Augmented Reality in Aerospace Manufacturing: A Review

Mauricio A. Frigo and Ethel C. C. da Silva
Production Engineering, Centro Universitário de Araraquara – UNIARA, Araraquara, Brazil
Email: mfrigo@hotmail.com, e-chiari@uol.com.br

Gustavo F. Barbosa
Mechanical Engineering, University of Sao Paulo – USP, Sao Carlos, Brazil
Email: gustavofb1974@hotmail.com

Abstract—This paper reviews the applications of Augmented Reality with an emphasis on aerospace manufacturing processes. A contextual overview of Lean Manufacturing, aerospace industry, Virtual Reality (VR) and Augmented Reality (AR) is provided. Many AR applications are provided to show that AR can be used in different fields of endeavor with different focuses. This paper shows two case studies in aerospace industries, presenting different forms of AR use in aerospace manufacturing processes to demonstrate the benefits and advantages that can be reached. It is concluded showing that gains of labor qualification, training costs reduction, inspection system and productivity of the business can be provided by the use of AR.

Index Terms—augmented reality, industrial AR, aerospace fabrication, AR in aerospace

I. INTRODUCTION

Skinner [1] states that manufacturing is driven to achieve high efficiency and low cost for the company to succeed in business. In order to remain alive and be successful in today's highly competitive global market, companies around the world are seeking for establishing Lean Manufacturing System [2].

Lean Manufacturing has been popularized since it can provide significant improvements in all segments of the manufacturing system, Behrouzi and Wong [2] said. Lean Manufacturing has sought to increase productivity and eliminate waste identifying what has value to the customer and generating a flow of value to the customer.

Kirner and Siscoutto [3] approach that with the emergence of the computer, a new form of interaction appeared in various environments, including the industrial environment, bringing more sophisticated processes that show new ways to avoid wastes that were previously done manually, developing simpler and faster ways to perform operations. Changing the level of knowledge required to perform these operations.

In the 60’s it comes to virtual reality where, according to Tori, Kirner and Siscoutto [4], it was possible to have a new generation of forms of interaction between man and machine, which inserts the user in a three-dimensional application environment of applications running on the computer relating the computer ability to react to the user actions instantly when it is detected in order to modify aspects of the application.

Augmented Reality (AR) is the augmentation of the real world with digitally generated sensory inputs such as visual or sound and it can be used in several types of applications [5].

In this way, the contribution of this paper is to make an overview of AR technology for aircraft fabrication processes and its potential gains, benefits and advantages.

II. LITERATURE REVIEW

A. Aerospace Industry

The increasing technological complexity, which is reflected in higher costs of new product development, has led the aircraft manufacturers to focus on design and assembly activities, transferring to the outsourcing the production of structural components as segments of the fuselage and wings. It has been observed in this way, a greater specialization of global players that look for establishing partnership agreements with their key suppliers in order to share the development costs and take advantage of specific skills. In short, they can advance in development and production of new aircraft, leading companies need to coordinate the supply chains, increasingly robust [6].

According to Seitz & Steele [7], the manufacturing of aircrafts in addition to being one of the most important sectors of manufacturing of durable goods due to its high added-value, is also the sector that most encourages the development of new technologies and which employs more skilled labor, such as technicians, engineers and researchers.

Aerospace industry is open to new enterprises but these investments should be done with extreme care, since the cost of development of new products is extremely high in this kind of industry. This makes it clear that errors are not allowed when it is invested in aircrafts fabrication [8].

B. Lean Manufacturing

The term Lean Manufacturing was first used in scientific means by the authors Womack, Jones and Roos...

The Lean is characterized as a powerful antidote to waste. It should go beyond the company and have a vision of the entire set of activities from conception of a product until its delivery to the final customer. Lean Manufacturing assumes that there are seven types of waste also known as Muda (Japanese term) that occur inside companies which we should eliminate. They are waste of excessive transportation, waste of inventory, waste of motion, waste of waiting, waste of over production, waste of over processing and waste of Defects (rejects or re-work) cited by Womack and Jones [10].

Hines and Taylor [11] claim that when we think about industry waste we can define it in three different activities, the activities that generate value for the product or service, unnecessary activities that do not generate value and the necessary activities but which do not generate value.

Manufacturing Global [12] with proposal to show the importance of Lean Manufacturing researched the market which would be the main companies in Lean, classifying them into the TOP 10 Lean companies in the world, compiled by the authors in the table below.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Toyota</td>
<td>Car Manufacturing</td>
</tr>
<tr>
<td>2</td>
<td>Ford</td>
<td>Car Manufacturing</td>
</tr>
<tr>
<td>3</td>
<td>John Deere</td>
<td>Agricultural Machinery</td>
</tr>
<tr>
<td>4</td>
<td>Parker Hannifin</td>
<td>Motion Control Technologies</td>
</tr>
<tr>
<td>5</td>
<td>Textron</td>
<td>Industrial Conglomerate</td>
</tr>
<tr>
<td>6</td>
<td>Illinois Tool Works</td>
<td>Engineering Manufacturer</td>
</tr>
<tr>
<td>7</td>
<td>Intel</td>
<td>Computer Chip Maker</td>
</tr>
<tr>
<td>8</td>
<td>Caterpillar Inc.</td>
<td>Machinery Manufacturer</td>
</tr>
<tr>
<td>9</td>
<td>Kimberly-Clark Corporation</td>
<td>Personal Care Corporation</td>
</tr>
<tr>
<td>10</td>
<td>Nike</td>
<td>Clothing Company</td>
</tr>
</tbody>
</table>

C. Lean Manufacturing in Aerospace

The Aerospace sector has recognized the opportunity to eliminate huge amounts of waste within its value streams with Lean Manufacturing. Cook [13] mentioned that Lean will do for aircraft industries what it did for car industry, affirming that panels and components damaged in operation can be quickly replaced at the front line without special customization in much the same way that car parts are ordered up and fitted in the commercial world.

Inside the aerospace industry, the Lean Manufacturing concepts have been applied increasingly, being the continuous flow an important factor in defining the assembly process. This condition favors the fluidity of the product along the line showing the evolution of the assemblies at each stage. The moving line design is a Lean Manufacturing behavior where Elizabeth Lund, Boeing 777 production director, claims that it is the most powerful tool available to identify and eliminate waste during manufacturing. The moving line drives the system, because it makes problems become visible and creates a sense of urgency in solving the root cause of all problems [14]. Fig. 1 shows the Boeing 777 moving assembly line.

The Brazilian aircraft manufacturer called Embraer that conglomerates production of commercial, military, executive and agricultural aircrafts and provides aeronautical services, adopted Lean Manufacturing and is having great results. Embraer Executive Jets [15] announced to media that Phenom 300 incorporated into the Phenom 100 assembly line in Melbourne, USA. The unit has a single line for the production of the Phenom 100 and Phenom 300 using Lean concept and if operating in two shifts, possesses the ability to assembly up to eight aircrafts per month. The team needed to accommodate the expansion of the line which was already contracted. The assembly line totals 160 employees. Fig. 2 shows the Phenom assembly line.

III. Virtual Reality

Kirner and Siscoutto [3] defined Virtual Reality (VR) as an advanced user interface to access applications running on the computer, allowing the display, handling and user interaction, in real time, in three-dimensional computer-generated environments. The sense of sight is usually the main sense in virtual reality applications, but the other senses like touch, hearing among others, can also be used in order to enhance the user experience.

Even with the advantages of virtual reality, it required special equipment such as helmet, gloves, stereoscopic glasses among others, to insert the user into the application space, where it is performed their interactions. In addition, the insertion of the user to the virtual
environment caused an initial discomfort and difficulties of interaction. Training was often necessary. These facts, according to Kirner and Siscoutto [3], inhibited the popularization of virtual reality as a new user interface.

Embraer’s Virtual Reality Center was inaugurated in February 2000. It is equipped with a modern graphic computer which enables Embraer engineers to visualize, through electronic models, the aircraft’s structure and systems during the development phase. The use of this modern tool allows Embraer to reduce the development time of any new aircraft. The customers can follow the aircraft development steps and are able to check the internal configuration, as well as define the paint scheme in an exact way. One of these fronts focuses efforts on the intensive use of Virtual Reality Center (VRC). This has allowed improvements of methodologies for fast lay out of three-dimensional arrangements of parts and components, as well as the fast execution of drawings and definition of manufacturing and assembly dimensions. Simulation of performance under stress also benefited [16]. Fig. 3 illustrates the VRC.

![Figure 3. Embraer’s virtual reality center in Brazil.](image)

IV. AUGMENTED REALITY

Augmented Reality (AR) is the augmentation of the real world with digitally generated sensory inputs like visual or sound. When applied to visual, as it was done for the current work, digital objects are registered spatially and rendered within the physical world often using a display device like a tablet or cell phone. Numerous advancements in technology have further enhanced the feasibility of using AR [5].

AR can be applied for several purposes in different areas. Azuma [17] presents the Augmented Reality being applied in six different categories presented below.

A. Medical

The Augmented Reality can be used by doctors to train for a surgery and can also be helpful to visualize tasks in the surgical room.

Surgeons can access enhanced senses with the Liver Explorer app by the developer Fraunhofer MEVIS. This app provides real-time AR guides and assistance to the medical practitioner. The device’s camera films the liver and, using AR, superimposes surgical planning data onto the organ. In addition, the software can react in real time.

These capabilities go beyond the MARTA (Mobile Augmented Reality Technical Assistance) system’s provision of context-sensitive information. Assuming the app receives positive evaluation, it is likely to be modified for future expansion into additional surgical fields [18]. Fig. 4 shows an example of a medical application.

![Figure 4. Augmented reality medical applications.](image)

B. Manufacturing and Repair

Assembly, maintenance and repair of complex machinery is the objective application of this category where the goal is to make the instructions easier to understand if they were available as 3D drawings superimposed upon the actual equipment showing how the tasks need to be done step-by-step with animations to let the directions even more explicit. Nowadays manufacturing AR is also known as Industrial AR.

Increasingly logistics providers offer added value to customers with services such as assembly and repair. For example, DHL not only collects materials from component providers for Audi, but also assembles these components into interior door panels that are then delivered to the Audi production plant in Germany.

Currently, skilled workers are required for such tasks, and each must be individually trained. However, in the future AR could train and aid warehouse staff to assemble a variety of products and ensure that high standards of service are maintained, potentially reducing cost for customers [18].

C. Annotation and Visualization

This category is when Augmented Reality is used to show information and contents. The figure below shows new application of this technology that can be used to provide information about the place that you are.

![Figure 5. Wikitude.](image)
Wikitude and Junaio are two leading examples of AR browsers that provide context-sensitive information software capable of recognizing locations or objects to link digital information to real-world situations. The software runs on any smartphone and displays additional digital information about the user’s surroundings in a mobile camera view [18]. Fig. 5 presents this specific application.

This additional digital information could be nearby places of interest, such as museums, shops, restaurants, or the pedestrian route to the next bus stop. The software includes image recognition, user position localization via GPS and WiFi, and 3D modelling [18].

D. Robot Path Planning

By using AR technology in robot path planning, the designed paths can be tested in the AR environment where the users can observe the simulated movement of the robot on-site and make improvements. As the AR technology develops, applications of AR in a wider range of fields can be expected [19].

E. Entertainment

The latest hand held video game consoles from Nintendo and Sony, the Nintendo 3DS and the Playstation Vita respectively, both have an on-board camera and come with a set of cards to be placed in the environment to act as markers for Augmented Reality games as shown below in Fig. 6 as follows [20].

Figure 6. Game characters being displayed on top of marker cards.

F. Entertainment

Azuma [17] presents this category as Military Aircraft referring the use of Head-Up Displays (HUDs) and Helmet Mounted Sights (HMS) to superimpose vector graphics upon the pilot’s view of the real world. Besides providing basic navigation and flight information, these graphics are sometimes registered with targets in the environment, providing a way to aim the aircraft’s weapons. Fig. 7 shows an example of nowadays pilot’s helmets.

Figure 7. F-35 Gen III helmet data sheet.

Military is one of the biggest investors in AR applications and continued to progress with AR applications not only in aircraft but also for troops on the ground that provides to soldiers identification of friend or enemy, night vision, and a greater ability to remotely coordinate small units. The helmet transmits detailed position information of a user to another, allowing the system to gather, map, and share information in real time on the battlefield. Another heads-up display (HUD) is used to project sensory information such as driving speed onto the windshield of some BMW cars. This enhanced-senses capability has been used by the automotive company since 2004, and BMW is constantly working to improve this HUD with additional features [18].

V. CASES OF AUGMENTED REALITY IN AEROSPACE INDUSTRIES

The advantages and benefits of AR have been widely applied by important aircraft manufacturers in global market. This section shows some related work beyond typical usage of AR on a synoptic analysis.

A. Boeing Case

Boeing is the world's largest aerospace company and leading manufacturer of commercial jetliners and defense, space and security systems. A top U.S. exporter, the company supports airlines and U.S. and allied government customers in 150 countries and has a long tradition of aerospace leadership and innovation.

With corporate offices in Chicago, Boeing employs more than 165,000 people across the United States and in more than 65 countries [21]. Fig. 8 shows the moving line of B777 production system.

Figure 8. Moving line of Boeing 777.

One of AR studies developed at Boeing was in partnership with Iowa State University described in the work “Fusing Self-Reported and Sensor Data from Mixed-Reality Training” in order to evaluate three different methods of presenting work instructions.

According to Richardson et al [5], the three methods were referred to as Desktop MBI, Tablet MBI and Tablet AR. The first mode is designed to mimic the instructions using Model-Based Instructions (MBI) on a stationary display located in a corner of one work cell and not visible from the work area. The Tablet MBI used the same instructions based on the exact model as the MBI desktop, but showed them to the trainee on a tablet PC mounted on a mobile arm. The Tablet MBI mode utilized the exact same Model-Based Instructions as the Desktop
MBI, but showed them to the trainee on a tablet PC mounted on a mobile arm device. The third was the Tablet AR mode using the same tablet as used in the Tablet MBI mode, but presented the work instructions to the trainee using Augmented Reality.

The Tablet AR mode used a custom Augmented Reality application and user interface built by Boeing Research and Technology. The interface and AR elements were selected through collaboration with Iowa State University. The screen of the Tablet AR mode was observed and recorded throughout using the same screen-mirroring software noted for the Desktop MBI and Tablet MBI modes [5].

Data of 46 participants were validated in that study, where 80% of these participants were between 18 and 20 years of age, 18% had between 23 and 30 years of age, and 2% were between 30 and 44 years of age. All participants were students and 78% of them majoring in engineering. There was an uneven gender split, 78% of participants were male and 22% female.

When comparing the traditional model based instructions with augmented reality instructions, there were different areas of interest, these are first time quality (lowest errors), fastest time and worker efficiency. Each of these areas shows how the approach of fusing system data with human subject data can further enrich training outcomes and measures.

Results covered in the previous section suggest that the use of augmented reality as a work instruction delivery method can increase first time quality and reduce time on task. The data also indicate that the use of AR also led to a greater emphasis on each task by the participants. It was found that those using Desktop MBI and Tablet MBI spent a large amount of time traveling and confirming information, looking at the screen. Finally, it was found that specific tasks can benefit more strongly from the use of Augmented Reality [5].

B. Airbus Case

Airbus is an aircraft manufacturer with facilities mainly in France, Germany, Spain and the United Kingdom and others, with a global diversity highlighted by the multi-cultural workforce of more than 58,000. The company's manufacturing operations around the world set industry benchmarks in both quality and efficiency standards.

Airbus develops its product family in response to market needs and in close consultation with airlines and operators, suppliers and aviation authorities. This approach ensures the company’s products to remain competitive through continuous upgrades. The company produces and markets the world's largest passenger airliner, the A380. Designed for the 21st century aviation industry, its unique size allows airlines to maximize their revenue potential through an optimized, segmented cabin, boosting their contribution to profit by up to 65 per cent per flight. Seating capacity ranges from 544 passengers up to 853 depending on the selected configuration [22].

Another industrial AR solution that is already in use comes from Airbus. With the master for a new aircraft production process developed entirely with digital tools, Airbus collaborated to create the MiRA (Mixed Reality Application) in 2009.

This app increases productivity in production lines by using AR to scan parts and detect errors. On the A380, MiRA, which today consists of a tablet PC and a specifically developed sensor pack and software, has reduced the time needed to check tens of thousands of brackets in the fuselage from 300 hours to an astonishing 60 hours. Furthermore, late discoveries of damaged, wrongly positioned or missing brackets have been reduced by 40% [18].

In the more commercial aerospace world, Airbus is using a technology known as MiRA, or Mixed Reality Application, where engineers installing equipment inside aircraft fuselages use a tablet computer and a sensor pack, which tracks their position and relates it to a Realistic Human Ergonomics Analysis (RHEA) tool, a full-scale 3D digital model of the aircraft they are working on. This enables them to call up an image of a bracket installation in the area where they are working to ensure that they have fixed it correctly. Geolocation devices attached to the aircraft interact with the sensor pack to allow them to view their work location from any angle. The RHEA is updated as each component is installed. This technique has helped reduce the time to inspect the 80,000 brackets inside an A380 fuselage, which hold systems such as hydraulics pipes, from three weeks to three days [23].

VI. CONCLUSION

The implementation of AR generates gains of labor qualification hiring less qualified worker because their
training for these specific tasks are easier whereas they also become easier to perform. Taking into regard that learning time is also extremely faster than the conventional way, it is also possible to compute gains with training costs reduction.

The early detection of non-conformities, avoiding costly corrections when performed later is another benefit such as a significant reduction in inspection time and the improvement of quality control process.

Augmented Reality when applied to aerospace manufacturing processes offers a faster production, higher quality and reliability for the production processes, as well as increasing the company’s competitiveness.

**REFERENCES**


Mauricio A. Frigo was born in Araraquara, SP, Brazil on October 2nd, 1991. He is a Bachelor of Science (B.S.) student of Industrial Engineering at University Center of Araraquara (UNIARA). Currently he is an intern at EMBRAER (Brazilian Aircraft Manufacturer) in the area of Manufacturing Engineering. His research interests are in lean manufacturing, manufacturing processes and aerospace assembly.

Ethel C. C. da Silva, PhD., was born in Sao Carlos, SP, Brazil on February 27th, 1966. She is graduated in Industrial Engineering – Materials – at Federal University of Sao Carlos (UFSCar) in 1990, she got a Master Degree in Mechanical Engineering (research area: Industrial Engineering) at University of Sao Paulo (USP), in 1994 and she got her PhD in Mechanical Engineering (research area: Industrial Engineering) at the same institution in 1999. She coordinates the graduation of Industrial Engineering at University Center of Araraquara (UNIARA) and teaches in the Professional Master's Program in Industrial Engineering of the same institution. She has been working in researches involving lean manufacturing and operation management.

Gustavo F. Barbosa, PhD., was born in Rio Claro, SP, Brazil on September 11th, 1974. He is graduated in Mechanical Engineering at University of Sao Paulo State (UNESP), Master and PhD in Mechanical Engineering at University of Sao Paulo (USP) related to design for manufacturing, assembly and automation. He has been a development engineer at EMBRAER (Brazilian Aircraft Manufacturer) since 2000 focused on manufacturing processes, Background on product integrated development, processes planning, new facilities implementation, shop floor assistance and training of new engineers and technicians. Current responsibilities are focused on perception, development and innovation of technologies for manufacturing regarding automated solutions.