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Design Technology of Aircraft Full Elastic Model Based on Multiple Materials

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Abstract. This paper introduces the design requirements and design methods of structural materials in the process of aircraft model design, and introduces the shortcomings of traditional methods in this kind of structural design. Based on this, a full elastic model design method combining metal and composite materials is established. This method has the characteristics of accurate and fast design and simple structure. In order to verify the effectiveness of this method, this paper lists two related aircraft model structure design schemes, and introduces the design process and design results. The experimental results show that the above method can effectively complete the aircraft full elastic model design, the model design is accurate, and can meet the needs of aircraft simulation.

Keywords. Aircraft structure, composite materials, model design, aeroelasticity

1. Introduction

Aircraft design needs to meet the needs of structural safety and lightness. The traditional structural design is usually completed by aluminum, titanium and other metals. With the rise of new composite materials, more and more aircraft begin to use carbon fiber, glass fiber and other composite materials, which have lighter structural mass and relatively higher structural strength.

In order to ensure the structural safety of aircraft, it is usually necessary to carry out the experiment of aircraft structure to test whether the aircraft can bear enough load. This work is usually realized by aircraft structure model. The model that can reflect the overall characteristics of aircraft is called aircraft full elastic model. This kind of model has the following characteristics and requirements. (1) Dimensional similarity: dimensional similarity refers to the same similarity ratio between the dimensions in all directions of flight and the aircraft prototype. (2) Static deformation similarity: static deformation similarity requires that the aircraft structure can produce structural deformation similar to the prototype when bearing the corresponding force. (3) Structural dynamic characteristics are similar: This requires that the structural stiffness, mass distribution, stiffness distribution and modal frequency of the aircraft are similar to those of the aircraft prototype.

In order to realize the above model design, researchers from various countries have done a lot of work. French [1-2] et al. Proposed a design method of elastic model, and used the method of increasing counterweight to make the model meet the dynamic similarity, and completed the corresponding test. Carlson [3] and others designed a

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model of an aircraft by using the aeroelastic cutting method. The internal beam is used to maintain the stiffness, and the external rigid wing surface is used to maintain the aerodynamic shape. Qian Wei [4] and others developed the test method of full elastic model and carried out the corresponding static aeroelastic test. Kou Xiping [5] completed the design of aeroelastic model combined with simulation analysis software. Liu Nan [6] and others completed the flutter test of the aircraft tail, and Ji Chen [7] and others completed the flutter test at hypersonic speed through the designed model. Yang Xianwen [8] and others also carried out corresponding wind tunnel test research on the model. In terms of dynamic experiments, Lu Bo [9] and others conducted wind tunnel tests for the characteristics of large wing deformation of civil aircraft. Liang Ji [10] and others also studied the influence of flow field on the dynamic characteristics of aircraft tail by means of wind tunnel test. Qian Wei [11] et al. Established the wind tunnel flutter test of the whole aircraft of an aircraft. Zuo Chenglin [12] and others carried out deformation measurement of helicopter rotor blade displacement.

2. Design Method

2.1. Insufficient Existing Technology

The existing model design methods have the following shortcomings:

(1) Using light wood as filling material has large additional stiffness and inaccurate model design.

(2) When hard foam is used as the filling material, the foam at the front and rear edges of the wing is easy to be damaged in the wind tunnel, and the deformation of the foam on the windward side is unavoidable, which will affect the aerodynamic force of the model in the wind tunnel.

(3) Using silica gel as filling material has high requirements for mold and high design cost.

(4) The extended beam has a certain impact on the section stiffness and reduces the accuracy of model design.

2.2. New Model Design Method

In order to overcome the above shortcomings of the prior art, a full elastic model design and production method is provided, and the purpose of elastic model design and production of wind tunnel test is realized by using a relatively simple design and production process.

Therefore, this paper provides a model design idea based on the joint preparation of metal and composite materials. The specific steps are as follows:

Step 1: calculate the section stiffness required by the model through the similarity relationship, and use the relevant three-dimensional modeling software to design the model section; Make the actual section stiffness of the model consistent with the section stiffness required by the model. The designed model section covers the front and rear edges of the wing. In step 2, the model main beam is made of metal material, and the leading edge and trailing edge of the main beam are made completely according to the front and rear edges designed in step 1. The main beam body is provided with grooves. Step 3: fill the grooves of the main beam with hard foam, polish the edges of the foam, ensure that the shape of the model is consistent with the aerodynamic shape of the wing model, and use glue to bond the foam and the metal main beam. Step 4: paint the foam surface of the wing and the junction between the foam surface and the metal to ensure the smoothness of the model surface.

2.3. Beneficial Effect

This technology can achieve the following beneficial effects

(1) The test model has high strength and is not easy to be damaged in the process of experiment.

(2) The additional mass and stiffness provided by the test model foam material are very small, which can make the test results more accurate.

(3) The design process is simple, the test cost is low, and the test processing difficulty is low.

3. Design Verification

In order to verify that the above design scheme can effectively realize the design of the full elastic model of the aircraft structure, two experiments are established to calculate whether the structural characteristics of the aircraft are consistent with the design

3.1. High Aspect Ratio Aircraft

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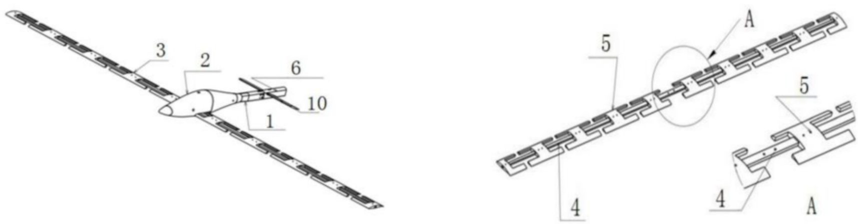
The head cover of this case is manufactured by 3D printing, which shortens the processing cycle and reduces the processing cost on the basis of ensuring high aerodynamic similarity, greatly reduces the added mass and added stiffness of the test model, and has higher accuracy; The wing, tail angle adjustment block and the tail can be detachably connected with the main body of the fuselage, which is convenient for direct disassembly and assembly in the wind tunnel. By manufacturing multiple tail angle adjustment blocks with different angles, they can be replaced quickly, so as to realize the iterative test of the tail with different angles of the same model.

The experimental model can be used for the experimental study of aeroelasticity of large flexible aircraft and the test of its trim characteristics. Its design principle is clear, the structure is simple, the interface between components is simple, easy to replace, and has strong universality.



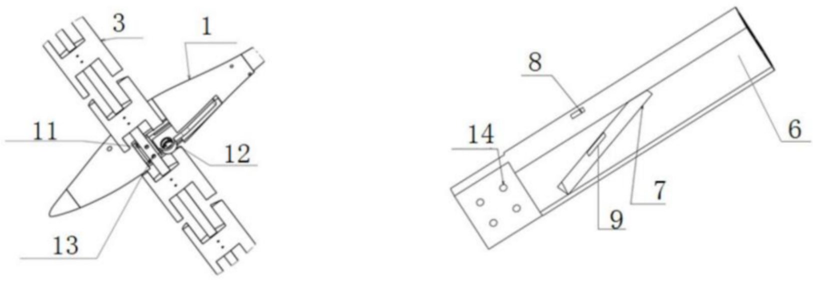


Figure 1. High aspect ratio aircraft.

As shown in the above figure, 1 is the tail of the aircraft made of aluminum alloy, 2 is the plastic head cover processed by 3D printing technology, 3 is the leading edge and trailing edge of the wing processed by 3D printing technology, 4 is the wing main beam processed by aluminum alloy, 5 is the fixing screws between the wing main beam and the front and rear edges, 6 is the replaceable section of the wing tail, 7 is the vertical tail rudder, and 8. Pin holes; 9. Locating pin; 10. Tail wing; 11. Wing mounting slot; 12. Connecting hole; 13. Bolts; 14. Rivet holes.

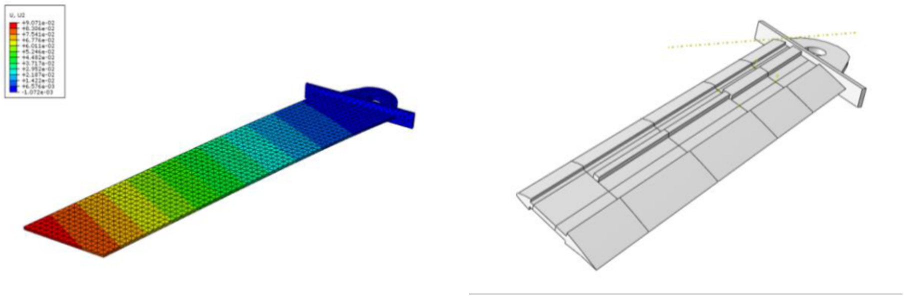
During the experiment, the main beam of the wing is used to simulate the stiffness of the aircraft wing. The plastic at the front and rear edges plays a role in maintaining the stiffness of the wing shape, and a layer of plastic cloth is wrapped outside the structure, which has the effect of maintaining the shape. The experimental results show that the structural model method of the aircraft is simple, the structure is firm, and the full elastic model simulation of the aircraft can be realized.

3.2. Elastic Wing Design

In the second experiment, an elastic wing was designed. During the design process, commercial software was used to evaluate the stiffness of the wing, as shown in figure 2 (a). Then, metal was designed as the main stiffness representation structure, as shown in figure 2 (b), and then filled with foam. The specific design process is as follows:

Firstly, in the process of ground test, the strain gauge is used to calibrate the force measurement results of strain gauge under different load conditions, establish the relationship between strain gauge indication and load, and obtain the corresponding relationship and formula between strain gauge indication and load by means of data fitting.

The indication of each strain gauge is obtained in the wind tunnel test, and then the corresponding formula obtained from the ground test is used for back calculation, so as to obtain the load result of the structure. The force measurement of elastic model includes two parts: static load and dynamic load. The static load is expressed as the mean value of the load, and the dynamic load is expressed as the amplitude of the load result near the mean value. During the test, the static load and dynamic load borne by the model can be measured respectively through data processing.



(a) (b)

Figure 2. Elastic wing design.

Twelve data sampling points are set up along the extension direction, and six sampling points are taken at the leading edge and trailing edge of the model respectively. Adjust the stiffness distribution of the plate to make the load data of each sampling point of the model under the simulation conditions close to the data of the aircraft model in the ground experiment. At this moment, the data of the test value and the calculated value are shown in figure 3. The abscissa is the node position number selected in the experiment, and the ordinate is the deformation of each position under loading.

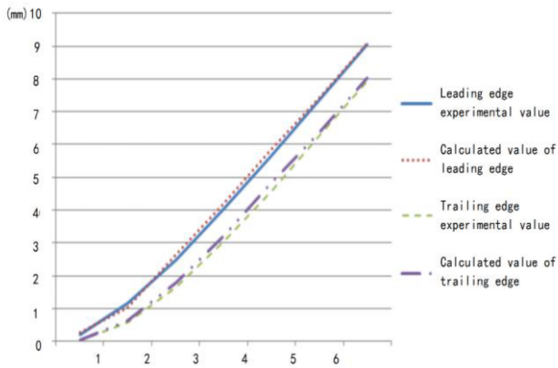


Figure 3. Comparison diagram between displacement of each point of flat plate model and test.

As shown in figure 3, it can be seen that node 1 and node 6 of the model have been consistent with the results of ground experiments, but there are some differences in the middle nodes. At this time, the mass and stiffness distribution of the middle position can be adjusted by adjusting the width of the stiffness strip in the middle part. These intermediate stiffness bars are shown in figure 2(b). Finally, the empty groove of the model is filled with rigid foam plastic or composite materials to make the shape of the structure consistent with the design goal. Finally, the surface is kept flat by painting.

The section design of machining model can be realized by CATIA. Then check the model according to the other two loading conditions of the static test, and the error values of the test model under condition 1-4 can be obtained, as shown in figure 4.

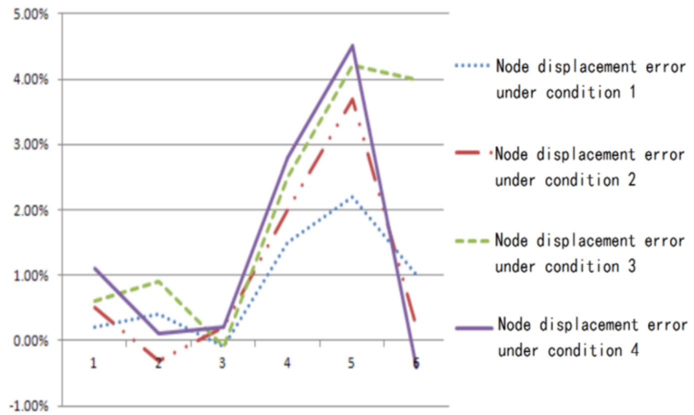


Figure 4. Model deformation design error under different working conditions.

As shown in figure 4, under different design conditions, the displacement difference between the design model and the design prototype is very small, and the error of most nodes is less than 4%. The design structure realizes the similarity of the structure by using a variety of different materials. The abscissa is the number of node positions selected in the experiment, and the ordinate is the maximum design error of the deformation of the model under various working conditions.

The front and rear edges of the model and other easily damaged parts are processed with the beam, which can meet the strength requirements of the model in the wind tunnel test. The surface is filled with hard foam to provide less additional stiffness.

4. Conclusion

This paper introduces the necessity of the design and manufacture of the full elastic model in the force measurement experiment of the elastic model, and introduces the need to use a variety of different materials to ensure that the quality, stiffness, shape, deformation and other physical quantities of the structure can be similar to the design goal. Using the above design concept, the paper completed the design of two models, one is a large span aircraft, the other is a fully elastic wing, and verified the design results. The results show that:

To sum up, this paper can draw the following conclusions:

(1) This design method of mechanical similarity model based on a variety of materials can effectively meet the needs of experiments. The designed model is similar to the design prototype in shape, deformation and other aspects.

(2) The structural design is simple and convenient, the aeroelastic model design and fabrication of high aspect ratio wing can refer to the method in this paper.

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