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Wind tunnel experiment research on geometrical nonlinear effect of high-aspect-ratio aircraft

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Abstract: In this paper, a wind tunnel experiment model for elastic aircraft with high-aspect-ratio is designed. The numerical simulation method is used to predict the state of the wind tunnel experiment, and the low-speed wind tunnel experiment is carried out. The purpose of this study is to verify the effect of geometric nonlinearity on the aerodynamic force of aircraft with high-aspect-ratio, and to obtain the aeroelastic trim parameters and influence of elastic deformation on aerodynamic forces. Some parts of the model are fabricated by 3-D print using nylon to reduce weight. The aircraft aeroelastic deformation is measured using the principle of binocular vision measurement, aerodynamic is measured using balance and angle of attack is measured using attack angle sensor. the elastic deformation is simulated coupled CFD method and finite state induced inflow aerodynamic model with geometrical exact intrinsic beam model which can accurately describe the geometrical nonlinear effect of high-aspect-ratio wing. By comparing the experimental data and numerical simulation results, the the influence of geometric nonlinear effect on aerodynamic force is quantitatively evaluated. Research show that the wind tunnel experiment device and supporting measurement device built for high aspect ratio aircraft can effectively acquire the influence of geometric nonlinearity on aircraft aerodynamic force.

Keywords: wind tunnel experiment; aeroelastic; 3-D print geometric nonlinearity; high-aspect-ratio

1. Introduction

For the large flexible wing of UAV and other large flexible wings, the aerodynamic characteristics of the aerocraft must be taken into account by the change of the aerodynamic characteristics of the aircraft and the structural stiffness and the dynamic characteristics.

The whole machine trim state is the benchmark for the dynamic characteristics and stability analysis of large flexible aircraft, and the calculation of whole machine trim load is also an important basis for structural design. Through the study of the geometrically nonlinear aeroelastic analysis method of large flexible wing, the aerodynamic load size and distribution form under large deformation state can be accurately judged, and the more accurate deformation results of the nonlinear structure are given[1-2]. Through the wind tunnel test, we further verify the theoretical analysis results, and judge the change rule of the trim parameters and the elastic correction of the whole machine in the large deformation state. For the design of the control system, the evaluation of flight performance and the determination of the flight packet line, the more accurate nonlinear aeroelastic analysis basis is provided, and the support is designed and developed[3].

Aiming at the scale model of large flexible aircraft, this paper designs the model of low speed aeroelastic wind tunnel test, and completes the longitudinal balancing wind tunnel test. By carrying out the aeroelastic wind tunnel test with large deformation, the design method of the large flexible model and the related test technology are mastered, and the foundation for the subsequent related experiments is laid, and the changes of the aerodynamic force, the balance parameters and the elastic correction caused by the large deformation are studied, and the static and static dynamic elastic characteristics of the typical overload and canonical velocity are obtained. At the same time, it is used to verify the numerical calculation method of large scale flexible aircraft geometric nonlinear aeroelasticity.

2. Test method and process

Six component balance is used to measure the model overload. An optical device is used to measure the deformation of a model wing, shown in Figure 1. Balancing attack angle is an important parameter to be obtained in this test. The MCS Technology (SANG1000-D060D) angle sensor is used to measure the angle of attack. The aircraft model is supported by ventral support, supporting rod and aircraft bearing, and the mechanism is designed to achieve the angle of attack and ensure safety.

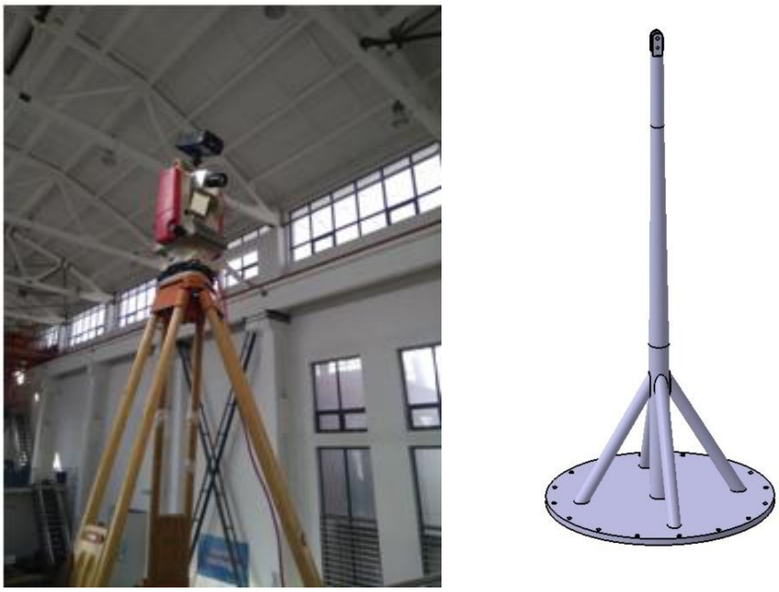


Figure 1 Optical deformation measurement device and Ventral support device

3. Design of test model

According to the three-dimensional CAD model, the rear fuselage configuration is simply practiced, so as to facilitate the installation of the tail rudder fixed angle structure. The view of the aircraft wind tunnel experimental model is shown in Figure 2.

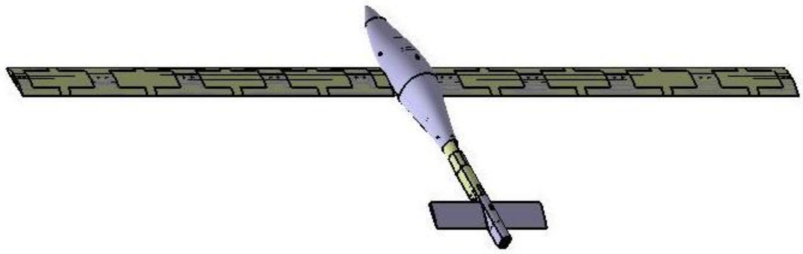


Figure 2 Wind tunnel test model

The speed of wind tunnel test is low and the wing load is small. Considering the cost of using traditional processing to fabricate complex surface of the test model is higher, the 3D print is used here to fabricate the complex component of the model. In order to evaluate the accuracy of 3D print process, the print error evaluation report is given by shape detection technology and typical component error is shown in Figure 3. RMS error is 0.08948mm according to max model length (119.989mm) and average error is 0.0551mm.

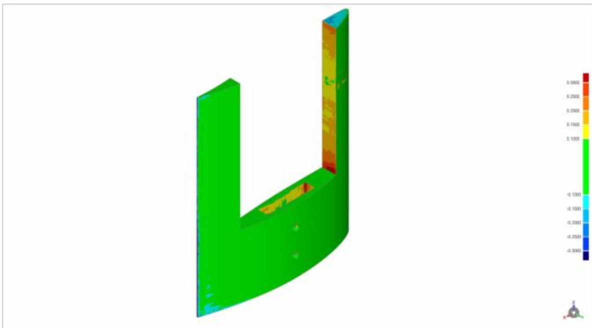


Figure 3 3D print error evaluation

The aerodynamic load is based on the CFD calculation results [4-6]. When the speed of flow is 35m/s, the attack angle is 12 degrees, the aerodynamic force is taken as the design load to carry out the deformation analysis of the wing structure. Under this station, the aerodynamic force of the whole machine is about 250N. In order to meet the wing tip deformation to reach 20% of half length of the wing, the thickness of wing of test model is designed to be 6mm and 7mm. When the wing width is 20mm and the thickness is 6mm (wing 1), the deformation and stress of the wing are shown in Figure 4 and Figure 5. The maximum deformation of the wing is 299mm, and the maximum Mises stress of the wing root is 630Mpa, which basically meets the design requirements.

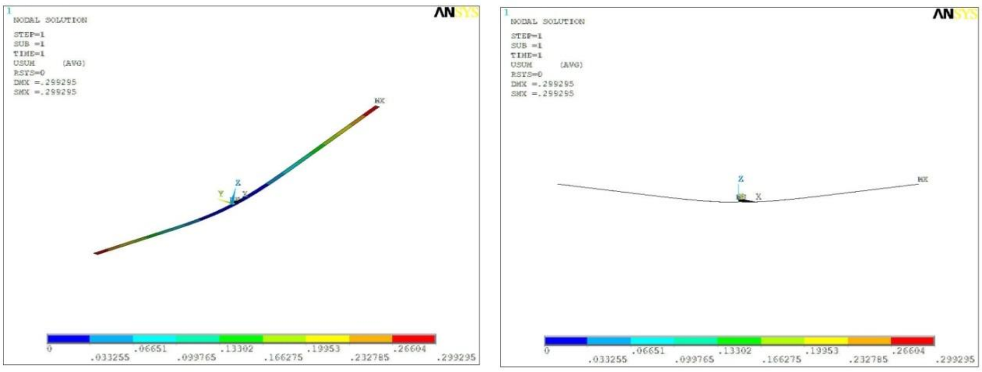


Figure 4 Deformation of the wing of test model

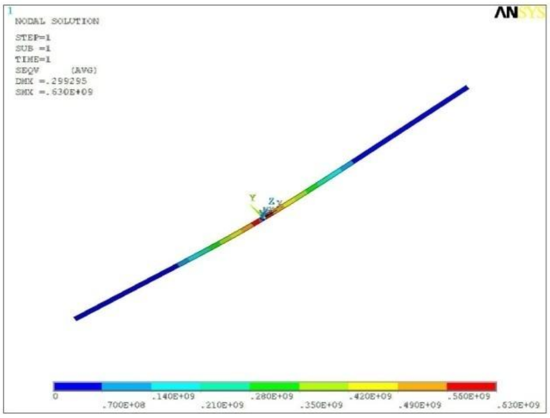
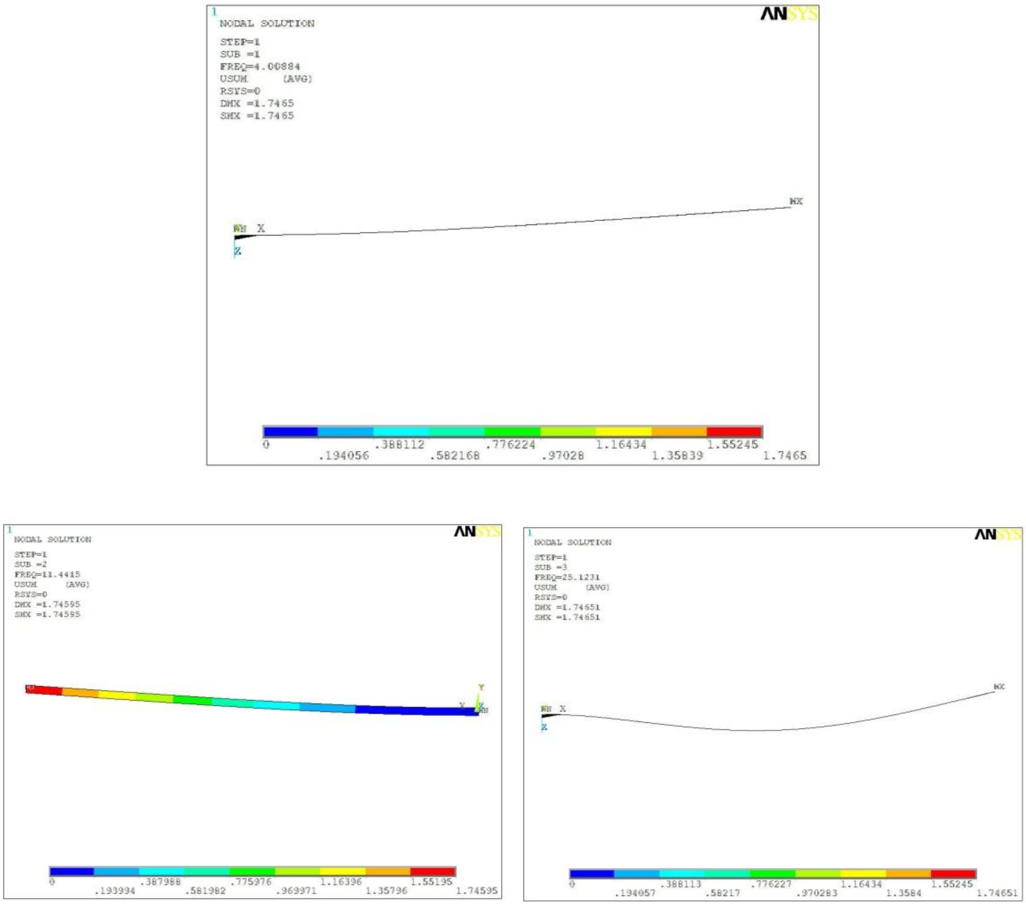


Figure 5 **Stress of the wing of test model**

4. GVT test and wind tunnel test

First, the modal analysis of wing structure is performed by finite element method. The fixed boundary condition is used at the wing root. The first five order vibration frequencies and modes are shown Figure 6. The results of GVT tests show that the results agree well with those of finite element analysis.



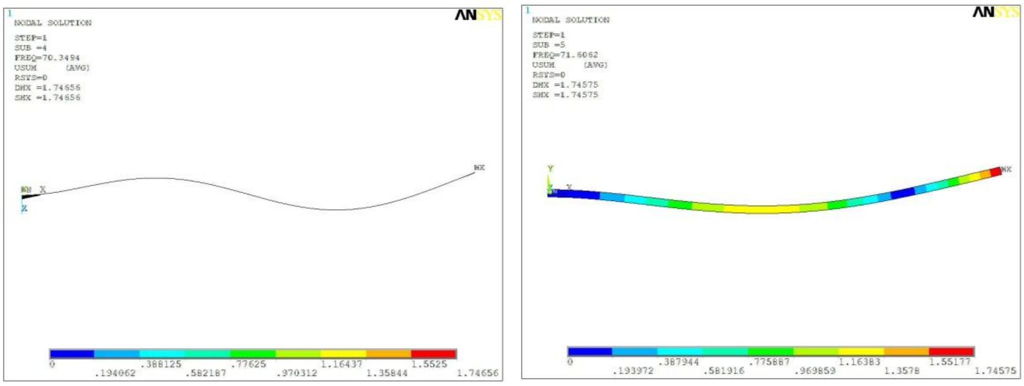


Figure 6 Mode analysis of test model

About 30 wind tunnel tests were carried out, including test of fixing wind speed to obtain balance angle of attack and fixing balance angle of attack, but changing wind speed to study the geometric nonlinear effect of large deformation. After the test, there are lots of data to be analyzed including balance, strain and deformation displacement data. The information of lift and resistance and strain information of one test states is shown Figure 7. The test condition is fixing balance angle of attack and changing the speed of inflow. The angle of attack is 3.77° and the speed of inflow are 15, 20, 25, 30, 35, 37 and 39m/s.

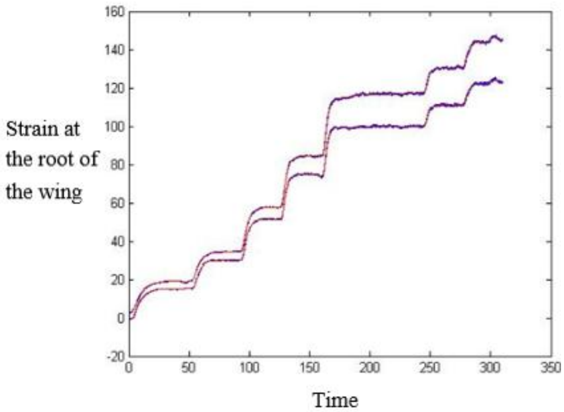


Figure 7 Wind tunnel strain test results

5.Conclusion

This paper completes the design and processing of aeroelastic test model for aircraft with large aspect ratio by combining 3D print technology with traditional machine technology. The model is designed to meet the geometric nonlinear effect of deformation under certain aerodynamic load. In the wind tunnel experiment, the balance state of aircraft is observed, and the information of strain, aerodynamic force and deformation under the condition of large deformation is obtained, which provides reference data for the comparison between the numerical calculation and the experiments.

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