Analysis of the opportunities of industry 4.0 in the aeronautical sector

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ABSTRACT

Introduced for the first time in Germany in 2011, Industry 4.0 is a concept based on the fusion between the digital and physical worlds, offering potential advantages in terms of flexibility, productivity, decreased expenses and improvement in quality. At the same time, the aeronautics industry, which has been making significant commercial progress in recent years, is perceived as a sector structured by innumerable regulations with strong hierarchization of sub-contractors at all levels. This hierarchization influences the economic dependence of these actors on their instructors, and these differences and difficulties represent an obstacle to the successful integration of digitalization in the aeronautical chain of production. This article presents an overview of the challenges of Industry 4.0 alongside those of the aeronautical sector, proposing a critical analysis of the opportunities offered by the former to the latter. Our work discusses the Fourth Industrial Revolution, a disruption based on the most important innovations of recent years, which will have a huge impact on the world we know today. It sheds light on the structure of the aeronautical sector and the importance of the "ClockSpeed" factor, due to the amount of technologies with different regeneration rates on board aircrafts. Finally, our analysis highlights the limits of Industry 4.0 and why it is relevant to apply it to aeronautics.

Keywords: Industry 4.0, Aeronautics, Clockspeed factor.

1. INTRODUCTION

Introduced in Germany in 2011 during the Hanover Fair [1], [2], today Industry 4.0 is a primary industrial concern in France, Europe and Worldwide. Known under different terms around the world, Industry 4.0 seems to assert itself as a way to share connectivity with the entirety of the operations within a factory.

If the myths and expectations of what is commonly known as the Fourth Industrial Revolution are real, does this justify its implementation to aeronautics? Is the 4.0 model really adapted to this rapidly growing sector? Or should we be cautious not to move too quickly with this model without first adapting its function to the specificities and challenges of the sector?

In order to fully grasp the subject, this scientific analysis is split into three sections, leading us to shed light on the following question: What opportunities can Industry 4.0 bring to the aeronautical sector?

Firstly, we will define a perimeter for the concept of Industry 4.0. We will then seek to understand the characteristics of the aeronautical sector and its future challenges. Based on these analyses, we will highlight the opportunities and limits of this industrial revolution in aeronautics.

2. INDUSTRY 4.0

The Fourth Industrial Revolution

To each century its revolution: the industrial sector, boosted by new discoveries and major innovations, has evolved and mutated continuously since the 18th century. First came steam engines, then mass production using electricity and assembly lines, and finally automation with the introduction of electronics and computers. We are now entering a fourth revolution influenced by the internet, Business Intelligence, remote connection and Cloud Computing [3].

Baptized "Industry 4.0" by the Germans during its presentation at the Hanover Fair in 2011 [2], [4] the concept is also known as "Factory of the Future" in France and "Smart Industry" in the United States. Built as an extension to the digital revolution and the use of complicated and ever-growing data, Industry 4.0 is the interconnection and cooperation of virtual and physical production systems with the product itself. Long term, this offers flexibility and the possibility to personalize a product or service for the consumer.

Influenced by digitalization, a new industrial revolution in now underway, and the major technological innovations of recent years are on the brink of provoking great changes in the industry, an unprecedented disruption for the years to come [5], [6].

Main technological transformations

A number of different organizations have referenced the driving technologies of the Fourth Industrial Revolution. It is therefore important to list the main 9 technologies of Industry 4.0 [7]:

- **Big Data and analytics**: techniques that are ready to be collected using data pulled from various sources. The use of this data in the context of Industry 4.0 allows decision-making in real time.
- **Autonomous robots**: robots are becoming increasingly autonomous, flexible, communicative and cooperative [8]. By interacting with their environment and products and as they learn from humans, they will provide the industry with a broader range of capabilities.
- **Simulation**: by using data in real time, simulation allows us to virtually model our physical environment with machines, products and even humans [7]. This allows operators to test and optimize processes and operations, decrease machine adjustment time and improve quality.
- **Horizontal and vertical system integration**: today, businesses, suppliers and consumers are rarely connected, and the same goes for different departments within one company. With Industry 4.0, the exchange of data develops cohesion (regarding products and production) between these different partners.
- **Industrial internet of things**: new technologies have allowed us to provide physical objects with real communication potential [9], [10]. When given to machines, this new-found communication allows them to interact with each other or directly with the products, but also to decentralize decision making, generating responses in real time [7].
- **Cyber security**: In order to ensure the development of Industry 4.0 and the interconnection of systems, it is essential to secure a large amount of communication channels without negatively impacting network performance [4].
- **Cloud computing**: communication and exchange of information have been made easy thanks to Cloud technology, which provides access to network connection. As performance has become increasingly impressive and reaction time gone down to only a few milliseconds, production machinery data and function will be available anywhere and from any terminal, all thanks to the Cloud [7].
- **Additive manufacturing**: already present in the industry, 3D printing is primarily used for individual prototyping. As this method progresses in terms of flexibility, speed and printing costs, it will be used to produce small amounts of personalized, complex and light products. Once decentralized, this system will reduce the amount of transportation of finished and in-process products by manufacturing close to the demand [5], [6].
- **Augmented Reality**: data availability in an integrated system provides users with new ways of accessing information. Today, we see a surge in the use of virtual and augmented reality technologies, such as the glasses used in manufacturing procedures, which allow wearers to visualize an environment by superimposing real and simulated objects, improving creation, manufacture and reparation procedures [11].

Impact and social challenges

The technologies of Industry 4.0 are currently available in their original version both in terms of hardware and software. But facing their implementation is the question of the new social model brought into factories by Industry 4.0 [12], [13].

More than an industrial project, Industry is a social project requiring the evolution of skills, the creation of new jobs and the development of training to prepare for the careers of tomorrow. Both American and French studies have confirmed that 65% of today's children will have careers that do not yet exist [14]. What we can be sure of, however, is that they will be required to have transversal skills ranging from mechanics to information technology, as well as good interpersonal skills.

Another major challenge for Industry 4.0 is the industrial decentralization of countries that have relocated en masse in recent decades. Thanks to new technological advances allowing Western countries to manufacture personalized products on demand, setting them apart from the mass production of emerging countries, the former will be best positioned to save jobs on their territories [13]. Collaboration is also at the heart of Industry 4.0 as it is directly connected to human reflection [6] and to the importance of understanding how greater cooperation is vital to working together more and better.

This global vision, shared by many in these sectors, is necessary today in the implementation and support of the complex initiative that is Industry 4.0.

3. THE AERONAUTICAL INDUSTRY

The aeronautical sector is characterized by its economic market, the organization of its Supply chain and the interaction with the different parties involved. Any changes made in this ecosystem require preliminary analysis to judge relevance and potential impact.

Economics of the aeronautical industry

The aeronautical industry generates low volumes targeted at a restricted and specific clientele (airlines, private aircraft buyers, states…). Commercial aircrafts, which represent without a doubt the majority of the sector's production, are sold only by a few hundred each year.

At the root of the weak automation in this sector are low production volumes and complex manufacturing, resulting in a need for significant labor throughout the production cycle [15], [16]. As labor accumulates throughout the process, production costs can reach up to 80% of total costs. It is interesting to note that the production program of a commercial aircraft is profitable to its manufacturer over an average of 10 years. This period, therefore, means a significant return on investment time and moreover, low resources for productive investments or R&D.

In this context, 4 challenges seem to present themselves to the parties involved in the aeronautical sector [17]:

- **Reduce production costs**, all the while continuing to meet specific client needs to stay ahead of the competition.
- **Increase the pace of production** to meet the growing demands of airlines.
- **Manage the increasing complexity** of programs due to the increase in number of different integrated systems and the introduction of new elements (composite materials, additive manufacturing…) that also impact production costs.
- **Manufacture reliable, quality products** to achieve Zero Defect, minimize risks and meet the standards enforced by controllers represented by the EASA (European

Aviation Safety Agency) or its American counterpart, the FAA (Federal Aviation Administration).

Supply Chain integration in aeronautics

The last two decades have been marked by an upward trend in demand in the aeronautics sector. The main ordering parties (OEMs: Original Equipment Manufacturer, such as Airbus, Boeing…) have struggled to keep the pace, resulting in numerous delayed deliveries and heavy financial penalties. To minimize the impact of increasing demand on the market, the OEMs imposed a vertical reorganization of the sector, based on risk-sharing between all parties, involving subcontractors as soon as projects are defined [18]. Building on their experience and supremacy in the sector, these OEMs have gradually refocused on their core business: defining aircraft architecture and major systems, integration, assembly and commercialization, leaving subsystem production phases to lower-ranking subcontractors [19]. Externalizing the industrial load onto their equipment manufacturers shares part of the technological and financial risks of aeronautical programs with first-tier partners (Risk-Sharing Partnerships program adopted by Airbus and Boeing, which allowed Airbus, for example, to secure 3.1 billion euros on the A380 program, around 25% of the total budget [20]. As a result, only companies with a global status that are capable of covering R&D costs and achieving economy of scale are able to work directly with aircraft manufacturers [19], [20].

The aeronautical Supply Chain is therefore organized as a vertical network, around a pivotal firm (the hub firm) and is composed of companies through which mobilized resources are constituted, identified and allocated to carry out a productive project. The hub firm is the first-tier subcontractor to whom the OEM delegates many technical responsibilities, but also that of the coordination of lower rank subcontractors [21].

The aeronautical supply chain pyramid can be divided into four levels [22]:

- <u>Original Equipment Manufacturers</u> deliver an aircraft complete with all systems. They are responsible for its qualification and certification.
- <u>System manufacturers or suppliers</u> (First-tier subcontractors) design or participate in the production of complete subsets for which they are responsible (engines, platforms, landing gear, on-board electronic systems…). They invest in industrialization as well as R&D. The economic-industrial risk incurred at the launch of a new project is shared with the ordering party [23].
- <u>Specialized subcontractors</u> (Second-tier subcontractors) are specialized in a technical field (mechanics, electronics, hydraulics, electric…). This allows them to produce non-divisible quasi-finite components according to quality standards and certifications.
- <u>Capacity or production subcontractors</u> (Third and fourth-level subcontractors) are generally medium to small sized companies selected according to their financial attractiveness. They provide "simple" components with clear functions and handle various specialized manufacturing technologies. This market is very competitive, and even more so since the rise of the use of copied, reproduced parts in the aerospace industry (PMA for Parts Manufacturer Approval) and approved by the FAA (Federal Aviation Administration).

The equipment manufacturer or parts supplier status is not static and depends on each program and on the Original Equipment Manufacturer. One can be equipment manufacturer at Airbus and parts supplier for Bombardier, or equipment manufacturer for the A380 program at Airbus and parts supplier for the A340 program for the same manufacturer [22].

Activity dependence and economic gaps

The aeronautical industry's contribution is similar in all Western countries. It positively impacts trade balance and represents an important part of GDP (Gross Domestic Product), making this sector a strategic one economically-speaking, as we can see for the year 2016 using Germany, the United-States and France as examples.

Table 1. Position of the aeronautical industry in Germany, USA and France in 2016 [17].

Country	Turnover	Aeronautical industry contribution
Germany	37,5bn €	220 companies
USA	N/A	Highest export rate in the country. 90,5bn $ of trade balance.
France	60,4bn € (+4,5%)	Highest rate of contribution towards foreign trade in France (2016)

However, these performances conceal differences in economic resources between the different players along the aeronautical Supply Chain, as well as tensions regarding power balance between first-tier players and those below. 70% of companies in the industry run with under 250 employees [16] and are usually subcontractors with production or capacity capabilities and a turnover of approximately 20 Million Euros, a far cry from that of the (fewer) first-tier players. These smaller players are also largely economically dependent on this sector, with orders making up to 80% of their total revenue. One in four companies are totally dependent on the industry [24]; small subcontractors struggle to diversify and open up to export due to lack of resources. Relationships between original equipment manufacturers and subcontractors also suffer from the difficulty in making the former accept the latter's industrial property rights as a result of R&D work carried out by subcontractors [19].

All of these difficulties added to the economic gap between different players in the sector halt the innovation and digitalization of production methods, interfering with the implementation of large industrial plans and the digitalization of production systems at every stage of a project. Still today, discussions between OEMs and subcontractors are more focused on costs and prices. This encourages subcontractors to develop production in countries at a lower cost, rather than focusing on technique and the development of digitalization in production [24].

ClockSpeed factor in the aeronautical industry

The aeronautical industry differs from other industries by the average life span of its products. An airliner has an average life span of 30 years. Consequently, manufacturers must produce aircrafts adapted to the evolution of the market while guaranteeing a constant standard of service and security throughout [25], a difficult task considering the diversity of subsystem components and technologies this requires. An aircraft is made up of different modules with varying regeneration rates, known as Clockspeed [26], which defines the regeneration frequency (significant evolution, shortage) of a certain technology. In aeronautics, this factor can vary significantly depending on whether the subject is engine technology or on-board electronics. For example, the technological evolution of engines is very slow (low ClockSpeed factor), whereas semiconductor technologies are known to have a short life spans (fast ClockSpeed factor) [27]. This desynchronization between technologies significantly slows the overall increase in rate of production, limiting the possibility of implementing digitalization programs throughout the aeronautical chain of production.

4. INDUSTRY 4.0 IN AERONAUTICS

Several industrial sectors are working to deploy digitalization and connected robotics to different stages of the production cycle. Nonetheless, not all 4.0 projects reach the final implementation stage. This is mainly explained by a reluctance to change and the struggle to understand the reasons for applying this new technology within a company [28]. The aeronautical industry is no exception.

Review of the current state of the subject

The aeronautical industry has undergone several changes in recent years, including the development of collaborative platforms shared by the different parties involved along the Supply Chain. The advantages of these platforms in terms of integration, cost reduction and competitiveness have encouraged their development [29]. BoostAerospace, a flagship project that illustrates this mobilization of resources was introduced by Airbus and its primary first-tier suppliers. The project is built on the sharing of three portals: Digital Supply Chain, Sharepoint on shared projects and sharing of PLM (Product Life Management) data between 1500 industrial and 11,000 identified users.

Aerospace manufacturers are heavily involved in other pillars of Industry 4.0, investing in 3D technology and augmented reality. These technologies participate in the overall reduction in aircraft weight by introducing new materials such as titanium [7]. Airbus, alongside Accenture, won “Best Mobile Service or Solution for Enterprise” (Mobile World Congress, Barcelona, 2017) for its wearable technology based on smart glasses, which allow operators to access all the data needed to mark exact seating positions on an aircraft by accessing a database on a private Cloud [30]. In 2018, STELIA presented a 1 sq. meter fuselage demonstrator with 3D technology [31] a small 3D printing revolution on a surface of this scale.

Fixed base robotics, as used in different large-scale production industries, has its limits when it comes to aeronautics. The low volume of production and high number of different tasks to carry out make this an inefficient option in this industry. This pushed Airbus, for example, to work with JRL (Joint Robotics Laboratory) on a new generation of robots with high mobility and the ability to move from one level to the next on the assembly line [32].

Basic fastening tasks during aircraft integration are a critical step for integrators. The amount of points to fasten can reach 400,000 and require over 1100 tools. At this level, the risk of human error is to be considered when carrying out these tasks. All these factors drove Airbus to work with Texas Instruments on a collection of smart tools which ensure drilling, fastening and the recording of measured data[33]. These connected tools guide the operator through a list of organized tasks and guarantee that the applied tightening torques are adapted to each placement using the correct tools.

The industrial illustrations of digitalization in aerospace show both the complexity of applying it to every level of production and the need to introduce it to meet specific problems on a case-by-case basis without impacting process rate and continuity.

Conclusions of academic research

The various examples given in the previous section show that digitalization in the aeronautical industry is only at its very beginnings. The specificities of this sector and the related production restrictions only slow down this digital integration and its globalization. Recent scientific and academic research on the subject confirms the observation: digital integration in aeronautics is complex.

Due to the significant amount of labor and level of intermediate stock required in the aeronautical sector, Airbus is currently financing research in partnership with the Polytechnic University of Madrid to study the modeling and optimization of scheduling and line balancing [34] to improve productivity. Research work at the Federico II University in Naples proposes a Digital Factory methodology to support the enhancement of an existing manufacturing cell. The study shows a 42% increase in productivity based on discreet event simulation [35]. Furthermore, the University of Nottingham has developed a new reconfigurable and adaptive production environment for the complete manufacturing of low-volume aerospace products with an accuracy better than ±0.1 mm [36].

These studies, among others, bring to light the fact that the aeronautical industry is still working on its original model of production based on the scheduling and line balancing of machines while introducing research by simulation or digital production model prototypes.

The limits of aeronautics 4.0

These past few years have witnessed numerous cyber-attacks targeting industrial systems primarily. In 2015, for example, attacks on industrial IT systems increased by 51% [37], while Healthcare, Manufacturing, Financial Services, Government Agencies and Education have been identified ad the most targeted sectors.

The strategic position of the aeronautical industry in the economy of historically leading countries in this sector (Western Europe and the USA) make it a perfect target for these types of attacks. These countries have recently found new competition in Asian manufacturers penetrating the market (China). Any destabilization of the sector would have a direct impact on the economical-political stability of the targeted country. This requires aeronautical industrialists to carry out heavy diagnostics of their IT systems and set up test and validation campaigns. All this is defined from the initial planning stages of digital transformation projects and supported by the implementation of protection systems, which modify over time in the face of constantly evolving threats [38].

The aeronautics industry is subject to many laws, standards and security regulations specific to the field. Product security during each phase of production of an aircraft is an important step requiring certification provided by competent authorities depending on each region (FF- Federal Aviation Administration for the United States and JAA- Joint Aviation Authorities for Europe). This is due to the fact that any technical failure in a finished airline product automatically causes human, economic and social impacts and consequences which are neither measurable nor acceptable [20]. Any changes in the production process means total compliance of the enforced regulations. The cumbersome nature of these regulations makes it difficult to change processes and results in a significantly challenging transition into an "all-digital" aerospace industry.

Today, the restrictions related to cyber-security and the strict regulations in the aeronautical sector are a real obstacle slowing the road toward Industry 4.0. The sector is therefore taking a gradual approach when facing its challengers by introducing new technological solutions, gradually certified on a safety and security level.

5. CONCLUSION

The review of the current state of research highlights the evolution in the industrial sector under the influence of digitalization. The 9 technological innovations (big data and analytics, autonomous robots, simulation, vertical and horizontal system integration, the industrial internet of things, cyber-security, Cloud, additive manufacturing and augmented reality) are all revolutionizing the industry as we know it, generating the need to rethink its social model. The rise of Industry 4.0 requires greater flexibility and collaboration among its players in order to develop an agile reaction to its global vision.

The aeronautical sector has its own specific characteristics and is seen as noble and demanding with a promising future. The sector is still very rarely automated due to low production volumes and is known to hierarchize its subcontractors. Although subcontractors in higher tiers are supported directly by the deciders at the top, this is very rarely the case for those in lower tiers, who are economically dependent on the sector and rarely have any investment potential, slowing down the implementation of digitalization within their own production systems. Additionally, the desynchronization between on-board technologies with Clockspeed and strict security regulations create further obstacles in the aeronautical sector, blocking the path toward total integration of digitalization all along the chain of production.

The results of our study demonstrate the multiple advantages that Industry 4.0 currently brings to the aeronautical sector, particularly in terms of productivity, flexibility and its capacity to stand out against other emerging markets. However, as it is a very specific sector, it still struggles to fully seize the opportunities of Industry 4.0. Digitalization is difficult to implement as quickly on a general level across the entire sector when compared to other sectors due to high security measures, strict regulations, varying regeneration rates between different technologies and the differences in primary concerns between OEMs and their lower-tier subcontractors. However, when the opportunities of Industry 4.0 are weighed up against its limits, it is clear that the integration of these new technologies is truly relevant. This should be done on a case-by-case basis, taking care to disassociate the needs while ensuring compliance of all regulations without impacting the rate of production in order to meet the needs of a demanding and growing market. But for this to work correctly and on a long-term basis, all those involved in the sector must work side by side, in order to evolve together at the same rate, without wasting the efforts made by one party and neglecting those made by the other due to lack of resources and support on behalf of the OEMs and their subcontractors at every level.

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