

Positioning System for the Aircraft Structural Assembly

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ABSTRACT

This paper presents a new conception of a positioning technology concept for aircraft structural assembly, for instance the manufacturing of the fuselage sections from shell panels and floor grids, the alignment of the sections to build the fuselage, and the joining of wings and tail units to the fuselage. The positioning system features a modular, reconfigurable, and versatile solution for various aircraft dimensions and different applications. It provides the customer with a holistic solution that considers the positioning task taking into account the operation conditions and the environmental influences within the very same control unit. The positioning system consists of three main modules that communicate over a standardized interface: A large-scale metrology system for an accurate identification of the positions and orientation of the aircraft components, a mechanical system for the handling of these components and a control system. The latter is the core module of the positioning system. It ensures a synchronous driving of up to forty-eight (48) axes and thus guarantees the proper handling of the aircraft components by no deflection during the assembly process. Highly efficient strategies and robust algorithms for the compensation of mechanical and thermal effects are embedded within the control system and guarantee high positioning accuracy. In performance evaluation tests within the project A350 XWB, an absolute accuracy less than ($\pm 0.1\text{mm}$) and a repeatability less than ($\pm 0.05\text{mm}$) for the positioning of large shell panels measuring almost 20 meters by 6 meters could be reached.

INTRODUCTION

Automated mating of large aircraft components offers an alternative solution for aircraft manufacturers to cut costs, improve process quality, and shorten time-to-market. More

and more, flexible and automated systems are replacing hard jigs throughout the whole process of aircraft structural assembly, for instance for the manufacturing of the fuselage sections from shell panels, the alignment of the sections to build the fuselage, and the joining of wings and tail units to the fuselage.

In the last decade, few approaches were proposed for automated assembly systems consisting of multiple manipulators, which act simultaneously to handle the aircraft components [1, 2, 3, 4]. Especially in conjunction with innovative composite materials and particularly the carbon fiber reinforced plastics (CFRP) which finds broad use in the new aircraft programs (B787 Dream liner, A350 XWB etc.), the challenge for these assembly systems consists in the proper handling and accurate positioning of the aircraft components. Furthermore, aircraft manufacturers impose extremely narrow tolerances in terms of absolute positioning accuracy less than ($\pm 0.1\text{mm}$), repeatability less than ($\pm 0.05\text{mm}$) and synchronization of the motion for all manipulators that constitute the positioning system [5].

In this paper, we present the “**EcoPositioner**” positioning system, a new conception of a modular and reconfigurable positioning technology that provides a holistic solution that considers the positioning task as well as the operation conditions and environmental influences. The positioning system can afford high flexibility and assure high product quality for aircraft structural assembly. We first discuss the key tasks in the assembly process of aircraft components. Then, we present the major components constituting the “**EcoPositioner**” positioning system:

A mechanical system consisting of multi-manipulators, or multi-positioners that pick up the aircraft component at

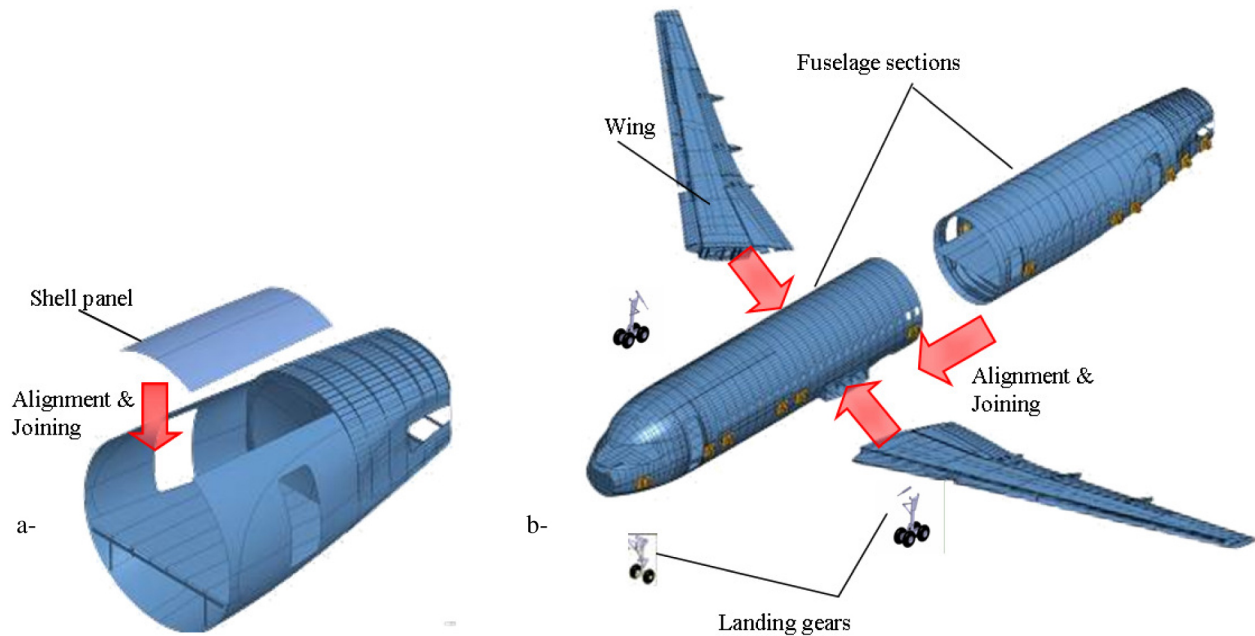


Figure 1. Main alignment tasks in the aircraft assembly process. a- Section assembly PreFAL; b- Final assembly FAL

defined attachment points and manipulate it in 6 degrees of freedom (3 translational and 3 rotational).

A measurement module, which consists of large metrology system and measurement software, provides information on the current and the ideal poses (positions and orientations) of the aircraft component. The current and the ideal poses are determined according to the reference frame related to the CAD-models of the components and the aircraft structure.

A reliable robot- controls platform that guarantees a high synchronization of up to forty-eight (48) actuated axes per control unit. The “*EcoRPC*” control system is well-proven worldwide, and is used in more than 6000 robot applications. With the aid of force sensors mounted on the end-effector of each positioner, the forces acting on the aircraft component can be monitored during the motion. This assures strain-free handling of the components, and thus, prevents them from uncontrolled deflection.

However, absolute motion synchronization, only, can neither account for the positioning accuracy nor for a damage-free handling of the aircraft components. Indeed, the mechanical system remains the major factor to reach a high accuracy, particularly, when the mechanical components undergo the impact of load and thermal variations. The essential part of this paper addresses an educated and reliable strategy based on an analytical approach to compensate the impact of load and temperature variations on the accuracy of the positioning system.

Finally, we outline the results of the performance tests of the positioning system for the production line of the fuselage section of a current aircraft program.

MAIN TASK IN THE ASSEMBLY PROCESS

If we analyze the mating process of the aircraft structure, we might realize that the main tasks consist in the alignment of structural components to each other, and joining them together. Be it in the process of the assembly of fuselage sections from single shell panels (PreFAL) or the assembly of the aircraft structure (FAL) as in [figure 1](#), the positioning of the components or working tools, for instance for drilling and riveting/fastening operations, represents the essential task during the whole process.

Especially for large and geometrically complex structural components, which by their very nature suffer from considerable physical distortion, the positioning task becomes more crucial. Classical assembly methods use large complex jigs, which are specially tailored for an aircraft type. The massive jigs physically control the shape of the aircraft component, and have to be moved together with the component to the assembly position. Using hard jigs does not need the assignment of highly skilled workers but are expensive, have long manufacturing lead times and cannot be economically modified for use on other aircraft types.

An alternative solution to the hard jigs consists in the use of flexible manipulators, in the following termed positioner, such as Cartesian or standard industrial robots. Combined with an accurate, large metrology system and an advanced

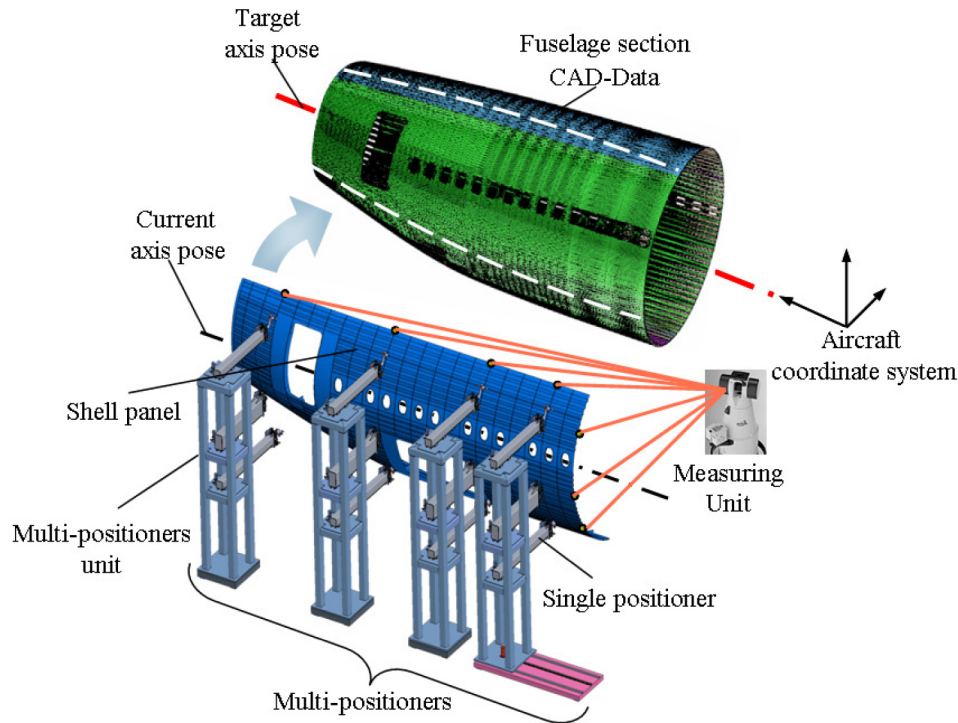


Figure 2. Main sequences in the assembly task

control system, the positioning task as shown in [Figure 2](#) can be structured as follows:

- Pickup of component using multi-positioners at defined attachment points located on the component
- Measuring the geometry of the component, for instance using a laser tracker and spherical mounted retro-reflectors (SMRs) that are placed at defined locations
- Adjusting the component geometry with respect to product design (CAD-data) using for instance Best-Fit strategies. This operation is some times necessary, especially for CFRP components
- Measuring the current pose of the component
- Generating the motion path from current to ideal pose as corresponding to the CAD data of product design. Advanced controls with robust path planning strategies are mandatory for this operation to avoid damage to the component
- Moving the component to ideal pose, taking into account the restrictions on the accuracy and the synchronicity of motion.

POSITIONING TECHNOLOGY

Considering the steps to be taken for the assembly of aircraft large components, we can easily deduce that, mainly, four functionalities have to be provided to carry out the assembly task. First, an accurate measurement of points specifically placed on the component to recognize its shape and

determine its pose must be taken. Therefore, various metrology systems can be used, for instance systems based on Laser technology such as Laser Trackers and Laser Radars, or a combined laser and infrared technology such as an indoor global positioning system (IGPS). Second, a safe acquisition, analysis and processing of the measurement data has to be assured. This task can be assured by metrology software, which can analyze the measurement data, and compare them with the CAD-data of the components and their locations in the assembly site using robust Best-Fit strategies. Subsequently, the current and the ideal poses of the component should be transmitted to the control system. The third task consists in the generation of the trajectory along which the component will be moved from the current to the ideal pose. Since multiple positioners simultaneously act on the component to conduct the motion, this task constitutes a tremendous challenge for any control system. For the path generation, the control system, not only has to account for the restrictions related to the workspace of each positioner, but also has to avoid any excessive strain induced by the positioner on the component during the motion. In addition, the transmission of the commands to positioners' drivers should occur synchronous to avoid any damage to the component. The crucial task throughout the assembly process consists in the execution of the motion. Despite all additional impact in terms of external loads and environmental conditions such as temperature fluctuation, the single positioner should feature a positioning accuracy superior to that required for the component itself.