International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 772-780 www.ijaem.net ISSN: 2395-5252

Impact of Industy 4.0 on aeronautics

Om Choudhary Rtanjay Shrivastava

Submitted: 15-11-2022 Accepted: 25-11-2022

I. INTRODUCTION

At the 2011 Hannover Fair, the German government used the phrase "Industrie 4.0" to refer to a politically-envisaged, technologically-supported, and computer-based transformation of the industrial sector. In recent years, the phrase has been used to describe emerging tendencies that hint to a new revolution based on the actual interaction between industrial robots and humans, and machines. Some authors (Cozmiuc & Petrisor, 2018) have proposed that four factors—interoperability, information transparency, technical support, and decentralised decision making—are driving this fourth industrial revolution. The goal of interoperability is to create a "total automatic factory," in which as much of the production process as feasible is automated by means of a network of interconnected computers, gadgets, equipment, and robots. Digital Twins (Miller, Alvarez, & Hartman, 2018) are the intended subject of the phrase "Information transparency," which describes the creation of digital replicas of physical items and the enhancement of those replicas with data collected from real-world sensors.

This study provides a wide overview of the potential effects of the programme drivers of Industry 4.0 on aircraft maintenance. To be more precise, the best Industry 4.0 practises for aircraft maintenance are chosen and given extensive coverage. Case studies dealing with genuine events are used to highlight the benefits and unresolved concerns, and they provide more evidence for the authors' proposals. Augmented reality (AR) and additive manufacturing (AM) technologies have been the focus of interest because of their potential to aid in maintenance activities and the creation of replacement components, respectively. There is a strong interest and pull from the industry sector, and the goal is to prove that Augmented Reality and Additive Manufacturing are useful tools in aviation maintenance. However, a lot of work needs to be done to develop an appropriate regulatory framework, which is required before the widespread introduction of these technologies in the aerospace systems maintenance process. Industry 4.0 is also focusing on (Hold, Erol, Reisinger, & Sihn, 2017) to introduce two disruptive technologies: the support to operators with information which can be visualised when needed to solve problems in short times, and the substitution of humans with cyber-physical machines to perform D3 (D-cube) operations (Dull, Dirty, Dangerous). Finally, the concept of decentralised decisions (Marcon et al., 2017) proposes intelligent machines capable of making decisions in an automated manner, resolving contradictions and complex planning problems without human intervention. This shifts the role of the operator from problem solver to supervisor. From a more practical standpoint, the goals of Industry 4.0 (Peruzzini, Grandi, & Pellicciari, 2017) can be met through the following means: the widespread adoption of cutting-edge technologies like AR and VR within businesses; the use of Additive Manufacturing (AM) to cut down on production times and make way for smart structures; the distribution of software tools capable of managing massive amounts of data (the so-called Big Data problem) within businesses (Santos, 2017); the creation of software The authors believe that the principles of Industry 4.0 may be used to the aerospace industry to improve design, maintenance, and structural health while in flight.

According to the terms of the CC BY-NC-ND licence, surveillance, and flight control, to mention a few. Civil aviation necessitates logistic systems able to offer replacement parts in short durations in distant places, where difficult maintenance jobs are commonly sought from local operators (FAA, 2018). Aeronautics is a complex and demanding industry, both in terms of design and maintenance. To back up these claims about the level of scientific and industrial interest, it is worth noting that the ADVANCE European Union H2020 project (Lee, Shin, Tsourdos, & Skaf, 2018) and its subsidiary programme AIRMES are focusing on maintenance strategies for Large Passenger Aircraft (Airline Maintenance Operations implementation of an E2E Maintenance Service). To give another illustration, French, Marin-Reyes, and Benakis (2019) write on the challenge of using Additive Manufacturing in the aerospace industry. Based on what we know now thanks to the research we conducted, it appears that the industry 4.0 programme may be used to cut down on maintenance times and make use of the new possibilities offered by technologies like AM and AR. Although there is a wealth of literature on these subjects, the original idea put out here is to present a long-term-evolution of maintenance based on ideas that are likely to be implemented in factories over the next decade. Timeline of the development of the technologies discussed in this research is shown in Fig.1.

As can be seen in Fig. 1, AM and AR have come a long way to attain their current capabilities and have matured to the point where they can be used in manufacturing and aviation maintenance. Yet, the widespread use of these technologies is now hampered by regulation and certification processes involved with adoption of these technologies; however, the market can drive the government towards the formulation of relevant rules. It is possible that these innovations will have a profound effect on the aviation sector and the maintenance schedules and operations of fleets of major commercial air- aircraft, helicopters, and general aviation aeroplanes. Significant new innovations in industrial engineering manufacturing processes are endorsed by the industry 4.0 initiative. It argues for the widespread use of cutting-edge smart solutions in today's factories, such as Additive Manufacturing and Augmented Reality. The purpose of this article is to examine the potential gains from using these new technologies in aircraft maintenance, with an eye on how ideas from automated production lines may be used there. The purpose of this study is to demonstrate how AR and AM may function within this framework and to explain the benefits it may offer over more conventional approaches to maintenance (Fioriti, Vercella, & Viola, 2018). Since AM and AR seem most suited to support on-ground maintenance activities, they have received most of the focus, while the other Industry 4.0 technologies mentioned above are better suited to in-flight operations. The ability to execute failure recovery techniques and data fusion in the event of a sensor's impaired performance is made possible using Big Data handling strategies, which are beneficial for implementing networks of sensors and obtaining in-flight real-time data. Additionally, the millions of remote sensors used to monitor aircraft structural integrity may be retrieved and fused with data using analytical algorithms now being developed for the benefit of Industry 4.0. The article is organised as follows: Section 2 will elaborate on the fundamental ideas behind AM, AR, and the Industry 4.0 initiative. Aeronautical maintenance and its incorporation into industry 4.0 is the focus of Section 3, while AR and AM applications are covered in detail in Section 4.

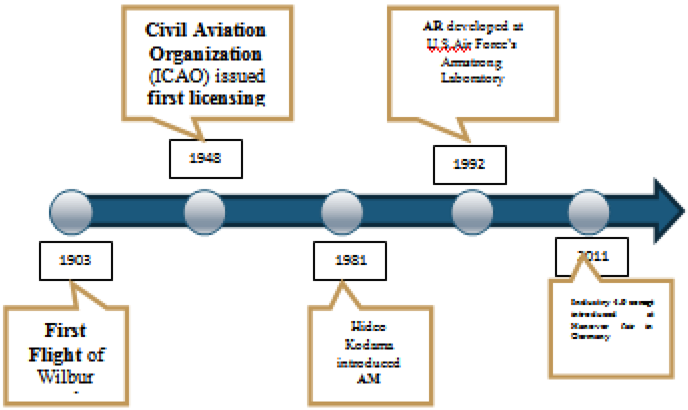

Fig.1 Technologies timeline

II. AUGMENTED REALITY AND ADDITIVE MANUFACTURING

2.1 Additive Manufacturing

When compared to conventional chip removal methods like the lathe or milling machine, additive manufacturing may be thought of as the inverse. Over the past few years, numerous AM methods have been developed and implemented (Gibson, Rosen, & Stucker, 2010). One way to categorise these methods is according to whether the raw material is a liquid (as in Fused Deposition Modeling (FDM) or Stereolithography (SLA)) or discrete particles (as in Selective Laser Sintering (SLS) or Electron Beam Melting (EBM)) or solid sheets (as in Laminated Object Modeling (LOM)). Deposition of a plastic filament along a predetermined route makes FDM a low-cost method for creating complex shapes. As the ABS or PLA wires are melted in a nozzle, the nozzle moves relatively in the 3D plane with regard to a construction table. After being extruded through the nozzle, the plastic hardens, allowing for the creation of a three-dimensional solid sculpture. SLA uses a photosensitive liquid resin that solidifies upon being struck by a laser beam; similarly, a solid form may be generated by polymerizing the liquid along a route, layer by layer. Non-structural components may be obtained with the use of both methods. However, SLS and EBM are required when high strength materials are needed since they are based on the melting of metallic particles. Aluminium, steel, and titanium powders are the building blocks for 3D printed metal objects that have the same structural qualities as machined or cast metals (Dutta & Froes, 2017). Last but not least, LOM relies on the stacking of single layers of adhesive-coated paper, plastic, or laminates to form a 3D object. However, the utmost flexibility of shaping makes AM intriguing since complicated forms may be created. Complex buildings built from a series of trusses of varying thicknesses (Lattice) (Savio, Meneghello, & Concheri, 2017) found that by increasing the volume by a factor of thousands, they were able to obtain a high level of structural efficiency by having all the material exhibit the the same level of stress. Trabecular structures are found in the skeletons of animals, including humans, as well as in the wings of some birds.

Leaves and branches of trees are often used as examples of naturally occurring efficient structures (Rosen, 2007). AM offers a variety of geometrical frameworks to efficiently form bodies. Lightening a product's load can help save resources, save wasted energy during transport, and ultimately lower pollution levels (Raymer, 1992). The three most popular topics in this field are homogenization (Vigliotti & Pasini, 2012), lattice structures, and topological optimization (Bendsoe & Sigmund, 2004). Topological optimization entails establishing a bounding volume within which a component can expand without compromising its integrity, determining the locations at which the component will be subject to constraints, determining the locations at which the structure will be subject to Forces, and, finally, designating the locations within the bounding volume within which no material may be deposited. In the example shown in Fig. 2, four constraint points and one force point have been chosen, and the component is optimised by being grown in such a way that its compliance (the product of the internal forces by its displacement) is minimised at each iteration. This is how highly efficient parts may be obtained.

A lattice structure is any component in which a dense substance has been replaced by a large number of elementary cells that are repeated in all three axes. The tetrahedral, cubic, and hexagonal cell forms are the most extensively used because to their high void-to-dense ratio. One of the outstanding issues in this area is the question of how to do FEM evaluations of lattice systems quickly. Since the beams that make up the cell's armour are so narrow, the smallest solid components that may mesh the component are cylinders of the same width.

A large number of elements are discovered in areas where studies are performedbecause of the large body dimension relative to this diameter. As a result, extensive processing time and high-powered equipment requirements are necessary for analysis. By calculating an analogous isotropic material that can be applied to a totally dense portion with the same geometry as the lattice one, the homogenization approach is able to solve this issue. It is feasible to analyse complicated structures in a fraction of the time and with far less processing effort with this method.

1.2. Augmented Reality

Azuma's fundamental study (Azuma, 1997) on augmented reality marked the beginning of a mature technology. The term "augmented reality" (AR) refers to a type of computer graphics in which simulated symbols are added to a live video feed of the real environment. It's a step forward for VR in which users don head-mounted displays or enter fully immersive CAVE environments. Unlike augmented reality (Gattullo, Uva, Fiorentino, & Gabbard, 2015), in which just CAD models, writings, or symbols are added to the scene, virtual reality (VR) cuts the user off from the actual world completely. See-through glasses (with a camera and tiny projectors on lenses) or mobile devices (tablets, smartphones) can be used for this purpose in augmented reality (AR), where the camera is used to frame the external environment and the screen is utilised for output (Di Donato, Fiorentino, Uva, Gattullo, & Monno, 2015). Because the virtual world is linked to the actual one, symbols' relative locations to the world's external reference system remain unchanged even if the camera's viewpoint is changed. This is determined by calculating the camera's position in space, either with or without the use of markers (often chessboard-based symbols whose form and size are a-priori known). In the latter scenario, a database contains images of the surrounding environment, and the camera's position in space is determined by comparing these images to the scene captured by the camera. Several augmented reality software packages (such ALVARTM (Kantonen, Woodward, & Katz, 2010; Alvar, 2018) and Vuforia TM (Vuforia, 2018)) now include maker less software packages, whereas AR toolkit (AR Toolkit, 2018; Billinghurst, Kato, & Poupyrev, 2001) is an example of a tool based on markers. Once the camera's location has been determined, CAD models, symbols, or inscriptions can be superimposed over the live feed (Ceruti, Liverani, &Bombardi, 2017). It is important to remember that augmented reality is a real-time approach, so as you move your camera around, the virtual symbols will shift position in the video output to match. The review study by Palmarini, Erkoyuncua, Roy, and Torabmostaedi (2018) demonstrates that 17% of the chosen publications deal with aeronautics, and that 33% of the studies overall explain assembly/disassembly jobs. Two maintenance activities were completed 7.7 and 11.6% faster thanks to the use of wearable technology, as reported in the research (Robertson, Bischof, Geyman, & Ilse, 2017), which presents the results of a pilot study in which 15 aero- nautical mechanics were interviewed. In addition, it should be noted that participants valued the elimination of the need to go to and from the plane, which is typically associated with manual operations that necessitate the use of ladders. Industrial literature reveals comparable outcomes; for .example, after Boeing and Iowa State University Technicians building a wing structure can save 30% of production time and improve quality when given tablets to use throughout the process. Airbus (2018) performed similar analysis, finding that the inspection time for the A380's fuselage brackets dropped from three weeks to three days.

III. MAINTENANCE IN AERONAUTICS 4.0

3.1. Maintenance in Aeronautics

The Aeronautics Maintenance Checklist Inspection, replacement of damaged or crushed parts (together with supply logistics) (Regattieri, Gamberi, Gamberini, & Manzini, 2005), replacement of sealants, fixing of coatings, refilling of lubricants or gases, and so on are all examples of the kinds of tasks encompassed by the acronym MRO in the aviation industry (e.g. in damping cylinders, hydraulic accumulators, condi- tioning systems). Maintenance, Repair, and Overhaul works to make sure that every time a commercial plane takes off, it complies with Airworthiness Directives. Due to the importance of MRO to flight safety, it is heavily controlled by national aviation agencies such as the Federal Aviation Administration in the United States, Transport Canada in Canada, and the European Aviation Safety Agency in Europe. The International Civil Aviation Organization (ICAO) also offers broad recommendations for the maintenance procedure. The Federal Aviation Administration and the European Aviation Safety Agency (FAA and EASA, respectively) are responsible for certifying operators working in maintenance. This is so because maintenance is a difficult and dangerous operation that can lead to flying mishaps without proper training. In this context, the SHELL model (Marx & Graeber, 1993) is useful; it connects four factors that have a major impact on the aviation system: software (rules, instructions, information, organisation), hardware (aircraft, material buildings), environment (climate, temperature, physical/social/political variables that can affect the operators), and liveware (humans) (human element: pilots, maintenance operators, ground crew). When things go wrong in aviation, it's usually because of a disconnect between the hardware and the live-ware (such faulty tool ergonomics) or the software and the live- ware (e.g. unclear manuals and documentation in general). From a historical viewpoint (Khee, 2009), regular upkeep was directly tied to each breakthrough in manufacturing and flight. In 1948, the International Civil Aviation Organization (ICAO) released the first standard for licencing maintenance employees. Back then, an aeroplane was essentially only an airframe, an engine, and some mechanical parts. Maintenance engineers have become increasingly specialised as a result of revolutionary breakthroughs in electronics, materials, and power plants. A general-purpose engineer is no longer enough to manage complicated sets of maintenance activities, which vary greatly from aircraft to aircraft and system to system. This is especially true in the realm of avionics and power plants. EASA/FAA Part 66 Aircraft Maintenance Personnel Licensing specifies the standards for Licensed Aircraft Maintenance Engineers (LAMEs) due to the growing significance of maintenance throughout the years. Each commercial operator (such as Alitalia, Lufthansa, Qantas, and United Airlines, to mention a few) is obliged by aviation authorities to produce the so-called Continuous Airworthiness Maintenance Program (CAMP), which must be included in its Operations Specifications (Operations Specifications). CAMP specifies each and every required regular and comprehensive examination for an airline. To be legally allowed to fly, aircraft need to have their regular maintenance verified by an Airworthiness Review Certificate (ARC) (Air Navigation Certificate). Therefore, commercial aeroplanes are subject to regular inspections that are carried out in accordance with manufacturer-developed protocols that are tailored to the specifics of each plane's structural design and on-board equipment. It is possible to schedule checks based on factors such as the number of flying hours, the frequency of take offs and landings (the points at which inertial loads are at their peak), or the passage of time since the last check (ageing problem). Most operators of commercial and civil aircraft adhere to a four-tiered maintenance inspection system (A, B, C, and D). Check A is a basic test that is performed after 200-300 uses. The cabin, engine pylons, control surfaces, and engines must all pass muster before passengers are allowed on board. Once 2000 flight hours have been logged, a "Check B" light check is performed (usually 6–8 months for a commercial aircraft). It may be finished in one to four days. All the A inspections are done, plus a thorough examination of the engines, the structure, all the moving components, the wings, and the composite materials (looking for crack or delamination). After 3500 flying hours, a thorough maintenance procedure known as Check C must be performed (18–24 months). Apart from the A and B checks, several components and groups are disassembled and carefully inspected during this inspection, which can take anywhere from 8 to 15 days and necessitates the aircraft being kept in a hangar by the Air Carrier Company (or being transported to a specialised maintenance company) (in particular engines and pylons). Check D, often known as an overhaul, is the most extensive kind of maintenance that can be performed on a plane. After about 9 years, or 18,000-26,000 flying hours, the aircraft undergoes Check D. It typically takes 60 days to deconstruct an aeroplane and evaluate its interior and exterior structure in great detail. After each Check D, a three-hour flying evaluation must be completed. Practically speaking, MRO necessitates that operators adhere to check lists where assembly/disassembly processes are provided in detail with explanatory illustrations and list of things to accomplish. To prevent time waste and a potentially confusing excess of unneeded parts on the shelves ("Lean Warehousing" concept), it is important to accurately detect components in need of replacement with spare parts provided "just in time" via the maintenance logistic (Regattieri et al., 2005) chain. Aeronautical structures are complex, and traditional maintenance methods based on paper manuals can lead to a number of issues. These include: inaccuracies in the manual's depiction of the structure's configuration; disassembly procedures that are difficult to guess based on two-dimensional pictures and schemes; doubts during maintenance tasks that necessitate inquiries to the aircraft manufacturer; and an excessive workload due to poor ergonomics (narrow places where one must stop or reach). Despite the introduction of a connection between software and liveware in the SHELL model (Marx & Graeber, 1993), the authors believe that standard maintenance manuals are not suitable. Article-based documentation is "slow, cumbersome, and prone to mistake," as stated in a recent paper (Koornneef, Verhagen, & Curran, 2017). As has been noted, the development of electronics, materials, and the power grid has coincided with the improvement of maintenance education and practise. In response, various subfields of engineering, not only aerospace, are beginning to incorporate ideas from the recently popularised "Industry 4.0" into their preventative maintenance plans.

3.2. An Industry 4.0 approach to maintenance in aeronautics

Aircraft maintenance might be significantly altered by the introduction of many major enabling technologies made possible by the Industry 4.0 initiative. Examples of technologies well-suited to both factories and aeroplanes include networking, the availability of large data, the possibility of decentralised and personalised production, networks of interconnected microsensors, smart and intuitive visualisation of information in remote operations, and automation. For instance, real-time local monitoring tactics on composite structures (Testoni, De Marchi, &Marzani, 2016) require huge data handling efficient algorithms (Analytics) to back them up. Airbus and Boeing, among other manufacturers, are looking into ways to enhance structural health monitoring. In order to monitor the structure and detect fracture development in the most efficient manner, this method collects data from millions of sensors (such as Bragg fibres embedded in composite constructions), making possible a genuine "damage toler- ance" strategy (Borello, Cestino, & Frulla, 2010). However, with the rise of Industry 4.0, technologies like AM and AR are poised to become integral parts of future maintenance plans.

1.2.1. Augmented Reality (A.R.)

AR can be helpful to acquire Augmented Maintenance Manuals and Illustrated Parts Catalogs, where the position of the item to maintain is intuitively given to the user on the real aircraft. The use of CAD models, symbols to indicate manual operations to carry out (such as a virtual screw driver), and virtual panels where to check operations and interact with gesture tracking technologies makes AR-based instructions particularly useful for assembly/disassembly activities. Using AM, centralised maintenance centres could produce virtual animations in real time to assist complicated operations, which could then be loaded to distant operators' devices if necessary. This has the potential to address one of the key issues preventing widespread adoption of augmented reality in industry: the length of time required to develop animations. For obvious reasons, it would be a time-consuming process to construct animated virtual sequences for each of the maintenance activities that are conceivable on a contemporary aircraft made up of millions of parts. As suggested in Ceruti, Liverani, and Marzocca (2015) for aviation maintenance, preparing a virtual assembly/disassembly sequence at a centralised office of an aircraft manufacturer only when needed by distant operators might be a more cost-effective method to use AR in an industrial environment. Augmented reality has the potential to greatly improve the realism and efficacy of many tasks, including training. The capacity of augmented reality to combine virtual and real components enables for the simulation of complicated scenarios without the requirement for components that may be unavailable (or cumbersome/dirty). When dealing with complicated tasks that cannot be effectively explained with typical paper instructions, the overall impact of AR on maintenance can be tremendous.

In addition, the paperwork needs to last for decades (because 20–30 years is the typical lifespan of a commercial plane): When compared to a paper-based maintenance strategy, where bulletins must be manually and periodically added to initial release manuals, AR can aid in maintaining procedures up to date. However, implementing all of a commercial aircraft's maintenance duties on AR might be a time-consuming process; for the time being, it is more practical to recommend implementing just the most crucial and time-consuming maintenance activities on AR. Time needed to develop a full maintenance manual in AR may be cut down in the near future thanks to the integration in CAD system of environments designed to prepare in short time augmented scenes.

3.2.2 Additive Manufacturing

When preventive maintenance is prioritised with an emphasis on AM, several new options become available. Once a digital model is ready, AM may be utilised to manufacture the necessary components. However, as said before, the greatest outcomes are achieved by doing a topological optimization and employing lattice-based structures. This allows for the fabrication of intricate shapes that would otherwise be impossible to achieve using conventional chip-off methods. In contrast, this is a futuristic viewpoint, as at the time of writing there is no regulation for structural elements manufactured by AM techniques, even if they have the same shape and material as those acquired via more conventional methods. How and when rules will be updated to permit certification of AM metal components is an open question. From a supply chain management perspective, several issues will be resolved, including the elimination of the need for consumables like spare parts and the introduction of an additive manufacturing machine and powders magazines. If the notion of a "digital twin" is widely adopted in the aerospace industry, components with new geometries might be manufactured as direct replacements for the old ones. Cracked or damaged components might be swapped out for more efficient optimised components in a mass production setting using chip removal tools, restoring the aircraft to its original form. In this latter scenario, the production costs of a conventional component are very close to those of an optimised component. A lighter aeroplane could be possible if its overall dimensions are such that the components experience the same amount of stress (and thus equal safety margin). Consequently, a digital twin will be required because, during the course of their lifetimes, aeroplanes will diverge from one another due to the incorporation of both traditional and additively manufactured components. On the other hand, if one adopts a less idealistic and more pragmatic stance, it might be argued that AM offers a means of decreasing stockpiles of non-structural spare components. maximum uselessness oif aviation manufacturers are willing to release digital models of parts and an FAA/EASA rule is made accessible for metallic parts manufactured from powders, the benefits of AM might be realised. Putting AM machines in maintenance hangars would shorten the supply chain for obtaining replacement components. In order to apply the principles of

Industry 4.0 to the aviation industry, there has to be a robust data sharing network between manufacturers of aircraft, airlines, and maintenance companies. As evidence for the foregoing claims, consider the fact that various components on commercial aeroplanes nowadays are manufactured using AM techniques: Air ducts (e.g. B787, Bell 429 helicopter), interiors/brackets (e.g. A350), propulsion (e.g. B737MAX fuel injection nozzle by General Electric), and tiny non-structural spare components are all places where AM has been included, according to Boeing (Malfitano, 2017). The A350XWB features over a thousand ULTEM 9085 components manufactured by Airbus. The ULTEM FDM thermoplastic was developed by the Stratasys Company (Stratasys, 2018) for use in the transportation sector; it has been given an FST (flame, smoke, and toxicity) rating; its raw material and filament structural properties have been certified; and its supply chain maintains material traceability, as is necessary in the aerospace sector. The current lack of readily available design data databases is a major roadblock to the widespread use of AM for structural components. Materials and fabrication must be tested and consistent (CFR 25.603 & 25.605), and the structure must be robust, therefore analyses and testing are necessary for commercial aircraft certification under US FAR 25 or EASA CS-25 regulations (CFR 25.305, 25.307 & 25.601). Because (just as one example) the same AM process might result in parts with a significant dispersion concerning the number/importance of flaws, extensive research relating to consistency are required before AM parts can be employed in structural applications. With the availability of regulated additive processes, qualified machines and workers, and FAA/EASA-specific regulation, AM structural components might be manufactured for use in maintenance. In conclusion, the use of AM to produce spare parts (both structural and non-structural) identical to those to be replaced can form the basis of a long-term roadmap for introducing AM in a maintenance process; (2) using gained experiences, standards, design methodologies, and technological processes can be developed for structural parts if airworthiness can be assured; and (3) using AM to reduce the spare parts warehouses for non-structural parts. Maintenance organisations would not be responsible for design validation, but would instead follow the authorised procedure to generate third-party parts from approved CAD models provided the aircraft manufacturer specified the characteristics and standard method for AM of spare parts. Also, the aircraft manufacturer would only have to validate parts once, relieving the burden on individual maintenance facilities. At the fourth and final stage, AM capabilities may be employed to create optimised spare components for use in upkeep procedures. For the most hefty replacement components, the aircraft manufacturer would supply a CAD model designed for on-site printing. In this instance, the aircraft manufacturer would have to spend more time and money validating and certifying the new technical features and forms of optimised components.

IV. CONCLUSION

This paper discusses how Industry 4.0 technologies could be applied in the field of aerospace maintenance. Augmented reality (AR) and additive manufacturing (AM) are two examples of cutting-edge technologies that offer an alternative to the conventional method of performing maintenance tasks. If a suitable AM machine and powders are available, a part can be manufactured in metals like Aluminium or Titanium, eliminating the need for large warehouses and shortening the logistical chain. And if a redesign of the component is feasible, then optimised lattice structures could be used to cut down on weight. Because AR combines virtual models with the real world, it can aid operators with user-friendly manuals. With fewer mistakes being made thanks to AR-enhanced maintenance manuals, efficiency gains in terms of both time and effort spent on tasks, as well as increased reliability, are to be expected. Using AR, a technician could locate a malfunctioning component, which could then be virtually extracted using reverse engineering methods and sent to AM for printing. Once the new component was ready, the operator could be shown how to put it in. The preceding claims are supported by two case studies that compare and contrast the benefits of using AR and AM in the aeronautics domain. The lack of regulations by aeronautical authorities, which should begin addressing the issues related to the introduction of this new technology to allow for its widespread spreading in the aeronautical field, is the main limitation of this approach. An additional issue is the need for high-powered, ergonomic hardware to support AR, as well as software to deal with issues like lighting variations, object occlusion, real-time video streaming, and high-quality image resolution. Availability of spare parts, criticality of components, manufacturing feasibility, regulations including initial and continuing airworthiness, and other critical factors should be considered prior to transitioning from a traditional to an AM production process because of the high cost of AM at the present time.

REFERENCES

[1]. Airbus Company website (2018).http://airbus-xo.com/real-benefits-virtual-reality/[Accessed: January 2018].

[2]. Alvar website (2018). http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/[Accessed: January 2018].

[3]. ARToolkit website (2018). https://www.hitl.washington.edu/artoolkit/ [Accessed:January 2018].

[4]. Azuma, R. T. (1997). A survey of augmented reality. Presence: Teleoperators and Virtual Environments, 6, 355–385.

[5]. Bendsoe, M. P., & Sigmund, O. (2004). Topological optimization, theory. Methods and application. Berlin: Springer-Verlag.

[6]. Billinghurst, M., Kato, H., & Poupyrev, I. (2001). The MagicBook: A transitional ARinterface. Computers and Graphics, 745–753.

[7]. Borello, F., Cestino, E., & Frulla, G. (2010). Structural uncertainty effect on classical wing flutter characteristics. Journal of Aerospace Engineering, 23(4), 327–338.

[8]. Ceruti, A., Liverani, A., & Marzocca, P. (2015). A 3D user and maintenance manual for UAVs and commercial aircrafts based on augmented reality, SAE Technical Paper 2015-01-2473.

[9]. Ceruti, A., Ferrari, R., & Liverani, A. (2017). Design for additive manufacturing using LSWM: A CAD tool for the modelling of lightweight and lattice structures.

[10]. Sustainable design and manufacturing 2017 (Vol. 68, pp. 756–765). Smart Innovation, Systems and Technologies.

[11]. Ceruti, A., Liverani, A., & Bombardi, T. (2017). Augmented vision and interactive monitoring in 3D printing process. International Journal on Interactive Design and Manufacturing, 11(2), 385–395.

[12]. Cessna Aircraft Company (1970). Illustrated part catalog for model 337, 1 March 1970, Wichita Kansas (USA) (p. 154).

[13]. Cessna Aircraft Company (1973). Service manual for model 337, T337, F337 and FT337, 1 February 1973, Wichita Kansas (USA) (pp. 5-21–5-26).

[14]. Cozmiuc, D., & Petrisor, I. (2018). Industrie 4.0 by siemens: Steps made today. Journal of Cases on Information Technology, 20(2), 30–48.

[15]. Di Donato, M., Fiorentino, M., Uva, A. E., Gattullo, M., & Monno, G. (2015). Text legibility for projected Augmented Reality on industrial workbenches. Computers in Industry, 70, 70–78.

[16]. Dutta, B., & Froes, F. H. S. (2017). The Additive Manufacturing (AM) of titanium alloys. Metal Powder Report, 72(2), 96–106.

[17]. Federal Aviation Administration (2018). FAA-H-8083-30A, Aviation maintenance technician handbook–General, available on line at: https://www.faa.gov/ regulations_policies/handbooks_manuals/ aircraft/.

[18]. Fioriti, M., Vercella, V., & Viola, N. (2018). Cost-estimating model for aircraft maintenance. Journal of Aircraft, 55(4), 1564–1575.

[19]. French, R., Marin-Reyes, H., & Benakis, M. (2019). Transfer Analysis of Human Engineering Skills for Adaptive Robotic Additive Manufacturing in the Aerospace Repair and Overhaul Industry, Advances in Intelligent Systems and Computing Volume 793, Pages 3-12 Joint proceedings of the AHFE International Conference on Advanced Production Management and Process Control, AHFE International Conference on Human Aspects of Advanced Manufacturing, and AHFE International Conference on Additive Manufacturing, Modeling Systems and 3D Prototyping, 2018; Orlando; United States; 21 July 2018 through 25 July 2018.

[20]. Gattullo, M., Uva, A. E., Fiorentino, M., & Gabbard, J. L. (2015). Legibility in industrial AR: Text style, color coding, and illuminance. IEEE Computer Graphics and Applications, 35(2).

[21]. Gibson, I., Rosen, D.W., & Stucker, B. (2010). Additive manufacturing technologies: Rapid prototyping to direct digital manufacturing (pp. 1–459).

[22]. Hold, P., Erol, S., Reisinger, G., & Sihn, W. (2017). Planning and evaluation of digital assistance systems. Procedia Manufacturing, 9, 143–150.

[23]. Kantonen, T., Woodward, C., & Katz, N. (2010). Mixed reality in virtual world teleconferencing. In Proc. IEEE Virtual Reality, Waltham, Massachusetts, USA, March 20 – 24 (pp. 179–182).

[24]. Khee, L. Y. (2009). Evolution of aircraft maintenance training. Journal of Aviation Management. LYK Aerospace Pte Ltd, Singapore.

[25]. Koornneef, H., Verhagen, W. J. C., & Curran, R. (2017). Contextualising aircraft maintenance documentation. International journal of Agile Systems and Management, 10(2), 160–179. https://doi.org/10.1504/IJASM.2017.086159.

[26]. Lee, C. H., Shin, H. S., Tsourdos, A., & Skaf, Z. (2018). New application of data analysis using aircraft fault record data. Journal of Aerospace Information Systems, 15(5).

[27]. Malfitano, B. (2017). Evaluation and implementation of additive manufacturing technologies for structural applications. In Proceedings of the International Committee on Aeronautical Fatigue (ICAF2017) and Structural Integrity 36th Conference & 29th Symposium, June 5th–9th (pp. 1154–1155). Nagoya, Japan.

[28]. Marcon, P., Zezulka, F., Vesely, I., Szabo, Z., Roubal, Z., Sajdl, O., ... Dohnal, P. (2017). Communication technology for industry 4.0. Progress in Electromagnetics Research Symposium, 2017, 1694–1697.

[29]. Marx, D. A., Graeber, R., & R.C. (1993). Human error in aircraft maintenance. Seattle, Washington: Boeing Commercial Airplane Group.

[30]. Miller, A. M., Alvarez, R., & Hartman, N. (2018). Towards an extended model-based definition for the digital twin. Computer-Aided Design and Applications, 15(6), 880–891.

[31]. Palmarini, R., Erkoyuncua, J. A., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. Robotics and Computer-Integrated Manufacturing, 49, 215–228.

[32]. Peruzzini, M., Grandi, F., & Pellicciari, M. (2017). Benchmarking of tools for user experience analysis in Industry 4.0. Procedia Manufacturing, 11, 806–813.

[33]. Raymer, D. (1992). Aircraft design: A conceptual approach. Washington, DC: American Institute of Aeronautics and Astronautics.

[34]. Regattieri, A., Gamberi, M., Gamberini, R., & Manzini, R. (2005). Managing lumpy demand for aircraft spare parts. Journal of Air Transport Management, 11(6), 426–431.

[35]. Robertson, T., Bischof, J., Geyman, M., & Ilse, E. (2017). Reducing maintenance error with wearable technology. IEEE.

[36]. Rosen, D. (2007). Computer-aided design for additive manufacturing of cellular structures. Computer-Aided Design and Applications, 4(5), 585–594.

[37]. Santos, M. Y., Oliveira e Sá, J., Andrade, C., Vale Lima, F., Costa, E., Costa, C., ... Galvão, J. (2017). A big data system supporting Bosch Braga Industry 4.0 strategy. International Journal of Information Management, 37(6), 750–760.

[38]. Savio, G., Meneghello, R., & Concheri, G. (2017). Optimization of lattice structures for additive manufacturing technologies. Lecture Notes in Mechanical Engineering, 213–222.

[39]. Stratasys Company website. ULTEM 9085 data sheet (2018). https://www.stratasys.com/materials/search/ultem9085 [Accessed: November 2018].

[40]. Testoni, N., De Marchi, L., &Marzani, A. (2016). Detection and characterization of delaminations in composite plates via air-coupled probes and warped-domain

[41]. filtering. Composite Structures, 153, 773–781.

[42]. The Area website (2018). http://thearea.org/augmented-reality-can-increaseproductivity/ [Accessed: January 2018].

[43]. United Kingdom Civil Aviation Authority (1992). Maintenance error. Asia Pacific Air Safety.

[44]. Vigliotti, A., & Pasini, D. (2012). Stiffness and strength of tridimensional periodic lattices. Computer Methods in Applied Mechanics and Engineering, 229–232, 27–43.

[45]. Vuforia website (2018). https://www.vuforia.com/ [Accessed: January 2018].

[46]. Zheng, P., Wang, H., Sang, Z., Zhong, R. Y., Liu, Y., Liu, C., ... Xu, X. (2018). Smart manufacturing systems for Industry 4.0: Conceptual framework, scenarios, and future perspectives. Frontiers of Mechanical Engineering, 13(2), 137–150.