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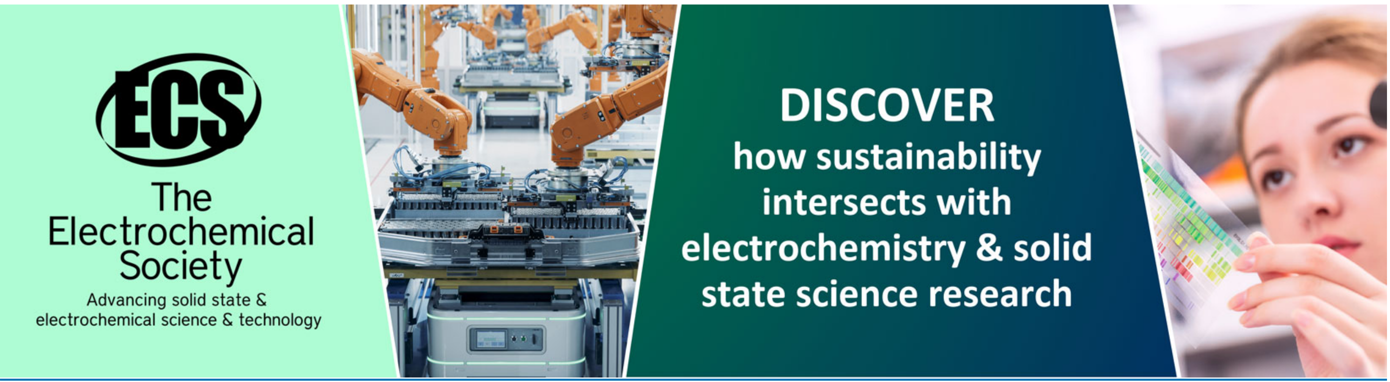

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Development of innovative technologies for manufacturing of certified narrow body aircraft composite flap

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ABSTRACT

Fiber-reinforced polymer composites perfectly meet the basic requirements of aircraft flaps being weight reduction critical for fuel saving and increased payload. New technologies have been designed and developed to increase competitiveness in the use of composite materials by ensuring a continuous manufacturing process, a streamlined and balanced flow of activities, synchronized as much as possible with customer and market demand, reducing material scraps and non-value-added activities.

Resin excess, tool mark-offs, out of tolerance dimensions are potential defects generated during the hand lay-up process of the skin manufacturing of composite flap.

Innovative technologies for manufacturing of certified narrow body aircraft composite flaps have been designed and developed in order to achieve the best quality of the product and the program ramp-up.

Detailed tooling analysis and several simulations, included process flow and bottlenecks detection, have been performed in order to design the new process with high level of automation and reliable devices for human safety and production repeatability, that fully meets the customer's expectations.

1 Introduction

Flaps are devices that provide the necessary increase of lift for take-off and landing of the aircraft. In particular, similarly wing, the primary function of the flap skin is supporting the aerodynamic pressure distribution from which the lifting capability is derived. These aerodynamic forces are transmitted in turn to the ribs and stringers by the skin. Resistance to shear and torsional loads is supplied by shear stresses developed in the skin and spar webs, while axial and bending loads are reacted by the combined action of skin and stringers [1].

With the introduction of carbon fibers in the 1970s, carbon fiber-reinforced epoxy has become the primary material in many wing, fuselage and empennage components. The structural integrity and durability of these early components have built up confidence in their performance and prompted developments of other structural aircraft components, being weight reduction critical for fuel saving and increased payload [2].

Upper and lower skin panels, are the carbon fiber-reinforced epoxy components of the wing flaps, characterized by higher manufacturing complexity, mostly if on the skin are co-cured stringers and spars. The manufacturing process used is hand layup of prepreg materials, widely applied for the reliability it offers, given its decades of implementation, ease of capturing nonconformance and performing inspection. Some the cons it offers is the slow nature of the lamination that can take up several days to finalize a part and it relies on the operator that is building it [3].

Since skin, stringer and spars are cocured, the current process requires, during the layup, several manual operations for handling, positioning and assembly mandrels and molds, that entailing low process repeatability and accuracy.
Furthermore, during the curing stage in autoclave, tools made in steel possess a CTE (coefficient of thermal expansion) too much high for tight tolerance parts to be produced at elevated cure temperatures.
In order to overcome aforesaid limiting conditions a new process has been designed with new lay-up tooling and automation of the most critical operations.

2 Current manufacturing process

The upper outboard skin panel, section shown in Fig. 1, is the most complex composite part in the manufacturing of the flap components and full representative of the current process and its limits.

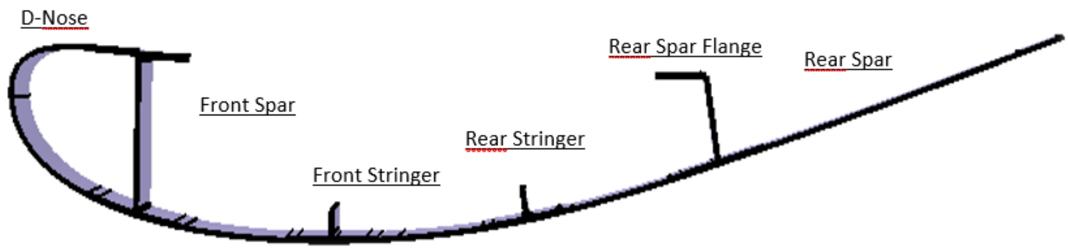

Figure 1- Upper Panel section view

This part is characterized by geometrical tolerances noted on the drawing per ASME standard [4] with surface and edge trim profile ± 0.040 inch.
Starting from Fibersim [5], manufacturing data are generated containing all the necessary boundary geometry and other information for nesting, cutting system and laser projection. Automated cutting of plies ensures low rate of scraps and cutting time reduction, laser projections of end of plies help the workers to build up the correct stacking sequence without any need of physical templates [6].
The lay-up process is performed in clean room (Fig. 2), an environmental controlled area equipped with temperature, humidity and overpressure control system.
Stringers and spars stack sequences are built on dedicate mandrels called plugs (front/rear) and intensifiers (central/rear) and manually assembled with the skin tool to build the monolithic part.
In order to fill the voids located in the joined parts, triangular composite tow filler called noodles, are placed in the inner side of stringer and spars (Fig. 3).
Fig. 4 shows the tool chain assembled of the upper outboard skin.

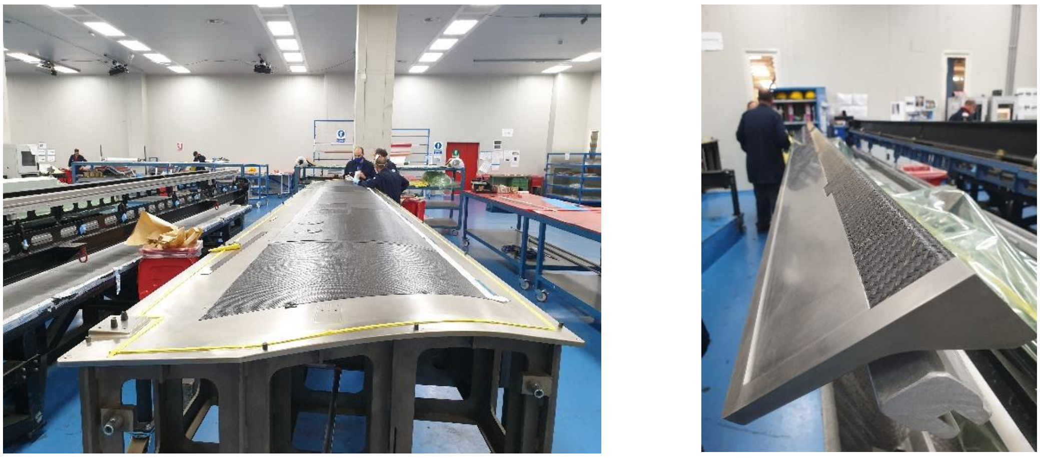

Figure 2 - Hand layup in clean room – skin tool mold and mandrel

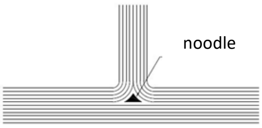

Figure 3 – Tow filler

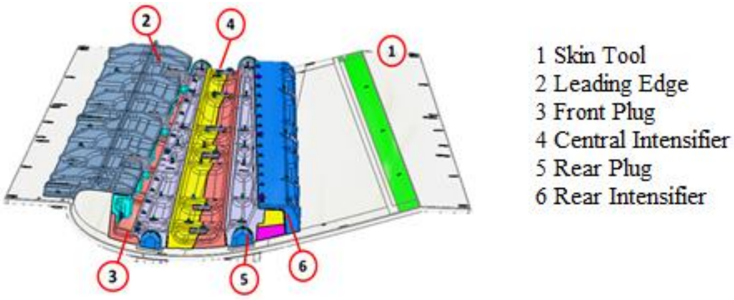

Figure 4 - Upper outboard skin panel tool chain

Common panel defects and related areas are listed and described in the Tab. 1 and, some of them, shown below in Fig. 5,6 and 7.

ID	DEFECT	AREA	CAUSE
1	**Non-compliance of the connecting radii**	Stringer/skin and Spar/skin interface (see Fig. 5)	Not controllable noodle placement (figure 5)
2	**Thickness out of tolerances**	Panel/ribs interface zone Rear spar (see Fig. 6)	Different CTE between mold, mandrels and other tooling components
3	**Profile out of tolerance**	Front/rear spar	Different CTE between mold, mandrels and other tooling components Mandrel/mold positioning and assembly not enough accurate and repeatable
4	**Resin excess**	Central area between two stringers	Carbon tools are not suitable for long-service life
5	**Tooling mark-off**	Rear spar D-nose (see Fig. 7)	Carbon tools are not suitable for long-service life (figure 8)

Table 1 - Common manufacturing defects

Tooling materials with high CTE and assembly process of mandrels and skin, that relies too much on the operator, are the root causes of geometrical dimensions defects detected on the final part (see defect ID 2, 3 in Tab. 1). The manual process for positioning and assembly of mandrels does not allow to place tow filler with enough accuracy and repeatability between stringers and spars (see defect ID 1 in Tab. 1). Carbon tools are not suitable for long-service life, generating over the time a decay of geometric characteristics and causing resin excess and mark off on the cured parts (see defects ID 4, 5 in Tab. 1).

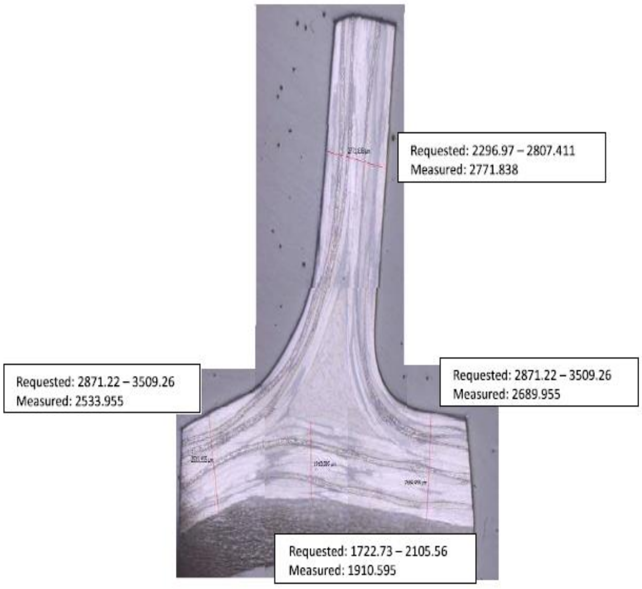

Figure 5 – Filler microsection view

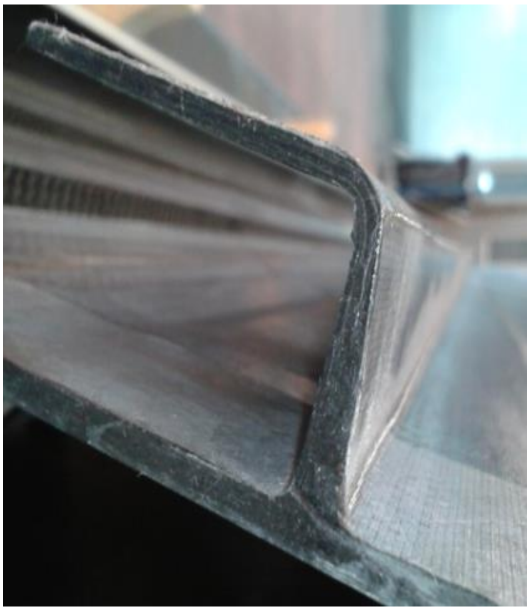

Figure 6- Out of tolerance rear spar thickness

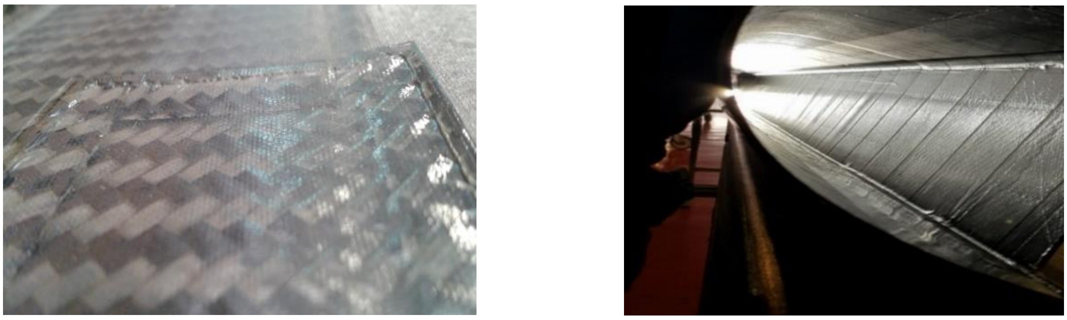

Figure 7 – Tooling mark off on the part

3 Redesign of the manufacturing process

The final purpose of the new process is to eliminate or dramatically reduce all the defects reported in Tab. 1, through redesigned tooling and implementation of automated process for tooling handling, positioning and assembly, all integrated with the hand lay-up process previously descripted.
Therefore, a new lay-up tool chain has been designed in Invar 36, a nickel-iron alloy offering the best performance of all metallic-based materials, in terms of durability and thermal properties.

The new tool chain will be fully integrated in an automated cell where all the uncured components (skin, spar and stringer) will be joined reducing drastically defects related to the filler placement and to the positioning and assembly of mandrels and mold.
The work cell has been designed composed of two main parts: Assembly Fixture (AF) and Turn Over Jig (TOJ), shown in Fig. 8.

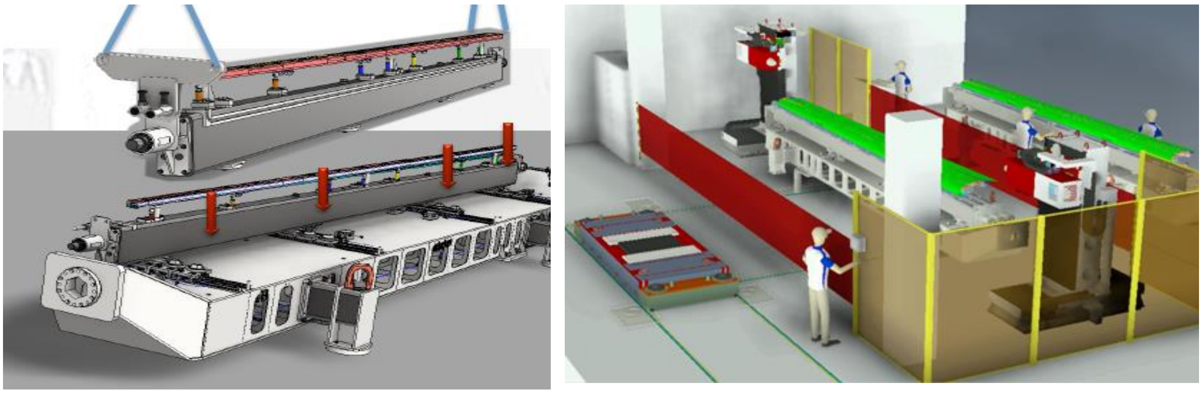

Figure 8 – Assembly Fixture and Turn Over Jig

The Assembly Fixture is a jig on which, spar and stringer mandrels, previously laminated in dedicated workstations shall be joined uncured, enabling the operator to easily fill the gap with the tow filler.
The TOJ consist in an automated manipulator whose purpose is to mate spars and stringers uncured with the uncured laminated skin. In order to perform this task, the manipulator shall be composed by two arms controlled in 4 axis (3 linear and 1 polar) each of one moving two spindles for the AF engagement and manipulation. Fig. 9 shows the cycle:

- mandrels previously laminated in dedicated workstation are assembled on the AF ;
- AF with mandrels is transferred by MGV (Manually Guided Vehicle) [7] in the TOJ area;
- TOJ lifts up AF and MGV moves away;
- TOJ rotates and approaches AF approaching to the skin tool and mandrels are placed on the mold

At the end of the cycle, all the components are joined together uncured, ready to final bagging before curing in autoclave.

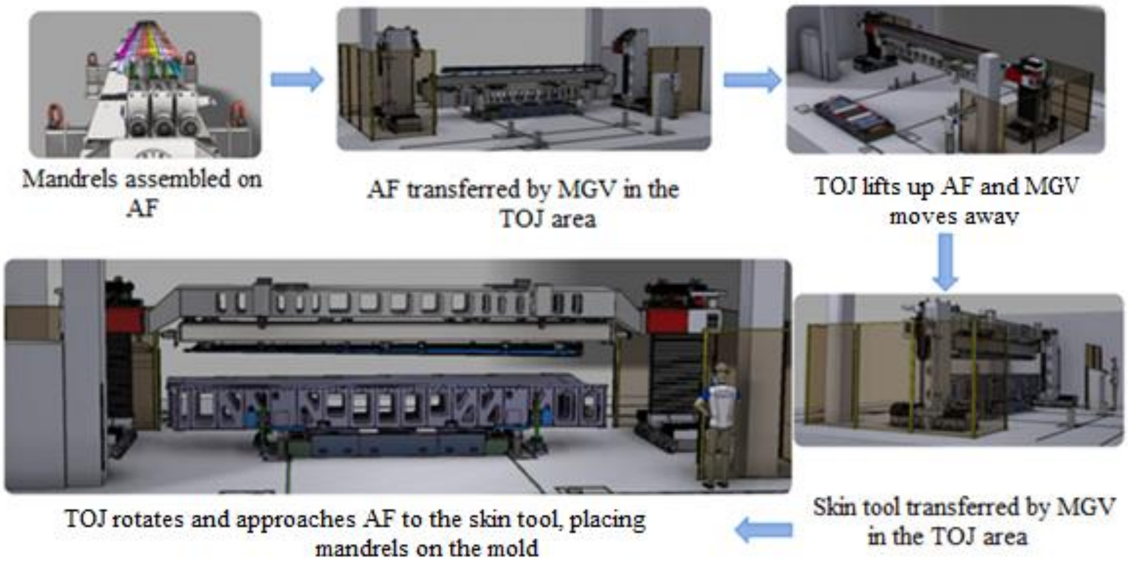

Figure 9 – AF/TOJ cycle

All the axis of TOJ shall be driven by brushless motors to ensure reliability, fluidity and accuracy in movements. The system controlled by Simotion [8] will follow the path according a 3D model and final approach will be adjusted through linear encoders in order to achieve accuracy and repeatability within ± 0.010 inch in the mandrels positioning. Fig. 10 shows the steps for the approaching of AF to the skin tool.

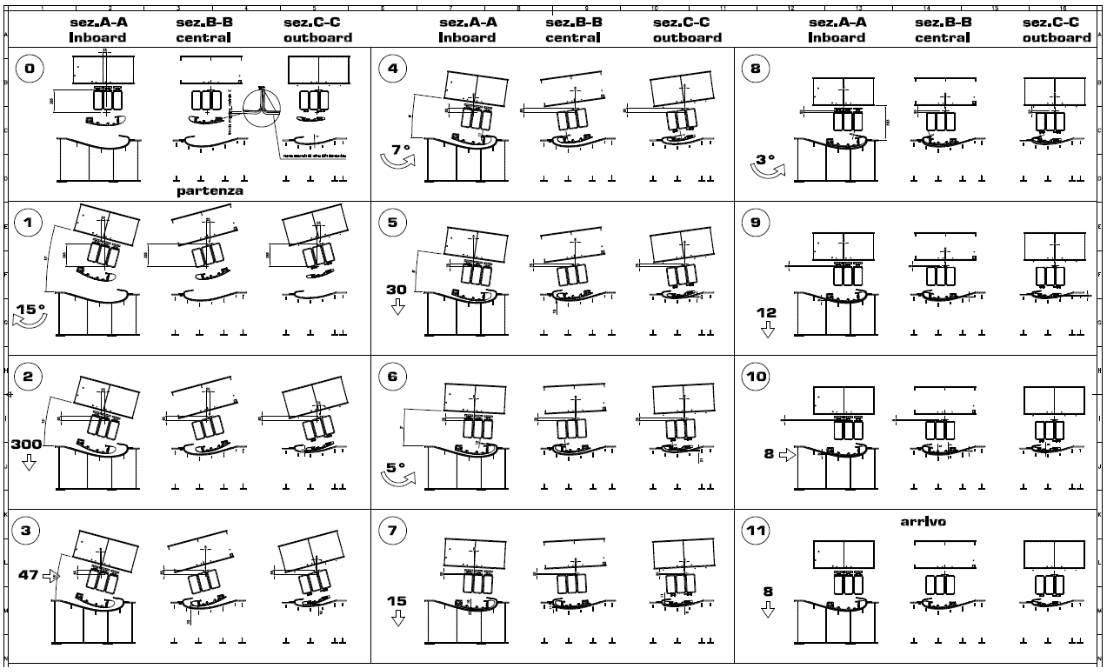

Figure 10 – Approaching and positioning of AF on the skin tool

4 Digital simulations

Implementation of the new process requires relevant capital investments and for this reason a digital twin of the current process and a simulation model of the redesigned process have been created.
The simulation tool used is Tecnomatix Plant Simulation, a software which provides discrete event simulation and through powerful graphical visualization, reporting features and genetic algorithms enable evaluation of the behavior of production systems [9]. In particular, as shown in Fig. 11, three different blocks have been modelled in order to assess the production system:

- Pre-Clean Room: activities performed before the clean room, this includes operation like tool cleaning and release agent application;
- Clean Room: activities performed in clean room, include all the operation of cutting, kitting, layup and bagging;
- Post-Clean Room: activities after the layup process, included autoclave and debagging.

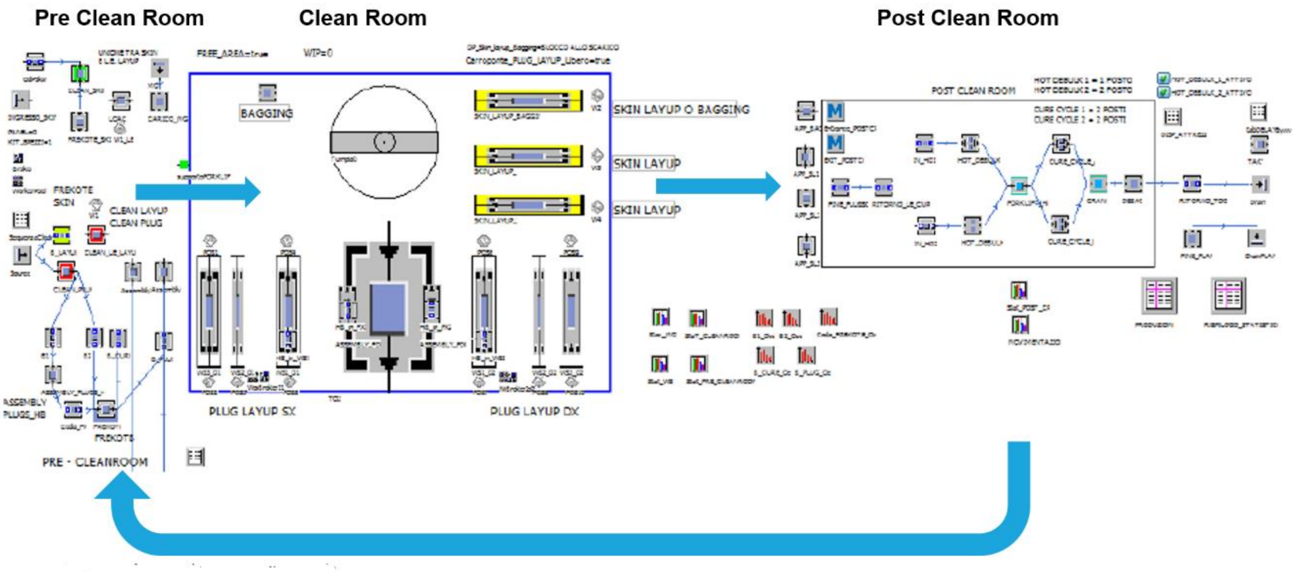

Figure 11 – Manufacturing Flow diagram for digital simulation

For each block all the relevant production data including cycle times, number of tool chains and number of shifts have been set parametric, enabling to carry out a sensitivity analysis.
Over 200 parameters, available on the user interface, have been tuned in order to get the best configuration that achieves production demand and optimization of workstations, labor requirements, equipment and layout.
The digital twin, simulating the current process, supply to the management a powerful tool for monitoring asset performance and utilization and supporting transition phase before the introduction of the new production system.
Besides, since the digital simulation of the new process cannot be verified until the start production of the new tooling and automated cell, simulation of the current process enable modelling approach validation, being accuracy of the production output easily checked.

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5 Conclusion

Preliminary test show that the new tool chain will drastically reduce the quality defects of the current production thanks to the durability and thermal properties of the invar material.
Moreover, the introduction of the automated cell will allow repeatability and precision in the most critical phases during the lay-up process.
Detailed analysis and digital simulations supported the evaluation of the impacts of the new production system, addressing the management to the production flow improvement through detection and elimination of bottlenecks, enabling to meet Customer requirements and demand of the next years.

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