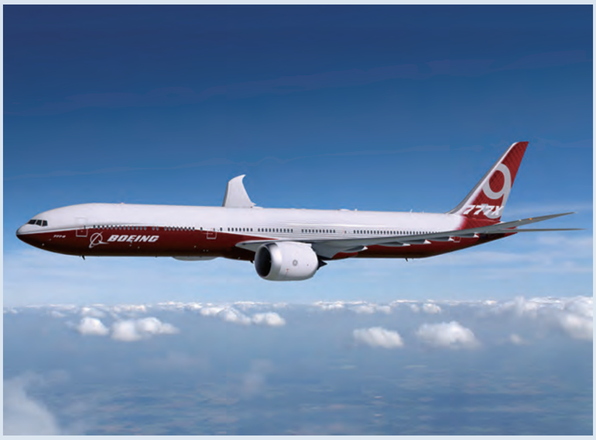
State-of-the-Art Large Commercial Aircraft Boeing 777X



As the number of jetliners is expected to steadily increase, the demand for the Boeing 777X, the successor to the Boeing 777, is expected mainly in crowded and long-distance airline routes. Boeing launched the 777X development program in November 2013 and plans to bring it into service in 2020.

We have participated in this joint international development from an early stage of design and worked on cost reduction and automation, for example, by deploying an automated design tool or enhancing the application range of assembly robots.

Introduction

According to a long-term forecast for commercial aircraft demand, the number of passenger jets in operation is expected to steadily increase because of a 4.6% annual average growth rate of revenue passenger kilometers over the next 20 years[1).

1 Background

The Boeing 777 is a best-selling twin-engine passenger jet realized by the international joint development of which was participated in by Kawasaki in the 1990s. It is expected that there will be demand for it mainly on busy passenger routes and long-distance routes under the current airport congestion and long-term increase in fuel prices. The Boeing 777X development program was launched in November 2013 as the successor to the Boeing 777 with the aim of further improving selling power and competitiveness.

2 Development Plan

For the international joint development of the 777X, Kawasaki took charge of the same production workpackage as the Boeing 777 as shown in **Fig. 1**.

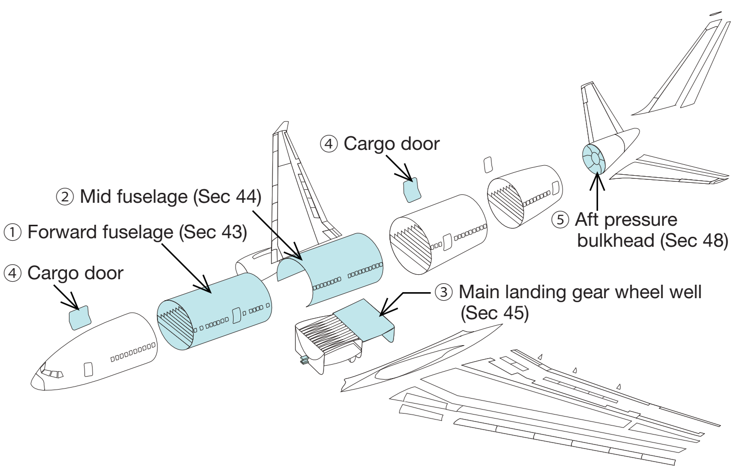


Fig. 1 Production workpackage in Boeing 777X

Before this aircraft development, we carried out technology development of materials, structures and manufacturing engineering for the main parts of the fuselage structures starting in 2013 in order to realize advanced aluminum fuselage structures under joint development with Boeing. This technology development is reflected in the actual production equipment and facilities. In the fuselage development, as is the case with the development of derivative airplanes of the 777, we also participated in airplane level work (known as program level work) in addition to design and analysis works as a member of the development team formed in the Boeing Company in the U.S. From September 2015 through June 2017, about 30 engineers took part in the joint development.

According to the initial plan, all design activity would be completed in the U.S. But, to improve manufacturability and design data quality, it was decided to design in Japan simultaneously, so a design team of about 30 members was formed. Designing it in Japan contributed to the overall development schedule and was highly evaluated by the Boeing Company because of the high-level communication and engineering capability that capitalized on the experience accumulated in past joint development projects.

3 Outline of the Aircraft

There are two types of the 777X. One is the Boeing 777-9 that has more passenger seats, and the other is the Boeing 777-8 that has the longer cruising range. The Boeing Company received the first order from Lufthansa German Airlines and then launched the development of the 777-9.

(1) Major Specifications

The 777-9 has a stretched fuselage as a derivative of the present Boeing 777-300ER. It has more than 400 passenger seats and its cruising range is 14,075 kilometers (7,600 nautical miles). Its wing structure is made of composite materials instead of the conventional aluminum alloy to improve aerodynamic performance. While the wing span is extended, it has folding wing tips so that it does not exceed the limit set by airports. It is powered by General Electric's new engines and its fuel efficiency 20% better than the present model. A comparison of the major specifications is shown in **Table 1**. As shown in **Fig. 2**, the latest interior designs such as LED lights, large cabin windows and humidifying devices are applied.

Table 1 Specifications of the 777-9 and the 777-300ER

Aircraft Model	777-9	777-300ER
Seats	414	396
Design Range 〔km (nm)〕	14,075 (7,600)	13,649 (7,370)
Overall Length 〔m〕	76.7	73.9
Wingspan 〔m〕	71.8 (64.8 on ground)	64.8
Overall Height 〔m〕	19.5	18.5
Engine	GE9X	GE90-115BL

Table 2 Major structure of workpackage (forward and mid fuselages) in the 777-9 and the 777-300ER

Aircraft Model	777-9	777-300ER
Passenger entry door location	Center of forward fuselage	Front of forward fuselage
Standard layout of passenger seats	10-across seating	9-across seating
Cabin pressure 〔kPa (psi)〕	62 (9.0)	59 (8.6)
Cabin window height 〔mm (in)〕	441 (17.36)	390 (15.36)
Fuselage skin material	AL2524 / AL2029	AL2524 / AL2024

(2) Change in Primary Structure of the Workpackage

In the case of the 777-9, as shown in **Fig. 3**, as the stretched part of the forward fuselage is located on the nose side of the forward fuselage (Sec 43), the position of the passenger entry doors are not all closer to the front unlike the present model. As the position of passenger entry doors are located closer to passengers in the central part of the fuselage, the emergency exits[2)] in the mid fuselage (Sec 44) were removed to reduce weight and cost.

For the seat configuration, the cabin width was increased to make 10-across seating the standard, and the side frame height was reduced by 42 mm (1.65 inches) at maximum on the broadside by changing the side frames of the cabin from sheet metal to machined integral parts.

Moreover, the cabin environment is improved in the same way as for the 787 by improving the cabin pressure and making the cabin windows bigger. Also, the reliability and maintainability were improved by applying a corrosion-resistant material (AL2029) to part of the lower skins of the fuselage. A comparison of the major structures of the forward and mid fuselages, which made up our workpackage, is shown in **Table 2**.

4 Challenges in 777X Design and Production

(1) Design

To improve marketing competitiveness, the 777X required redesign of almost all of its major structural parts to optimize the cost and weight, in addition to design changes due to changes in specifications, while its fuselage structure followed the basic structural type of the present model. Therefore, within the limited schedule and budget, it was required to create many models and drawings. Moreover, to expand the scope of application of automation, it was necessary to ensure tool clearance and reflect the specifications of production equipment such as robots and machine tools in the design at an early stage.

Fig. 2 Interior image of the 777X

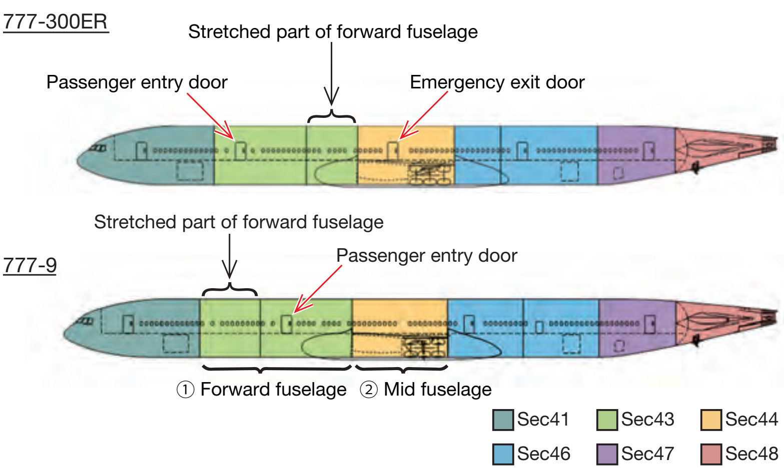


Fig. 3 Overview of change to the fuselage extension

(2) Production

In the production of the 777X, it was necessary to increase the level of precision for final assembly by the Boeing Company and for side frame integration.

(i) Final Assembly by the Boeing Company

As shown in **Fig. 4**, the Boeing Company decided to make changes by introducing a jig-less assembly method that makes full use of robots into the final assembly line of the fuselage. With this decision, the conventional jig-and-tool-based method was changed to a method that uses coordination holes drilled in the panels of our workpackage. If the precision of these coordination holes was poor, the fuselage would not be able to be assembled as designed in the final assembly process by Boeing, which would cause much adjustment work. As poor precision would be a hindrance to planned production, it was necessary to increase the precision of the coordination holes of the panels.

(ii) Side Frame Integration

As shown in **Fig. 5 (a)**, as the present 777-300ER has a structural type in which the side frame parts made of sheet metal are attached to the fuselage skins using shear ties as structural members, the unevenness of the frames and skins themselves can be compensated for by the shear ties. As shown in **Fig. 5 (b)**, on the other hand, the 777X uses machined integral parts, including shear ties, and its structure has been changed to directly fasten side frames to fuselage skins. Therefore, it was necessary to increase precision because of the possibility of significantly increasing the work of fill gaps in the assembly process. Moreover, aiming at further increasing the efficiency of productivity, we decided to expand the scope of automation, not only by making use of conventional assembly equipment but also by developing robots.

Fig. 4 Final assembly using robots (at Boeing)

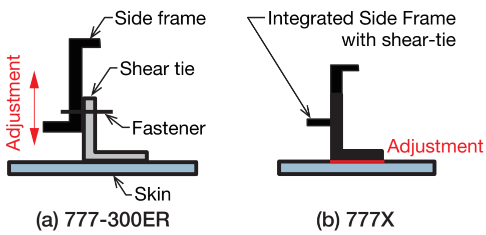


Fig. 5 Integrated side frame

5 Efforts

(1) Design

To improve the efficiency of the design work, automated design tools that use the relational design and programming functions of CATIA V5 CAD software were applied to major structures of the fuselage. Relational design is a function of CAD software that automatically adjusts 3D shapes when the dimension values of parts are changed. 3D models of parts and some of the 2D drawings were both automatically created based on the 3D models using this function. Automated design tools can also be used to decide on shapes and fastener locations of parts by considering design requirements, materials to be applied and production equipment in advance. This has made it possible to design many parts of consistent quality with a small number of people in a short period of time.

The decrease in strength due to burrs and elastic seals that are caused at the time of drilling cannot be accepted in some cases at the fastener joints where faying surface seals are applied between parts for airtightness and corrosion resistance. In such cases, we coordinated with the production and technology division and specified detailed production information such as drilling methods, the sequence of fastener installation and clamping methods/locations in production drawings and process control drawings.

(2) Production

(i) Increase in Precision

As part of our efforts to increase precision, we made temperature control during part processing stricter. In the past, we compensated for the operation programs of production equipment in response to the temperature environment immediately before processing. But, as temperature changes cannot be accounted for when processing is in progress, it sometimes caused a slight difference in the precision of parts between the highest and lowest temperatures during daylong processing. In the case of the 777X, it was made possible to carry out processing at the specified design temperature by eliminating disturbances due to temperature correction in the machining of side frames as large structural members, assembly work of 10-meter or longer fuselage skin panels and the sub-assembly work of stringers. For the fuselage skin panels, we produced skin retainers equipped with the high-precision actuators shown in **Fig. 6** for processing as designed and realized high precision drilling of coordination holes.

In addition to measures for increasing the precision of parts, the final assembly of panels was changed from conventional vertical installation as shown in **Fig. 7 (a)** to horizontal installation as shown in **Fig. 7 (b)**, and the inner surface of the fuselage skin panel was followed evenly in a stable manner to the jig and tool standards, making it possible to construct the inner surface of the panel as designed.

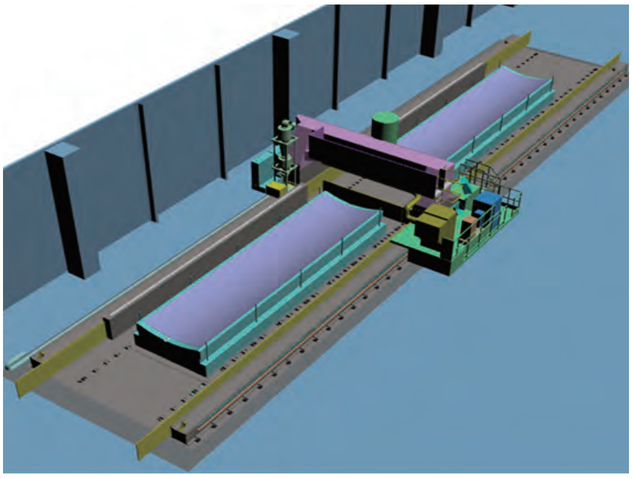


Fig. 6 Coordination hole drilling system with a high precision actuator

(a) Vertical installation

(b) Horizontal installation

Fig. 7 Final assembly jig

Fig. 8 Enhancement of automation using a riveting machine

(ii) Expansion of Automation

In the final assembly, we were able to automate the conventional work of manual installation. In addition to panel splice work, installation of machined integral frames and structures around doors were automated by the riveter shown in **Fig. 8**.

As part of the expansion of the scope of automation, we also introduced a new method that combines robots, equipment, jigs and tools. We reviewed the method that combined conventional drill templates and general-purpose power feed drills, and realized large-diameter drilling with high rigidity robots and the sub-assembly work that combined riveters and robots. Moreover, we also achieved multi-machine handling work by combining high rigidity robots and large jigs and tools.

Conclusion

We completed the delivery of the first 777-9 jet from Nagoya Plant 1 in February 2018. Next, The Boeing Company plans to acquire a type certificate after the first flight in 2019, and to start delivery to airline companies in 2020. Boeing has received orders for more than 300 aircraft as of the end of April 2018.

At present, we are proceeding with the development of the 777-8 as a derivative airplane, and we will progress with the development in cooperation with the Boeing Company to further increase efficiency and make improvements based on the experience we gained from working on the 777-9. Lastly, we would like to express our thanks to the International Aircraft Development Fund and Japan Aircraft Development Corporation for their guidance and support.

Reference

1) Japan Aircraft Development Corporation, Market Forecast for Commercial Aircraft, 2017-2036, pp. 26 (2017)
2) FAR Part 121 Sec. 121.291: Demonstration of emergency evacuation procedures

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