The Design of Static Test Scheme for Composite Aileron Structure of Large Aircraft

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Abstract: According to the load conditions and structural features of composite aileron structure of large aircraft, the design techniques of full-scale static test scheme of aileron is studied, which can be used to examine the static strength and verify the airworthiness compliance of aileron structure. The overall test scheme design was carried out from the aspects of test load, test support, damage introduction and measurement scheme, and created a set of test design processes that meet the requirements of airworthiness. Loads screening was carried out by using strain coverage principle, the aerodynamic loads were transformed into test load by coordinate transformation. The wing was used as the aileron test support section, and a ground support device can also be designed to carry out aileron bench test. The introduction mode of aileron structure damage was defined, including the type, location and size. A reasonable layout of strain and displacement sensors was given for test measurement. Test results showed that the static test scheme in this paper can be used for the airworthiness compliance verification of static strength of aileron structure.

Keywords: Composite, aileron, static test, test scheme, airworthiness verification

1. Introduction

Composite materials have the advantages of high specific strength, high specific stiffness and good designability. They have become the basic materials of aerospace structures and are widely used in aircraft structures. The proportion of composite materials in aircraft structure has become one of the important indicators to measure the advanced nature of commercial aircraft. At present, composite materials are widely used in ailerons and other control surface structures in advanced large aircraft, which can reduce the structure weight on the basis of meeting the strength and stiffness. However, composite structures are sensitive to inherent defects and damage, and the failure modes are diverse and complex. At present, there is a lack of reliable analysis methods, which makes the reliable application of composite materials in the main structures of large aircraft face great challenges[1-2].

AC20-107B gives the building block test verification method[3] as an acceptable verification method for composite structure verification (Fig. 1). Full scale test is at the highest level of building block test. It can be used to verify the correctness of FEM and overall verify the structural strength. It plays an important role in the process of airworthiness verification.
In this paper, the full-scale static test scheme design of composite aileron structure of large aircraft is studied in detail. The test scheme design was carried out from the aspects of test load, test support, damage introduction and measurement scheme, and a set of test design process was summarized, which can be used as reference for the test of composite structure components.

2. Aileron Structure

Aileron is usually installed at the trailing edge of the wing near the wing tip, and is connected with the wing box through hinge joints and actuators. The main function of aileron is to control the rolling motion of the aircraft (Fig.2). Ailerons of large aircraft are generally wedge-shaped structures made of composite materials and aluminum alloy materials. Composite structures usually include skin, beam and ribs, joints are generally aluminum alloy structures.

The aileron is generally a fixed axis rotating structure. The hinge axis of the aileron is formed by the hinge joints. The aileron can be deflected up and down through the extension of the actuator. The serious loads to be considered for ailerons are divided into three cases: upward deflection, downward deflection and loads parallel to the hinge line. The load parallel to the hinge line is the load condition specified in CCAR25.393[4]. The load magnitude is small, and the stress level of the aileron is low, which mainly corresponds to the severe condition that the joint bears lateral load.

When the aircraft flies horizontally, the aileron is in the state of 0° and bears the aerodynamic lift. When the aircraft rolls, one aileron deflects upward and one aileron deflects downward. The lift of the aileron with downward deflection increases, and the lower skin bears larger upward aerodynamic load. The load of the upward deflection aileron becomes downward, and the upper skin bears the downward
aerodynamic load (Fig. 3). The downward aileron load increases on the basis of the original lift force, resulting in a larger load in the down deflection condition, and the most serious condition of the aileron is the down bias condition.

![Aileron Loading States](image)

**Figure 3. Aileron loading states**

### 3. Test Support Scheme

In order to carry out the test scheme design, it is necessary to define the supporting state of the test. The support of the test should reflect the load and force transfer of the actual structure in flight. The aileron is connected with the wing beam through multiple joints. In flight, the aileron will be driven to coordinate deformation through the joint after the wing is deformed under load [5]. That is to say, even if the aileron is not loaded, the aileron skin will generate random deformation strain, which will affect the aileron strain distribution. The specific influence size and whether it can be ignored need to be determined by simulation analysis [6].

In order to analyze the influence of wing deformation on aileron, the finite element model of aileron internal force was used to calculate the aileron's strain. The load case with the maximum hinge moment of aileron was selected, and the matching load was applied on the wing, and the aileron was not loaded. The influence of wing deformation on aileron strain under this condition can be obtained through FEM. In general, the influence of wing deformation cannot be ignored, and the influence of wing deformation should be considered in aileron test support scheme.

There are two kinds of support schemes which can realize the coordinated deformation of wing. The first one is to install aileron on the wing of the static test aircraft, and the wing is applied with matching load to carry out the test. This scheme directly simulates the real state, but it will affect the test cycle of static test aircraft. The second is to carry out aileron test on the bench, and design the support device with adjustable joint to simulate the wing deformation. The scheme will not affect the whole test cycle, but it has higher requirements for the design of support device [7].

In this paper, the aileron supported on the wing was studied. In the test, if the static test aircraft is applied with matching load, the aileron assessment can be realized accurately, but there are too many loading points, resulting in a waste of resources. The aileron is installed near the wing tip on the outside of the wing. Only the deformation of the outer wing will affect the aileron strain distribution, while the deformation of the inner wing will only cause the aileron to produce rigid body displacement (Fig. 4), and the influence on the aileron strain can be ignored. Therefore, in the test, it is not necessary to apply matching load on the whole aircraft, only the matching load on the outer wing and the trim load on the inner wing to prevent excessive wing deformation.
4. Test Load

The determination of load is very important for the test whether it can meet the test requirements. In this section, the selection of aileron test load, load conversion and optimization were studied, the load screening principle and load processing steps were given, and the aileron test load design method was formed.

A. Load screening

In the flight load of large aircraft, there are dozens of serious load cases of aileron downward deflection. It is necessary to select representative dangerous case which can basically cover other cases. Because the strain distribution of aileron is affected by wing deformation, it is necessary to consider the serious situation after the superposition of aerodynamic load and coordinated deformation.

Aileron test load was selected according to the principle of "minimum M.S.". According to the critical conditions corresponding to the minimum safety margin of each main structure and main connection of aileron, the dangerous cases can be screened, and the cases can be combined according to the specific safety margin[8].

According to the internal force results of aileron finite element method and strength calculation method, the safety margin of aileron composite wing structure, joints and connections can be obtained. According to the safety margin, the preliminary screening of load dangerous cases was completed, and the strain distribution curve shows that the selected dangerous conditions can also achieve the assessment purpose in the secondary stress area of aileron structure. The dangerous load case of composite structure and metal joint may not be the same one, which can be evaluated separately or design a new test load according to the load cases.

B. Load processing

The original load is the aerodynamic distributed load, and the test load is the concentrated load at each loading point. After the dangerous load case was determined, the original load should be converted into the concentrated load at the loading point that can be used for test loading[9]. The aileron was divided into several stations according to the rib. When the rib spacing is too large, a virtual station can be added, as shown in Fig.5. Loading points were set at both ends of the rib station, the front loading point is the intersection point of rib and beam, and the rear loading point is the intersection point of rib and trailing edge.
The load processing steps are as follows:

a) A local load coordinate system was established (Fig.6). The origin of the coordinate system is located in the center of the first hinge joint in the inner side. The X-axis direction is from the origin to the tail edge of the aileron, Y-axis is the direction of combined force of load under dangerous working conditions, the Z-axis is from the origin to the aileron spanwise outside.

b) The aerodynamic distributed load in the aircraft coordinate system was transformed into the local load coordinate system.

c) The transformed distributed load was processed by profile, and the distributed load of adjacent stations was combined into concentrated load of station profile.

d) The load of the rib station was evenly distributed to the loading point according to the moment balance.

![Figure 6. Test load processing](image)

5. Damage Introduction

In the process of manufacturing and using, the composite parts on aircraft will have defects or damages. According to the requirements of CCAR-25 and the recommendation of AC20-107B, manufacturing defects and damage in the process of use should be introduced in the full-scale verification test of composite structures, both of which are essential in the verification[10].

Before the test, it is necessary to complete the damage threat assessment of aileron structure, which includes manufacturing defect threat assessment and operational damage threat assessment[11]. The tasks to be carried out in the threat assessment of manufacturing defects include: to collect the information about the location and size of the defects of the test pieces produced by aileron suppliers in the early stage; to collect the inspection capability of the NDT system of each aileron supplier for various manufacturing defects; to collect the requirements for manufacturing defects in the manufacturing acceptance documents of aileron suppliers.

Operational damage threat assessment mainly includes the determination of damage source, damage location and damage size. The potential impact damage sources of aileron composite structure include: tool drop, hail, tire debris, runway gravel, lightning, rotor blasting debris, bird strike and other conventional impacts, as well as serious collision between service vehicles and aircraft, abnormal flight overload, abnormal hard landing and other unconventional impact. In the test, only conventional impact is considered[12].

The introduction principles of embedded defects in full-scale test pieces of aircraft composite materials are as follows:

e) The embedded defects should be arranged in the parts prone to manufacturing defects, such as the fillet area of the beam edge strip.

f) The embedded manufacturing defects should be placed in the dangerous details of the structure and have no coupling effect with other types of damage.

g) The embedded manufacturing defects should be located at the thickness of the structure with large interlayer stress.

h) Due to the need to monitor the status of defects during the test, the location of embedded defects should be easy to detect.

The principles of introducing damage to the full-scale test pieces of aircraft composite materials in the later stage are as follows:

a) The damage introduced should be arranged at the position easy to impact or scratch.

b) The damage introduced should be arranged at the dangerous details of the structure and not coupled with other types of damage.
According to the damage threat assessment results, combined with the introduction principle of embedded defects and impact damage, the type, location, size of aileron embedded defects and the size and location of impact damage were determined. The damage arrangement of aileron skin is shown in Fig. 7.

6. Aileron Test Measurement Scheme
Full scale test measurement includes strain measurement and displacement measurement. The strain measurement needs to reflect the overall strain distribution of the structure, and the displacement measurement results should be able to reflect the spanwise and tangential deformation of the structure[13].

The layout principles of aileron test strain gauge are as follows:

\( c \) The arrangement of strain gauges should reflect the force transfer of the structure. Select some load transfer sections and arrange strain gauges to measure the strain distribution of the whole section and verify the finite element model. Strain gauges are arranged on the main force transmission path, especially on the single force transmission path structure. The load transferred on each force transmission path is calculated by strain measurement, and the finite element model is verified.

\( d \) The overall strain value of aileron is small, and the verification strain gauges should be arranged at the position with larger strain value to facilitate data comparison.

\( e \) The strain gauges used for verification should not be arranged in the parts with large stress gradient, and the parts with uniform cross-section should be selected for the arrangement of strain gauges.

\( f \) Strain gauges should be arranged at key load transfer joints.

\( g \) For the buckling skin under low load, the buckling condition was measured by pasting strain gauge.

The aileron displacement measuring points were arranged at the beam and rear edge of aileron, and 5 displacement measuring points were distributed on average. The specific number is adjusted according to the actual demand. Figure 8 shows the arrangement of aileron strain gauges and displacement measurement points.

7. Test Acceptable Criterion
The test acceptable criterion is determined according to the airworthiness clause, which is used to judge whether the test is acceptable or not. Before, during and after the test, corresponding inspection shall be conducted to ensure that the test meets the airworthiness requirements.
The test inspection contents are as follows:

h) Before the test, it is confirmed that there is no deformation of the assessment structure and the fasteners are in good condition.

i) During the test, the strain of the test structures and other bearing structures should be measured.

j) During the test, the load should be monitored in real time.

k) Monitoring the strain and displacement of key assessment parts.

l) Check whether the ultimate load holding time meets the requirement of 3 seconds.

m) After the test, check whether the structural parts are deformed and whether the fasteners are in good condition.

The acceptable criterion of aileron static test are as follows:

a) The ultimate load bearing time of the tested structure shall not be less than 3 seconds.

b) The tested metal structure has no crack or damage.

c) There is no harmful permanent deformation of the structure: a) there is no obvious permanent deformation of the structure through visual inspection; b) after the completion of each test, check that the aileron rotation is not stuck.

d) There is no fracture or damage of fasteners in the connection.

e) There is no harmful expansion of damage at the leading position of impact damage of composite structure.

f) There is no new damage in the composite structure.

8. Design Flow of Test Scheme

The test scheme of composite structure of large aircraft involves the research contents of test load, support mode, measurement method, damage introduction and other aspects, including various inputs such as airworthiness clauses, structural numerical model and analysis method [14-16]. In this paper, the whole process of test scheme design was studied, and the flow chart of test scheme design was formed, as shown in Figure 9.

![Test scheme design flow chart](image_url)

**Figure 9.** Test scheme design flow chart

9. Conclusion

In this paper, the test scheme design technology of composite aileron for large aircraft was studied, the main conclusions are as follows:

1. The influence of wing deformation on aileron strain should be considered in the test. In this paper, a test support scheme based on static test aircraft was proposed.
2. The method of load screening and load treatment for composite aileron was put forward, and the transformation from aerodynamic distributed load to test concentrated load was realized.

3. The damage sources of aileron structure were determined by using reasonable damage threat assessment method, and the introduction principles of embedded defects and impact damage were given.

4. The layout principle of aileron structure measurement scheme and test acceptable criterion were proposed to ensure the airworthiness compliance of the test.

5. A set of test scheme design process meeting the airworthiness requirements was formed, which can be used as reference for static test of composite structures.

6. According to the test scheme, the aileron ultimate load static test was completed, the test loading process was stable, the results meet the requirements of the test qualification criteria, and the aileron structure assessment was realized, which shows that the test scheme is effective and reasonable, and meets the requirements of airworthiness provisions.

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