Flight Tests of MRJ

Mitsubishi Aircraft Corporation

The Mitsubishi Regional Jet (MRJ) is a next-generation regional jet developed by Mitsubishi Aircraft Corporation that realizes both the world's highest-class operational economy and outstanding cabin comfort at the same time. After its first flight on November 11, 2015, we have been currently conducting flight tests of the MRJ at Grant County International Airport, in Washington, USA. Meanwhile, at the Mitsubishi Aircraft Headquarters in Japan, technical work for the type certification necessary to bring the aircraft into service is progressing. Manufacturing of the production model has also started, and development is being accelerated for delivery to airlines in both Japan and the United States.

In the past, we presented the MRJ development status in the Mitsubishi Heavy Industries Technical Review ("Mitsubishi Regional Jet (MRJ)" in 2014 and "The First Flight of the MRJ" in 2016). This paper reports on flight tests of the MRJ.

1. Background

The MRJ, which received the go ahead for its development after receiving an order from All Nippon Airways Co., Ltd. (ANA), made its first flight on November 11, 2015. Then three flight test aircraft began flight, and the flight tests in Japan using the flight test aircraft and ferry flights to the United States were carried out. Currently the four flight test aircraft are proceeding with the flight tests in the United States. We are promoting tests and design work, including the flight tests, for the type certification that proves the safety of the aircraft, and will continue development toward delivery of the finished aircraft.

2. Development state

As mentioned above, the main development work of the MRJ is currently underway in both Japan and the United States. In other words, the compilation of the overall development work is being carried out at the Mitsubishi Aircraft Headquarters in Nagoya Airport Terminal Building in Toyoyama Town, Aichi Prefecture, and the flight tests which is an important part of the development is being carried out at Grant County International Airport, in Washington, USA.

The Mitsubishi Aircraft Headquarters in Japan oversees tasks related to the management of the overall development and the model certification, as well as the accompanying design work. Discussion and examination of related matters are being carried out every day between the Aircraft Engineering and Certification Center of the Ministry of Land, Infrastructure and Transport's Civil Aviation Bureau adjacent to the Nagoya Airport Terminal Building, where the Mitsubishi Aircraft Headquarters is located.

At the Moses Lake Flight Test Center (MFC) at Grant County International Airport, in Washington, USA, flight tests and ground tests of the first to fourth flight test aircraft are being conducted.

All this work in the United States and Japan is conducted to confirm the performance and safety of the aircraft and obtain the type certification. Type certification is a system to validate the safety of a newly designed and manufactured passenger aircraft. It also ensures that the MRJ meets the safety regulations (technical requirements) set by the Japan Civil Aviation Bureau (JCAB), the Federal Aviation Administration (FAA) and the European Aviation Safety Organization (EASA). This is achieved as a result of significant technical operations including the flight tests, the ground tests, the test of standalone equipment and the examination of the type certification documents by authority officers to prove the safety of the aircraft by combining these test results with analysis. Based on the challenges and the results of accidents encountered since the emergence of passenger aircraft around the world, etc., the regulations that form the basis of the type certification have been progressing up to the present time and new requirements have been set one by one to avoid the recurrence of accidents and ensure safety. This means, in other words, that newer aircraft need to meet newer (stricter) requirements that are newly set. It goes without saying that the development of a passenger aircraft means to design and manufacture a safe and comfortable aircraft. However, the type certification, which is a task of objectively proving that the safety of the aircraft conforms to the regulations, accounts for a large part of the development. This is one reason why the MRJ is a major challenge for Japan, which has not experienced the development of a new passenger aircraft since the YS-11 (**Figure 1**).

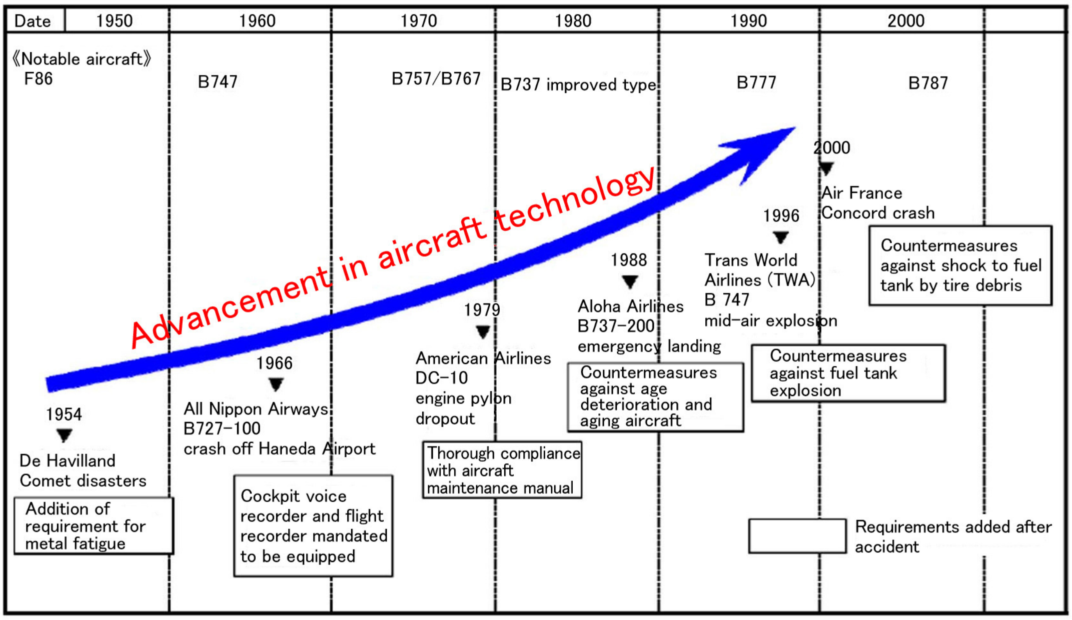

Figure 1 Technological progress of aircraft and history of safety requirements

Specifically, the examination of the type certification confirms the safety of the aircraft using the drawings, analysis (calculation), and tests for various fields and parts such as the aerodynamics, structure, and equipment systems of the aircraft. Since a passenger aircraft is exposed to a range of environmental conditions and operating conditions (number of passengers, amount of fuel, etc.) in the series of operations of takeoff, cruising, landing, and ground maintenance, confirmation of the safety of the aircraft is conducted for all conditions assumed during the operation. The conditions that must be proven are prescribed by the regulations set by each authority. Many diverse tests such as flight tests and ground tests carried out using an actual aircraft, partial system ground tests of the flight control system and the power supply system, endurance tests and environmental tests carried out by standalone equipment to be mounted in the actual aircraft, etc., need to be conducted. The MRJ's equipment is developed and manufactured by partners all over the world, so tests of standalone equipment are carried out around the world by each partner.

The final examination material for obtaining the type certification consists of an enormous volume of documents, and back in the days of paper documents, it was even said that the weight of the material would be as heavy as the aircraft. The engineers of Mitsubishi Aircraft in Japan are mainly in charge of facilitating the examination of these documents by the Civil Aviation Bureau. The examination is very detailed and takes a long time. Sometimes the design of the aircraft is changed to conform to regulations during the certification and examination process. In fact, during the development and the type certification of the MRJ, some parts needed a design change and related technical work was required.

Currently, at Mitsubishi Aircraft, many overseas engineers are working together to develop the MRJ, which is such a major challenge. Many of them have experience in the development of overseas aircraft or at related equipment manufacturers. The development site is literally internationalized. In the development of a new aircraft, the MRJ, they experience a global workflow method by themselves and are building a new framework. In addition to overseas engineers, staff from MHI group companies and domestic associated companies have also joined in the framework and together they are making every effort for the development.

In the next section, the latest state of the flight tests using actual equipment, which is an important element among many tests for the development and the type certification, is presented.

3. Flight tests

After the first flight of the first test flight aircraft at Nagoya Airport, three flight test aircraft had their first flight to start the flight tests that play an important role in the development of the MRJ.

During the first set of flight tests, the first aircraft mainly underwent the confirmation of the basic aerodynamic characteristics and the performance of the aircraft, as well as the functions of various aircraft equipment. During this period, the flight altitude and speed were limited to safe ranges, and various tests of the safety of the aircraft were carried out.

When the basic confirmation of the aircraft was completed, the first test flight aircraft, together with the second test flight aircraft that had completed its first flight, gradually expanded the flight altitude and speed to the highest attitude and speed that the MRJ targets, while checking the controllability and stability of the aircraft, to measure various data. During this period, in addition to checking the controllability and stability of the aircraft and the functions of various equipment, dangerous tests for actual flight checks of the flight limits were conducted. Examples of these flight tests are shown below.

3.1 Tests of flight characteristics

In the flight tests at the early stages of the development of a passenger aircraft, tests to confirm the limit of flight, that is, to confirm the flight envelope, represented by a stall test, flutter test, and load test are carried out, and then a wider variety of technical tests such as an equipment function check test are carried out. In this way, by conducting the tests under circumstances not encountered under normal operation after the aircraft enters service and obtaining data, the flight envelope, including the stall speed, where the aircraft can fly safely is specified clearly in the manual for in-service operation to completely prevent stalls and flutter in operations with passengers and ensure safety.

(1) Stall test

Aircraft fly in the atmosphere with the lift force obtained by the wing. Lift force is an upward force generated by the wing moving at an angle (called the angle of attack) in the direction of flight, that is, the direction of air flow. When the attitude of the aircraft becomes upward and the angle of attack of the wing increases, the lift force obtained also increases. However, if the angle of attack becomes too large, on the contrary, a stall where the lift decreases rapidly occurs. To prevent a passenger aircraft from encountering such a dangerous stall after it enters service, a stall test in which the aircraft flies at the stall boundary condition is conducted in the development phase beforehand to check the stall characteristics and stall speed of the aircraft. Based on the results of the analysis carried out prior to the flight tests, the speed is gradually decreased to the anticipated stall speed and the angle of attack is increased. Then, when a certain speed and angle of attack are reached, a stall where the angle of attack of the aircraft decreases (nose lowering) and the flying height decreases begins to occur. By repeating these tests again and again, the stall speed of the MRJ, which is one of its flight characteristics, was checked. In addition to the stall speed, the attitude of the aircraft before and after the stall (change in the speed and altitude, change in the controllability, vibration of the aircraft, etc.) are also investigated in detail since they are important data related to the safety of the aircraft after it enters service. In the case of the MRJ (MRJ 90), we have carried out many flight tests as stall tests so far, and confirmed that the stall speed is roughly in line with the prior analysis and that the characteristics of the aircraft before and after a stall have no extreme attitude and the pilot can control the aircraft (**Figure 2**).

Figure 2 Stall test

(2) Flutter test

Similarly, a flutter test confirms the limit of the flight speed of an aircraft. Flutter is a phenomenon where vibration increases due to the interaction of the force acting on the wing surface and the elastic deformation of the wing structure at the time of high-speed flight where the speed of the air passing along the wing surfaces of the wing and empenage becomes high, as does the pressure of that air (referred to as dynamic pressure). If the intensity of this vibration, that is, the flutter, exceeds a certain limit (dynamic pressure limit), the vibration may diverge and destroy the airfoil surface in some cases. To prevent the aircraft from experiencing such dangerous situations after it enters service, as with the stall speed, a flutter test is performed to confirm the aircraft's limit speed (flutter speed) in the flight tests. Since the flutter conditions vary depending on various parameters such as the speed, altitude, aircraft weight, etc., many flutter tests for various flight conditions and aircraft conditions (weight and center of gravity) are conducted so that these parameters can be included.

(3) Load test

In a manner similar to the flutter test, the load test is conducted to measure the load acting on the aircraft during flight. Inertial force and aerodynamic forces act on the aircraft flying in the air, so load is applied to each part of the aircraft. This flight load is predicted by conducting analysis beforehand in the development phase, and the aircraft structure is designed to have sufficient strength so that the aircraft can withstand the load.

To verify that the strength design is appropriate, a strength test is first carried out on the ground using structural test equipment, and then the load is measured by a flight test. This proves that the aircraft can safely fly without breaking apart no matter what load it receives within the range of the set flight envelope.

Tests (1) to (3) can be said to be dynamic tests to confirm the aircraft's limits. In addition, there is a speed calibration test, which is a modest but important test conducted in the early stage of development.

(4) Speed calibration test

The speed and altitude of an aircraft (not limited to passenger aircraft) during flight are calculated by measuring the air pressure around the aircraft. Because the flow of air around an aircraft that is flying at a high speed is complicated, the measurement of the pressure fluctuates depending on the installation position, angle, etc., of the Pitot tube (**Figure 3**), a pressure measurement instrument, the necessary correct air pressure cannot be obtained in some cases. Therefore, flight tests to verify whether the pressure value measured by the Pitot tube correctly represents the altitude and speed are carried out in the initial phase of development. For this purpose, a pressure gauge called a trailing cone is extended from the tip of the vertical fin at the rear of the flight test aircraft to a distance that is sufficiently far away where there is no effect from the air flow around the aircraft to measure the atmospheric pressure (**Figure 4**). Data under various flight conditions are acquired to confirm that the pressure value measured by this trailing cone and the value displayed on the aircraft's instruments measured by the Pitot tube are the same. If there is a difference between the two values, a change of the mounting position, angle, etc., of the Pitot tube on the aircraft is considered so that both values become the same at an early stage of the development. The flight tests also confirm that the measured value of the trailing cone is correct. For this check, the flight test aircraft passes at a low altitude (low pass) near a barometer set on a building or other structure that is as tall as possible and the measurement value of the trailing cone and the measurement value of the barometer on the ground are compared. Such special pattern flights are usually carried out on the premises of an airport. In the case of the MRJ, this test was conducted at the Noto Airport in Wajima-shi, Ishikawa Prefecture with the cooperation of local related parties (**Figure 5**).

Figure 3 Pitot tubes on MRJ

Figure 5 Speed calibration test at Noto Airport

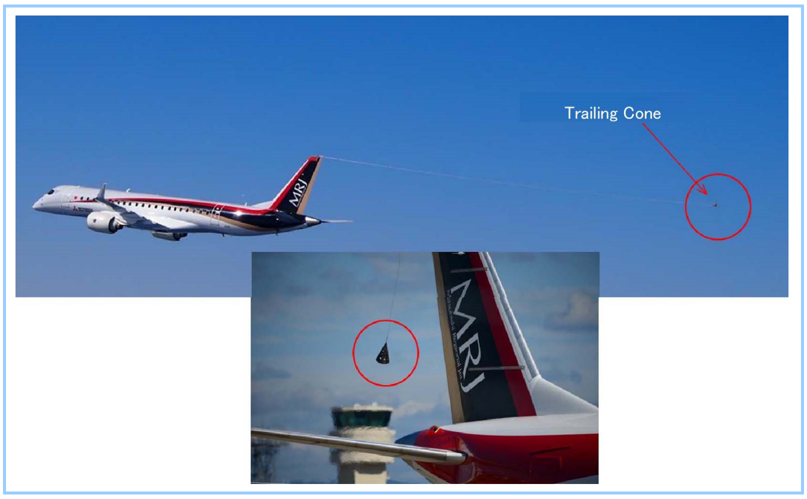

Figure 4 Speed calibration test - trailing cone test

3.2 Special tests

Tests described in Section 3.1 are development tests of flight characteristics of an aircraft. Also for the equipment or systems of a passenger aircraft, which is a complicated piece of machinery, special tests unique to the development phase are also conducted.

(1) Failure simulation test

An aircraft has double or triple redundant systems (two or more of the same components) for electrical, hydraulic, and other systems so that the aircraft can continue the flight and land at an airport safely even in the case of a failure. In the design phase, it is verified by analysis that the safety is ensured even if one system fails. In the final phase, it is verified by actually simulating a failure in the flight tests that the aircraft behaves as designed and its safety is ensured.

One of the typical examples of failure simulation tests for a passenger aircraft is an engine failure simulation test. Many recent passenger aircraft are equipped with two engines. In terms of the aforementioned redundancy, the aircraft needs to be designed so that it can land safely even if one engine stops during flight, and this capability needs to be proven. To prove this, the capabilities to cope with failures with an extremely low probability of occurrence under normal operation like stall and flutter, such as whether the aircraft can continue flight and land safely with one engine stopped intentionally, whether the engine once stopped can be restarted, etc., must be demonstrated.

In the flight tests of the MRJ, in the initial phase soon after the first flight, we conducted a flight with one engine stopped to confirm the safety of the aircraft including the ability to restart the engine.

Since the flight test aircraft were moved to the United States, more special tests have been conducted. Some notable examples are presented below.

(2) Natural icing test

In February 2017, the fourth flight test aircraft was moved from MFC to Chicago O'Hare International Airport, and then the natural icing test was carried out based at the airport. This test checks the size of the ice that adheres when the aircraft flies intentionally into a cloud that causes ice to adhere to each part of the aircraft in the winter. If ice adheres to the aerodynamic surface (the surface of the aircraft) in particular, including the wing, the wing surface shape may be lost and the necessary aerodynamic characteristics cannot be obtained, causing control to become difficult and the continuation of the flight to be impossible as a result. As with other passenger aircraft, the MRJ is also designed, assuming a certain extent of ice adhesion, to allow safe flight with ice adhesion. However, it is necessary to make icing occur in an actual flight test and confirm safety. The natural icing test of the MRJ was carried out in the sky above North America's Great Lakes, as was the case in the development of many passenger aircraft in the past. After several flight tests while searching for the target icing conditions, we were able to carry out the test in the desired icing environment, and it was confirmed that the flight can be safely continued under such conditions (**Figure 6**).

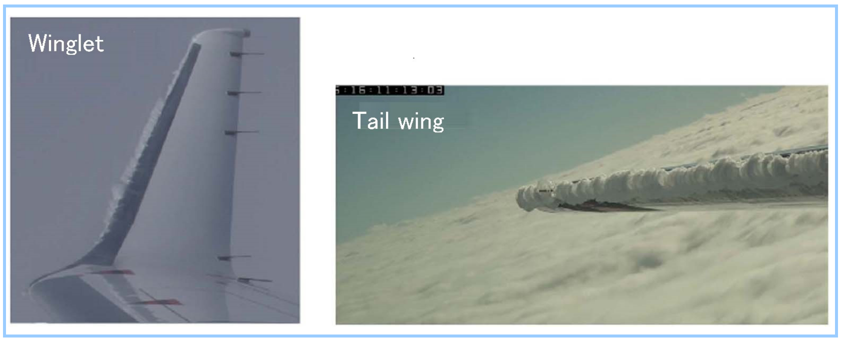

Figure 6 Icing state in natural icing test

(3) Extreme cold and heat test

We conducted an extreme cold and heat test as an in-house test at the McKinley Climatic Laboratory at Eglin Air Force Base in Florida from February 28 to March 17, 2017, using the same fourth aircraft. In this test, a severe temperature environment of extreme cold (-40°C) and extreme heat (50°C) was artificially created indoors at the test site, and the operation of the aircraft, engine and equipment was checked under such extreme conditions. As a result of this test, we confirmed that the engine, auxiliary power plant, other important equipment, etc., all operated as designed, even under harsh environmental conditions (**Figure 7**).

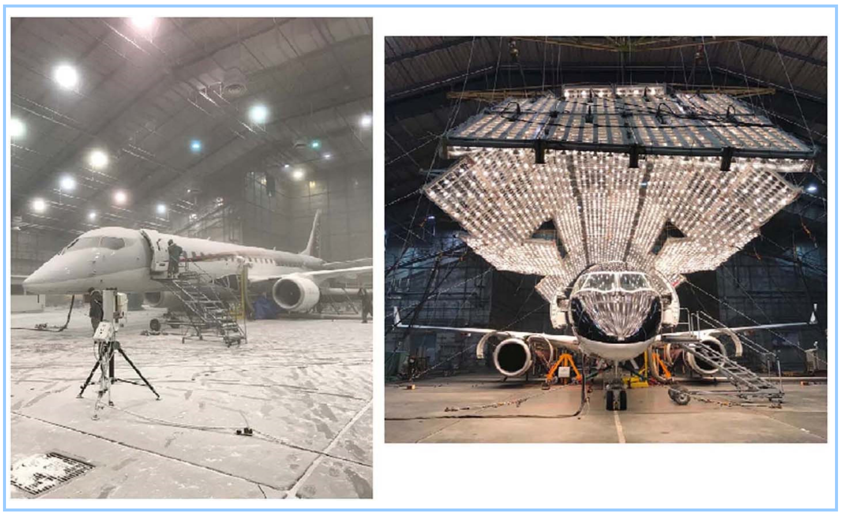

Figure 7 Extreme cold and heat test

(4) Snowy and icy runway test

The runway where an aircraft takes off and lands is not always in a normal dry condition. Various checks are conducted on a snowy and icy runway under snowfall conditions, which may be most dangerous for takeoff and landing. For this purpose, the aircraft runs on the snowy and icy runway with the engine and simulates takeoff to confirm that it can run, stop, etc., safely. We conducted the snowy and icy runway test from December 2016 to February 2017 at MFC, which was hit by record-breaking heavy snow, to confirm the safety (**Figure 8**).

Figure 8 Snowy and icy runway test

Many of these various flight tests involve Mitsubishi Aircraft test pilots. They make flights to measure technical data to prove the safety of the aircraft under various flight conditions and extreme situations that airline pilots usually do not experience.

3.3 Test state

As presented in this paper, the flight tests of the MRJ have been conducted smoothly so far since the first flight through the initial flight tests and then the full flight tests after transferring testing to the United States. In the development phase, the words "tests conducted smoothly" does not mean "tests without problems." It is not possible to develop a new type of aircraft without encountering problems. The aircraft is improved by overcoming the various problems that occurred in the development phase, especially during in-flight tests. Thereafter, the type certification, which is proof of the aircraft’s safety, is obtained, and safe operation after delivery is realized.

In the process of development, we face many challenges in flight tests and technical examination for type certification. To overcome these challenges, we repeat the flight tests many times, and sometimes even improve the design of the aircraft. To create safer and more comfortable passenger aircraft, Mitsubishi Aircraft engineers, pilots, maintenance personnel and testing staff are working on new technical issues every day.

In such a development process, Mitsubishi Aircraft's test pilots have come to highly appreciate the MRJ. The high stability and controllability felt by the pilot of the first flight has remained unchanged in subsequent flight tests. Nevertheless, we are continuing with a significant number of flight tests to obtain the type certification, which proves that the aircraft flies safely under various flight and operating conditions as mentioned in this paper. For that reason, tests in extreme states and with design changes responding to test results are continuing. Based on the evaluation of the test pilots, the MRJ has sufficient capability for normal flight at the present time, but to prove the safety of the aircraft including under the extreme conditions required for the type certification, further flight tests and examination for the type certification are required. Based on the high evaluation from the pilots and the test measurers on board the test flight, we are certain that the MRJ will be a great next-generation passenger aircraft.

4. Exhibition at International Paris Air Show

During the flight tests in the United States in June 2017, the flight test aircraft was exhibited on the ground at the International Paris Air Show, which is a global air show.

This air show is one of the world's largest air shows and is held every two years in Europe, alternating between Le Bourget in the suburbs of Paris and Farnborough in the suburbs of London, and is an effective opportunity to showcase the superior features of the MRJ using actual equipment to the general public including customer airline companies through the media, as well as to publicize the latest state of the development, especially the flight tests. We adjusted the schedule of the flight tests in the United States, and repainted the 3rd flight test aircraft in blue and white colors, the corporate image color pattern of ANA, to show our respect to the company as the first customer of the MRJ. The aircraft was ferried over the Atlantic Ocean and overland to Le Bourget Airport.

The aircraft that arrived before the air show session was exhibited in the ground exhibition area from June 18 to 21 in the first half of the exhibition and was visited by many people in the aviation industry and the media. In addition to an explanation of the current state of the flight tests, the interior, as well as the exterior of the aircraft, was also opened to allow visitors to experience the interior comfort of the MRJ. Many more visitors visited the exhibition than in previous years to see the debut of the real MRJ (**Figure 9**).

While four flight test aircraft continue flight tests every day, it was a great accomplishment that people could gain an understanding of the MRJ itself and its development

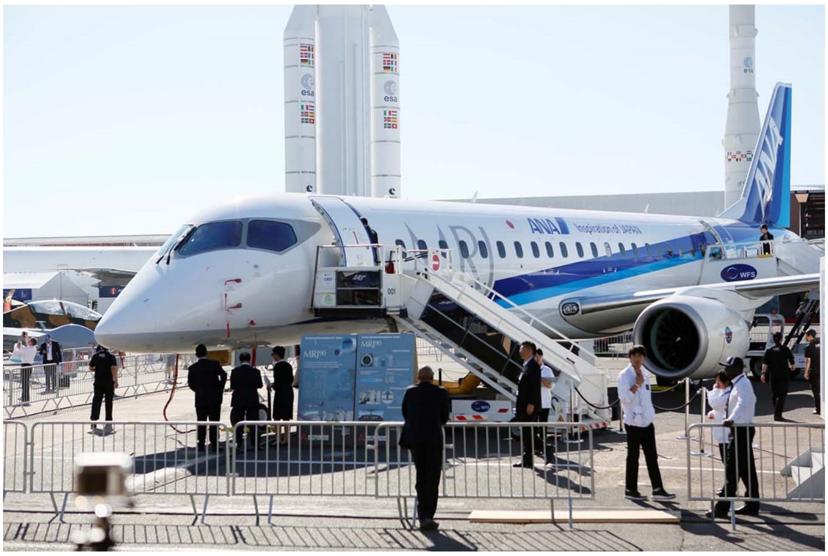

Figure 9 Exhibition on the ground at International Paris Air Show

5. Future schedule and business outline

We will continue the flight tests of the MRJ in the United States to acquire the technical data necessary for its type certification. In Japan, meanwhile, we will compile the data of these flight tests, the various ground test results, and the analysis results to prepare materials for the examination of the Civil Aviation Bureau, which is the final stage in the type certification.

As mentioned above, in the process of obtaining the type certification, safety will be ensured including safety measures against aircraft problems.

The development state presented here is related to the MRJ 90 (90 seats). We have also started to manufacture test flight aircraft of the MRJ 70 (70 seats), another type of the MRJ. Currently, both the MRJ 90 and MRJ 70 are manufactured at the Mitsubishi Heavy Industries final assembly plant.

As presented in this paper, the development of a passenger aircraft takes a significant amount of manpower and a long time to execute many processes including design, tests and type certification, and the MRJ is in the midst of such processes. Going forward, the MRJ developers will continue development while overcoming the difficulties encountered, as in the past.