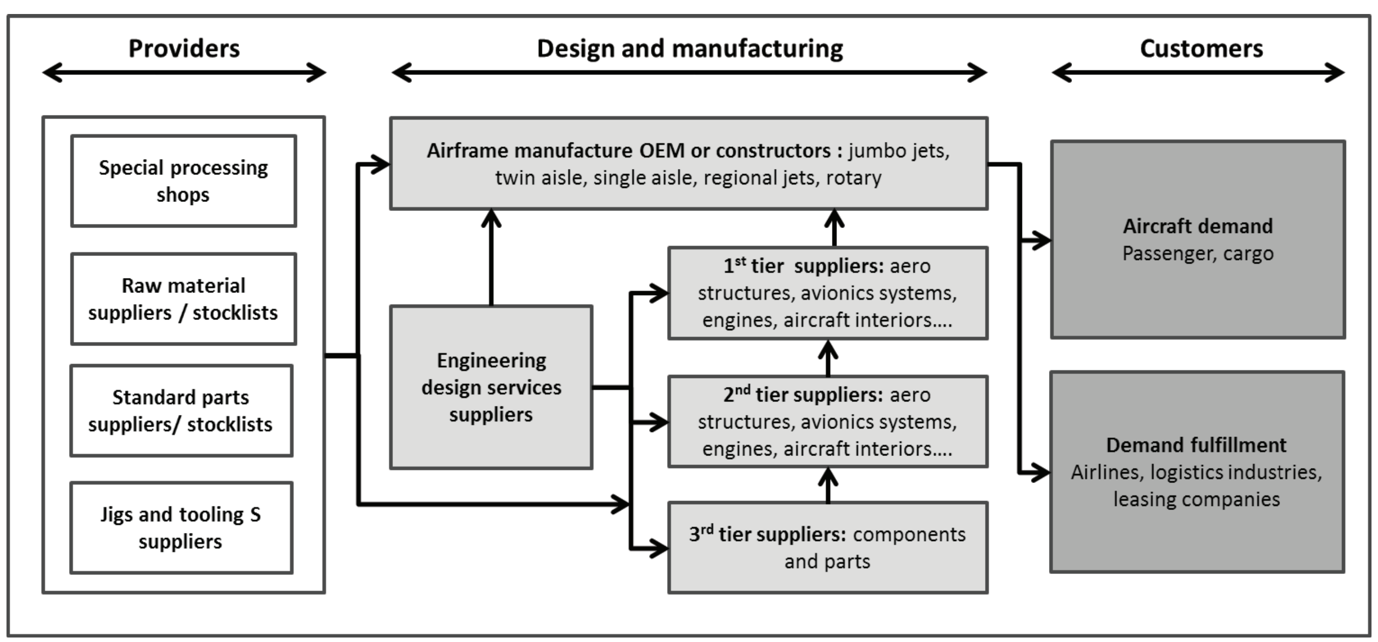

FIGURE 2. *Aerospace industry (from Romero et Rodrigues-Viera, 2013)*

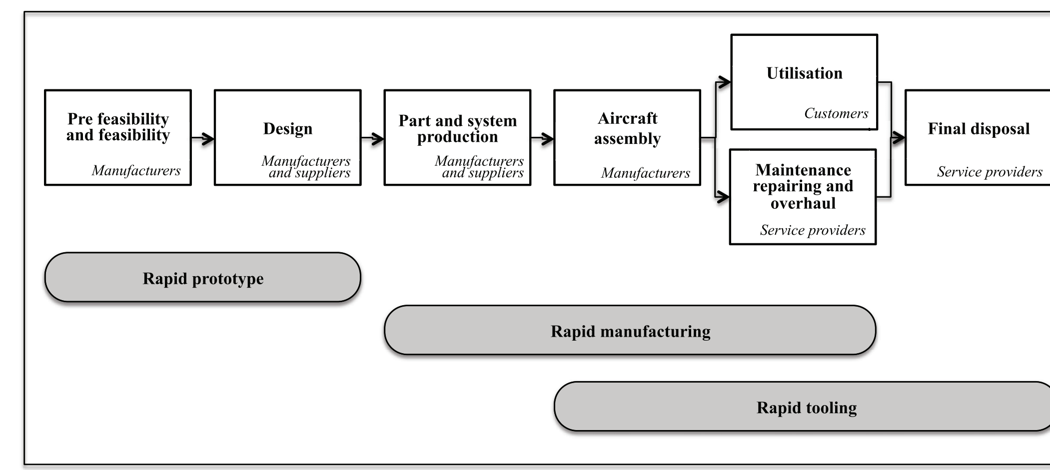

FIGURE 3. *Aircraft product lifecycle and AM applications*

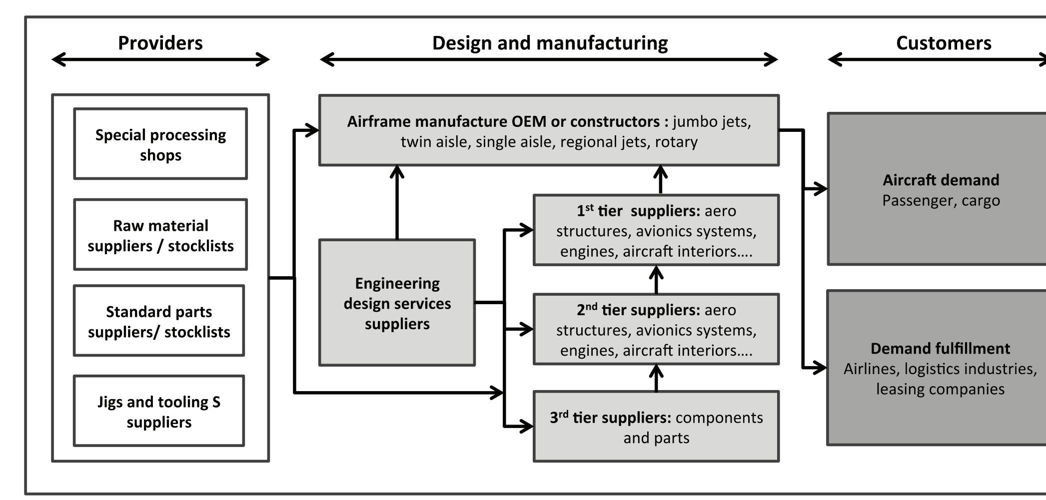

FIGURE 4. *Aircraft development and production actors (adapted from Autodesk, 2009)*

4.1.2. SCM and AM

Constructors and service providers execute aircraft production and its maintenance into extend supply chain frames, which result in increasing costs. The aerospace industry must manage different providers *(see* **Figure 4***)*, different aircraft pieces and deal with the variability of pieces and nomenclature.

AM could support SCM competencies by decreasing supply chain complexity. AM applications made supply chains more elastic, bringing manufacturing closer to the assembly, utilisation and MRO location. Following this approach, there will be fewer requirements for parts and components transportation, which alter the production and MRO flow and will almost make logistics costs disappear. AM enables industrial relocation with important issues such as production de-regionalization for parts, economies for import and export customs and environmental footprint reduction. Indeed, an aircraft integrator would not need to bring all the pieces from remote countries *(such as Airbus which transports aircraft pieces from Spain, Germany, Portugal and England to France)*; they can be manufactured onsite *(in Toulouse, France)*.

AM enables production and MRO without inventory, which implies a supply chain which is more efficient and less risky *(Khajavi et al., 2014)*. For instance, MRO providers could have minimum inventory level for each piece since they could manufacture them if required, thus enabling the reduction for the need of maintaining safety inventory. In this case, organizations do not need to keep in stock high-cost and long-lead parts such as gear rotors because they can print them when needed. Therefore, management of spare parts inventory should require reorganization. Aircraft spare parts demand pattern follows a 20/80 Pareto curve: 80% of the parts are needed frequently; but they only account for 20% of the supply chain expenditure *(Liu et al., 2014)*. In this case, two different approaches to integrate AM technologies could be adopted, namely centralized and distributed supply chain *(Holmstrom et al., 2010)*. The centralized technology is more suitable for parts with low average demand; relatively high demand fluctuation and longer manufacturing lead-time *(20% of the parts needed)*. The distributed one is suitable for parts with a high, average demand or very stable demand and short manufacturing lead-time *(80% of the parts demanded)*.

AM applications could also trigger lean and agile practices in the aerospace supply chain. AM enables a greater production flexibility, which is achieved by reduction of time of new production launching and inventory, efficient capacity utilization, which is provided through labour costs reduction, delivery of materials calculation, depending on the needs, and special arrangement of production facilities.

5. Conclusions

Is AM a new industrial revolution? This paper has showed that aerospace organizations are rethinking their business model by adopting AM technologies. AM changes aerospace project management by eliminating manufacturing and assembling limits, by improving product design and by reducing lead-time for aircraft development, production and MRO. Therefore, the aerospace industry could become more agile and "lean". AM enables the elimination of waste in tooling, materials, labour and methods of production and reduces time to improve efficiency throughout the aerospace supply chain and aircraft lifecycle.

Even with the above improvements, there are limitations that make AM technologies not yet widely adopted in the aerospace sector. The current drawbacks are slow print speed, limiting AM use for mass production, technology costs, material quality problems and reliability and reproducibility limits. Furthermore, SCM and PLM aerospace actors should integrate all together AM capacities together in order to support 3D manufacturing flow. The AM process is well-known, but it should now overcome some manufacturing constraints and explore new forms for 3D design. Such limitations are certainly surmountable, and constitute challenges for research, technological development and innovation.

authors

Alejandro Romero is a professor at School of Management (ESG) from Université du Québec à Montréal (UQAM) and associate researcher at the research chair on project management and at research chair on management of aeronautical projects. He holds Information Technology Engineering Degree (Universidad Anahuac, Mexico), M. Sc. and Ph.D. in Technology Management (Ecole Polytechnique de Montréal, Canada). In the past 10 years, he has participated as a consultant in several technology implementation projects for different industries (healthcare, government, energy, pharmaceutical, manufacturing, retail, etc.) in Latin America (Mexico, Colombia and Venezuela) and in North America. His research interests are: adoption and diffusion of technology innovation, technology management, organizational transformation and healthcare quality. He has published several articles within technology and project management field

Darli Rodrigues Vieira Ph.D., is a professor in Project Management at the University of Quebec in Trois-Rivières (UQTR). Holds the research chair in Management of Aeronautical Projects. His current research focuses on project management, product development, logistics chain management, strategy and management of operations, and management of MRO (Maintenance, Repair & Overhaul).

references

Autodesk *(2009)*. Digital prototyping for the Aerospace Supply Chain, white paper.

Berman, B. *(2012)*. 3-D printing: The new industrial revolution. Business horizons, 55*(2)*, 155-162.

Bibb, R., Bocca, A., Sugar, A., & Evans, P. *(2015)*. Surgical applications. Medical Modelling: The Application of Advanced Design and Rapid Prototyping Techniques in Medicine, 137.

Campbell, R. I., De Beer, D. J., & Pei, E. *(2011)*. Additive manufacturing in South Africa: building on the foundations. Rapid Prototyping Journal, 17*(2)*, 156-162.

Fogliatto, F. *(2010)*. Mass Customization: Engineering and Managing Global Operations. Springer.

Ford, S. L. *(2014)*. Additive Manufacturing Technology: Potential Implications for US Manufacturing Competitiveness. Journal of International Commerce and Economics, 1-35.

Franke, M., & John, F. *(2011)*. What comes next after recession? – Airline industry scenarios and potential end games. Journal of Air Transport Management, 17*(1)*, 19-26.

Freedman, D. H. *(2012)*. Layer by layer. Technology Review, 115*(1)*, 50-53.

Gebhardt, A. *(2012)*. Understanding Additive Manufacturing: Rapid Prototyping, Rapid Tooling, Rapid Manufacturing. Hanser Gardner Publications.

Gibson, I., Rosen, D. W., & Stucker, B. *(2010)*. Additive manufacturing technologies. Rapid prototyping to direct digital manufacturing. New York, London: Springer.

Grimm, T. *(2004)*. Users' guide to rapid prototyping. Dearborn, MI: Society of Manufacturing Engineers.

Hague, R., Campbell, I., & Dickens, P. *(2003)*. Implications on design of rapid manufacturing. Journal of Mechanical Engineering Science, 217*(1)*, 25-30.

Harris, I. D., & Director, A. M. C. *(2011)*. Development and Implementation of Metals Additive Manufacturing. DOT International, New Orleans.

Holmstrom, J., Partanen, J., Tuomi, J., & Walter, M. *(2010)*. Rapid manufacturing in the spare parts supply chain: Alternative approaches to capacity deployment, Journal of Manufacturing Technology Management, 21*(6)*, 687–697.

Hopkinson, N., Hague, R. J. M., & Dickens, P. M. *(2006)*. Rapid manufacturing. An industrial revolution for the digital age. Chichester England, John Wiley.

Khajavi, H., Partanen, J., & Holmstrom, J. *(2014)*. Additive manufacturing in the spare parts supply chain. Computers in Industry, 65, 50-63.

Liu P., Huang S. H., Mokasdar A., Zhou H., & Hou L. *(2014)*. The impact of additive manufacturing in the aircraft spare parts supply chain: supply chain operation reference *(SCOR)* model based analysis, Production Planning & Control: The Management of Operations, 25*(13-14)*, 1169-1181.

Lyons, B. *(2014)*. Additive manufacturing in aerospace: Examples and research outlook. The Bridge, 44*(3)*, 13-19.

McKinsey *(2013)*. Industrie 2.0, Jouer la rupture pour une Renaissance de l'industrie française. Consulted at: http://www.innovation.rhone-alpes.cci.fr/

Noble, J., Walczak, K., & Dornfeld, D. *(2014)*. Rapid Tooling Injection Molded Prototypes: A Case Study in Artificial Photosynthesis Technology. Procedia CIRP, 14, 251-256.

Nyanga, L., Van Der Merwe, A.F., Matope, S., & Tlale, N. *(2012)*. E-Manufacturing: A Framework for Increasing Manufacturing Resource Utilisation. CIE42 Proceedings, 16-18.

Reeves, P., Tuck, C., & Hague, R. *(2011)*. Additive manufacturing for mass customization. In Mass Customization. Springer London, 275-289.

Rifkin, J. *(2012)*. The third industrial revolution: How the Internet, green electricity, and 3-d printing are ushering in a sustainable era of distributed capitalism. World Financial Review, 1.

Romero, A., & Rodrigues, D. *(2013)*. Traceability as a key competency for the aeronautical industry: An exploratory study. International Journal of Business and Management Studies, 2*(2)*, 443–457.

Schindler, C. *(2010)*. Product life cycle management: A collaborative tool for defense acquisitions *(Master's thesis)*. Monterey CA: Naval Postgraduate School.

Smartech Markets *(2014)*. Additive manufacturing in aerospace: Strategic implications. White paper. Consulted at: http://www.smartechpublishing.com

Smelov, V. G., Kokareva, V. V., & Malykhin, A. N. *(2014)*. Lean Organization of Additive Manufacturing of Aircraft Purpose Products. International Journal of Engineering & Technology, 6*(5)*.

Romero. A., & Rodrigues, D. *(2013)*. Traceability as a key competency for the aeronautical industry: An exploratory study, International Journal of Business and Management Studies, 2*(2)*, 443–457.

Thomas, D. S., & Gilbert, S. W. *(2014)*. Costs and Cost Effectiveness of Additive Manufacturing. U.S. Department of Commerce. Consulted at: http://nvlpubs.nist.gov/nistpubs/Special Publications/NIST.SP.11 76.pdf

Tiwari, M., & Harding, J. A. *(2011)*. Evolutionary Computing in Advanced Manufacturing. John Wiley & Sons and Scrivener Publishing.

Witik, R. A., Gaille, F., Teuscher, R., Ringwald, H., Michaud, V., & Månson, J. A. E. *(2012)*. Economic and environmental assessment of alternative production methods for composite aircraft components. Journal of Cleaner Production, 29, 91-102.

Wohlers, T., & Caffrey, T. *(2013)*. Additive manufacturing: going mainstream. Manufacturing Eng, 151*(6)*, 67-73.

Wood, D. *(2009)*. Additive Layer manufacturing at Airbus–Reality check or view into the future? TCT Magazine, 17*(3)*, 23-27.

Zaleski *(2015)*. GE's bestselling jet engine makes 3-D printing a core component. Fortune. Consulted at: http://fortune.com/2015/03/05/ge-engine-3d-printing/