Development of Large-sized Aircraft Fuselage Panel Mixed-flow Production Line

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As the competition between Boeing and Airbus has been intensifying, the market environment of our main product, large-sized aircraft fuselage panels, is required to change to a manufacturing and production system that can quickly follow production fluctuations and cost reductions. As a means to solve the problem, we have reviewed the conventional production system that is centered mainly on skilled workers and relies on many large-sized stationary jigs, and then worked on the development of a mixed flow production line incorporating automation equipment that realizes production flexibility, high quality and labor saving. In this paper, the newly developed mixed flow production line is presented.

1. Development background and features of new production line

1.1 Product features and difficulties in manufacturing aircraft

Our company produces the aft fuselage section in the shape of fuselage panels divided in the longitudinal direction and the circumferential direction of the aircraft (**Figure 1**). The dozen or so fuselage panels have the following characteristics.

(1) The panels differ from each other consisting of single-curve surfaces and multiple-curve surfaces.

(2) The component configuration includes many long, thin-plate, deformable, and non-rigid parts represented by the outer fuselage panels.

(3) The assembly accuracy is 1 mm or less despite being such long and non-rigid parts.

For this reason, the conventional production system prepares large stationary jigs (**Figure 2**) dedicated to each of the fuselage panels for each assembly process, and the component parts are held in the shape of the aircraft body with the large stationary equipment during production. However, production using these stationary jigs involves many operations in narrow spaces and is mainly based on work operation performed by skilled technicians, so it is difficult to apply automation. Furthermore, since multiple fuselage panels are simultaneously assembled in multiple processes, the process management requires labor, and inefficiencies arise as a result.

In addition, since the product is assembled while moving across multiple stationary jigs, assembly errors accumulate every time a stationary jig is moved, and therefore maintaining accuracy becomes complicated.

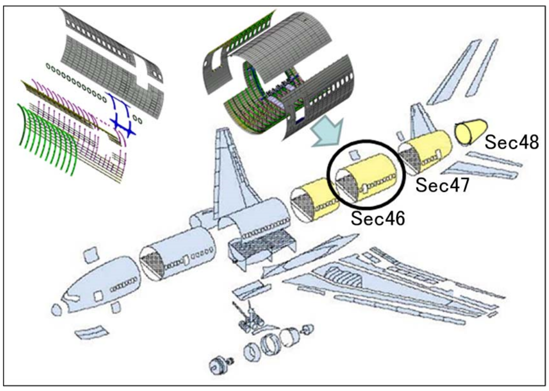

Figure 1 Fuselage division schematic drawing

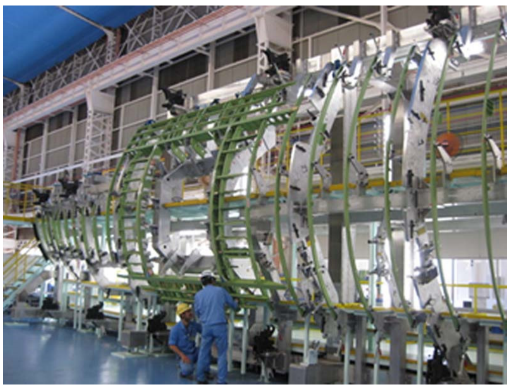

Figure 2 Conventional stationary jig

1.2 Functions and concepts required for new production line

For creating a new assembly line, we set out the basic policy of eliminating dependence on skilled technicians, eliminating the stationary jigs, and improving flexibility, and worked on the development of the M-PAL (Multi-panel Pulse Assembly Line) mixed-flow production line based on the concept below.

(1) Application of movable jigs that hold non-rigid, long-shaped parts to the designed shape of the aircraft accurately
(2) Transfer of the movable jigs on the automated conveyer system to minimize cumulative error
(3) Mixed flow assembly line capable of assembling a dozen or so kinds of panels
(4) Introduction of automated equipment aggressively such as handling robots, new type automatic riveters, inspection devices, etc.
(5) Standardization of manufacturing processes of a dozen or so kinds of panels to introduce linearly-arranged integrated production lines
(6) Introduction of highly-integrated management system that enables real time monitoring of production status, quality and health of each piece of equipment on M-PAL by utilizing IoT technology

2. Specifications of M-PAL (Multi-panel Pulse Assembly Line)

Figure 3 shows the configuration of M-PAL. M-PAL has thirteen (13) work stations and the process is summarized into the following four (4) major processes:

(1) Process of setting the fuselage skins: Positioning and temporary joining of fuselage skins and door surrounding structure onto the movable jigs
(2) Process of drilling and riveting the outer surface of panel
(3) Process of drilling and riveting the internal frame structure
(4) Inspection of dimensions required for the assembled fuselage panel

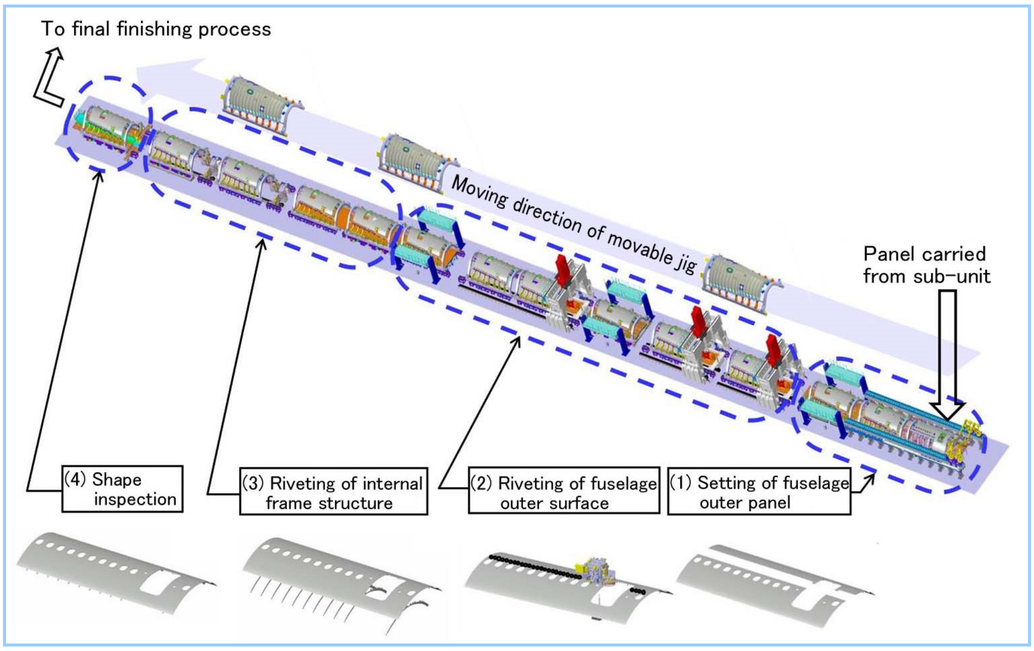

Figure 3 MPAL process schematic drawing

2.1 Assembly processes of M-PAL

Fuselage panels differ in the existence of boarding door structure, the shapes of single-curve surfaces and multiple-curve surfaces, etc., and the processes and work volume of assembling work of such fuselage panels vary significantly. To make M-PAL capable of processing various types of fuselage panels, it was necessary to divide the assembly process of each panel into common work and special work. The common work was set into M-PAL first, and then additional work stations were set for the special work. A simulator was used to determine the processes and stations. The simulation was repeatedly carried out so that panels with different working volumes can be produced smoothly to confirm the feasibility of the line.

2.2 Integration of automatic riveter into line

For this mixed flow production line, we considered the equipment configuration of the assembly line, centering on the automatic riveter that performs automatic drilling and riveting. Conventional automatic riveters have a weak point that it takes a lot of time for handling work for loading and unloading fuselage panels, so we set out the specifications of the jig and the conveyor system so that the handling efficiency of fuselage panels could be improved. We selected Gantry-type automatic riveters (**Figure 4**) for the outer surface of panels to eliminate panel handling. Three (3) sets of Gantry-type automatic riveters are set in a line to share the task and secure mutual back-up of riveters. In addition, an automatic riveter (**Figure 5**) for riveting of the internal frame structure was also incorporated into the line, and the applicable range of automatic riveting was greatly expanded.

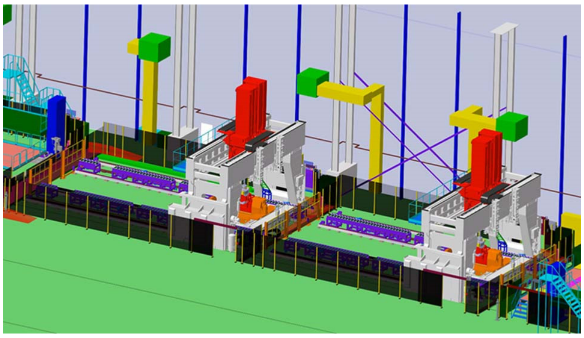

Figure 4 Gantry-type automatic riveter

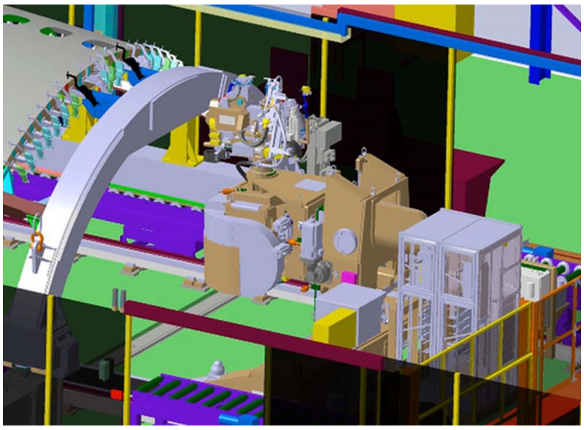

Figure 5 Internal frame automatic riveter

The conveyor system connects 13 stations in M-PAL so that the fuselage panel can be easily transferred throughout the line. The fuselage panel is placed on a movable jig and sent to the automatic riveter in the as-placed posture, and then the work operation is automatically started. At this time, the conveyor system is provided with a reading function of the IC tag so that the product inserted into the line can be identified, and the object program from the host system can be downloaded. In addition, an interlocking function that allows move of the jig upon the completion of work of each piece of equipment such as the automatic riveter is provided.

2.3 Concept of jig

The conventional stationary jig has a structure in which a fuselage panel is placed vertically in consideration of the working posture of the worker. On the other hand, for the jig of M-PAL, a structure in which a fuselage panel is placed horizontally was adopted in consideration of the size of the automatic riveter and the stability during running on the conveyor. To secure a wide riveting area of the automatic riveter, the movable jig holds the peripheral part of a panel without holding the center of the panel, and improves the accessibility of the automation device. At this time, in the first process of M-PAL, the panel shape accuracy is ensured by temporarily combining the header tool (**Figure 6**) with the panel center part holding function and the movable jig to support the panel component parts and maintain the panel shape. The header tool incorporates NC automatic control so that a dozen or so kinds of fuselage panels with different shapes such as a single-curve surface, a multiple-curve surface, etc., can be freely positioned. This makes it possible to guarantee maintenance of the shape and the accuracy using the jig concept changed from a large stationary jig to a movable jig.

With conventional stationary jigs, errors between jigs occurred every time a panel was unloaded and loaded between processes, resulting in adverse effects on the accuracy of the product. In M-PAL, however, errors between jigs caused by unloading and loading of panels were eliminated by progressing the assembly work by using a movable jig.

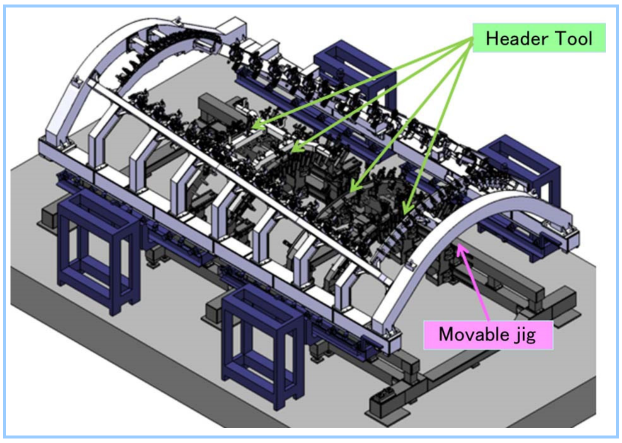

Figure 6 Header tool and movable jig

3. New technology applied to processes

3.1 Handling of outer fuselage panel by robot

In the conventional production system, multiple workers position a fuselage outer panel on each dedicated jig while using a crane and slings to check the interference between the part and the jig. The crane work was a time-consuming operation that requires repeated horizontal and vertical movement to position the panel while paying attention to safety at work and to interference between a part attached to the inside of the fuselage panel and the dedicated jig. On the contrary, in M-PAL, a robot handling system where a robot holds a suction pad to suck the fuselage panel and moves in the circumferential direction or in the direction perpendicular to the plane is applied (**Figure 7**).

With this robot handling system, one fuselage panel is sucked by two robots and cooperatively handled. The cooperative control of the two robots and the 3D correction system enable a fuselage panel as long as about 8 m to be positioned in the reference position provided on the jig. By this robot handling, the time taken to put the fuselage panel to M-PAL is drastically reduced in comparison to the conventional method.

Figure 7 Handling robot

3.2 Automatic shape inspection

Aircraft fuselage panels are required to have key hole position accuracy and shape accuracy as a basis for the final assembly of the aircraft fuselage at our customer's factory. The previous production method uses the dedicated jig and gauge to determine acceptance/rejection. However, M-PAL adopts a shape inspection system so that the digitization of the assembling accuracy and cycle time saving are both satisfied at the same time. This shape inspection system uses a robot with three-dimensional photographic measurement equipment (**Figure 8**) to perform automatic measurement. In addition, all digitized quality data is accumulated into the server to be used for the future improvement of quality and the early detection of any problems with M-PAL.

Figure 8 Shape inspection equipment

3.3 Automatic appearance inspection

In the case of the conventional production method, the final quality inspection of the panel surface was performed by a qualified skilled inspector after the completion of assembling work. Because no quantitative guidelines of the acceptance judgment were clarified, a skilled inspector was required. M-PAL applies an appearance inspection system to eliminate the need for a skilled inspector and clarify the quantitative guidelines. The appearance inspection system is an image processing system that incorporates AI for detection of scratches on the panel surface based on an image captured with a high-resolution camera, and the judgment accuracy improves due to the learning function. As a result, the judgment guidelines that previously required skilled work have been quantified.

3.4 Utilization of IoT

As described above, this mixed flow production line improves the quality and work efficiency by introducing automated equipment and a conveyer system, for which an integrated management system was also developed. The integrated management system not only monitors the status of equipment and jigs and the production status, but also supports downloading of an NC program for the automatic riveter and collects real-time data of equipment processing conditions and quality records. The information can be monitored from anywhere, such as the management department, the field office, the parts manufacturing department, etc. We plan to utilize the collected big data also for improvement of the quality and work.

4. Future prospects

As demands for the aircraft manufacturing industry increase and market competition intensifies, innovation of the aircraft fuselage panel production process is urged, and there are great expectations for a technical revolution. In order to eliminate tailored production using stationary jigs, we developed M-PAL to introduce mixed-flow production that was difficult in the past to the aircraft manufacturing industry for drastic efficiency improvement. In this fiscal year, we started to apply M-PAL to the actual production of a dozen or so different kinds of panels while carrying out debugging and teaching of the programs for various automation devices, aiming at the establishment of the production line. Despite the launch phase with a low rate of production, certain effects of the introduction of the mixed-flow production line are beginning to appear, such as the fact that workers can be consolidated in a reduced manufacturing area in comparison to the conventional method and the work progress can be visualized. In the future, we will work on activities for the further leveling of the line balance and the shortening of the tact time.