DESIGN, MANUFACTURE AND FREQUENCY EXPERIMENT OF A NOVEL FLUTTER MODEL FOR AGARD WING 445.6 WITH STRUCTURE-SIMILARITY

Wei Qian*, Yuguang Bai*, Dong Wang**
***School of Aeronautics and Astronautics, Faculty of Vehicle Engineering and Mechanics, Dalian University of Technology, Dalian 116023, China; **Aerodynamics Research Institute, Aviation Industry Corporation of China, Shenyang 110034, China**
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Abstract

As a famous reference model over the world, AGARD WING 445.6 can be commonly used to test the accuracy of many numerical methods or codes for flutter computation. At the beginning of the present work, No.3 model with weakened stiffness was modelled by finite element method to prepare a basis of the AGARD WING 445.6 model design. Then a reference structure-similarity flutter model of AGARD WING 445.6 was designed and manufactured based on structure dynamic similarity principle. The actual dynamic pressure range of a pressurized intermittent wind tunnel in China was considered during the design process. After a frequency experiment of this model was completed, numerical modal analysis and flutter computation of this model were also completed by employing MSC/Nastran software. It was found from the experimental and computed results that the reference structure-similarity model of AGARD445.6 WING in this paper can generally provide consistent basic modes and flutter characteristic compared to the original structure. So the proposed model can satisfy the requirement of the pressurized intermittent wind tunnel in China, and the corresponding experimental results of this reference model can be used to check many numerical methods or codes for flutter computation.

Introduction

A standard wing model, which is accompanied with established wind tunnel test results and structure mode parameters, has significant application value for numerical simulation codes of transonic flight. AGARD WING 445.6 wing has been widely proposed as such a representative model [1]. Based on previous studies, No.3 model with weakened stiffness can present experiment data of flutter phenomenon, so this model is a rare one which can validate numerical method for flutter prediction such as CFD. Since the wind tunnel used by us is a blow-down pressurized wind tunnel, the dynamic pressure range of it is from 45kpa~80kpa at Ma=0.9. This range is about ten times than previous studies, so a reference flutter model for the adopted wind tunnel is necessary for engineers in China.

There are many effective investigations based on flutter wind tunnel tests by adopted AGARD WING 445.6 model, these practice presented significant advances for CFD technology.

In this paper, the No.3 weakened stiffness model of AGARD WING 445.6 is used as the reference. Based on the range of our wind tunnel, a reference model was designed and manufactured by adopted structure dynamic similarity principle.

During the studies: the same aerodynamic shape was used as the initial AGARD WING 445.6 model; the structure stiffness was improved by used high strength steel and carbon fiber skin; and the first four modes and coupling rule of flutter characteristic of the model must be consistent. With this model, the corresponding results of flutter wind tunnel tests can be used to check many numerical methods or codes for flutter computation.

1. Numerical simulation of AGARD WING 445.6

The initial test model of AGARDWING 445.6 provided by NASA Langley Research Center was made by peach [1], and it was manufactured with many small holes to reduce assembled stiffness, as shown in Fig.1. The main characters of this wing include: aspect ratio is 1.644; taper ratio is 0.6529; sweep angle for 1/4 chord of wing is 45°; and airfoil shape along the flow direction is NACA65A004. Previous studies presented the first four modes of this model, as shown in Fig.2.

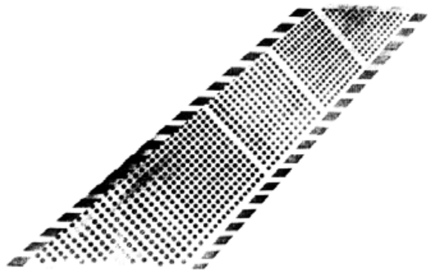

Fig.1 Actual structure of No.3 model of AGARD WING 445.6

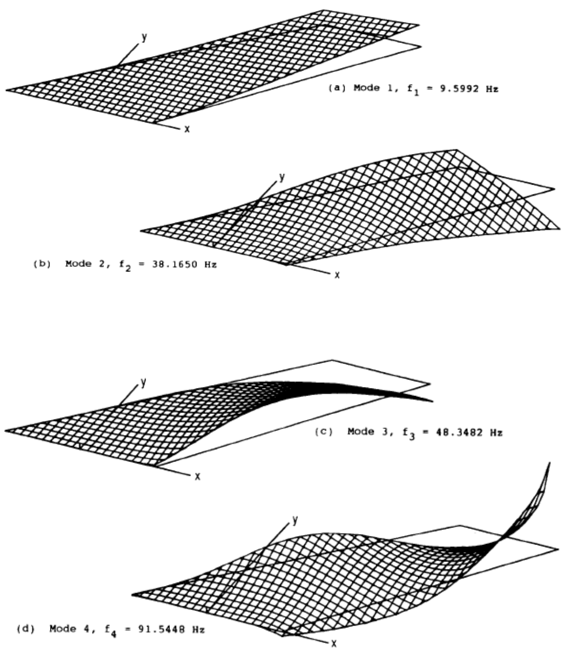

Fig.2 The first four modes of No.3 model of AGARD WING 445.6

A wind tunnel test was implemented by NASA Langley research center and a relationship between flutter dynamic pressure and Mach number was proposed as shown in Fig.3.

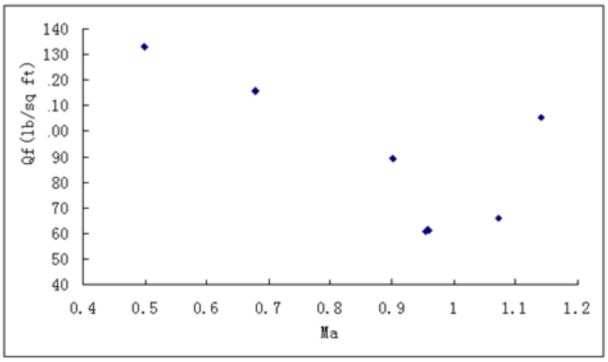

Fig.3 Relationship between flutter dynamic pressure and Mach number

Based on these initial structure character, FEM modeling rule was established: Mahogany material can be recognized as a kind of orthotropic material with a sweep angle of the principal direction was 45°; the model can be divided to 10*10 parallelogram plate element, thickness of each plate was imported as the distribution of the former wing thickness; the density of the plate element was established by the total weight of the model; and material modulus was trimmed by optimal process. After FEM model was finished, Fig.4 presented the thickness distribution and Fig.5 presented the computational results of the first four modes.

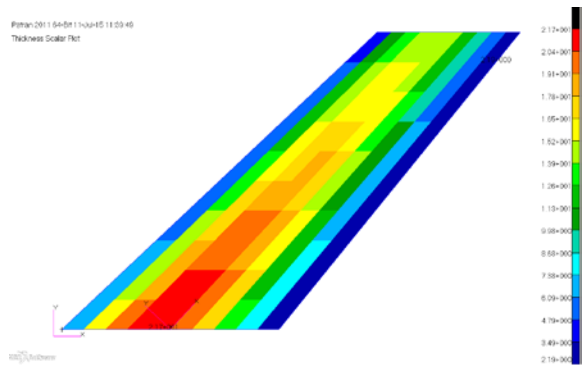

Fig.4 Thickness distribution of the FEM model of the original structure

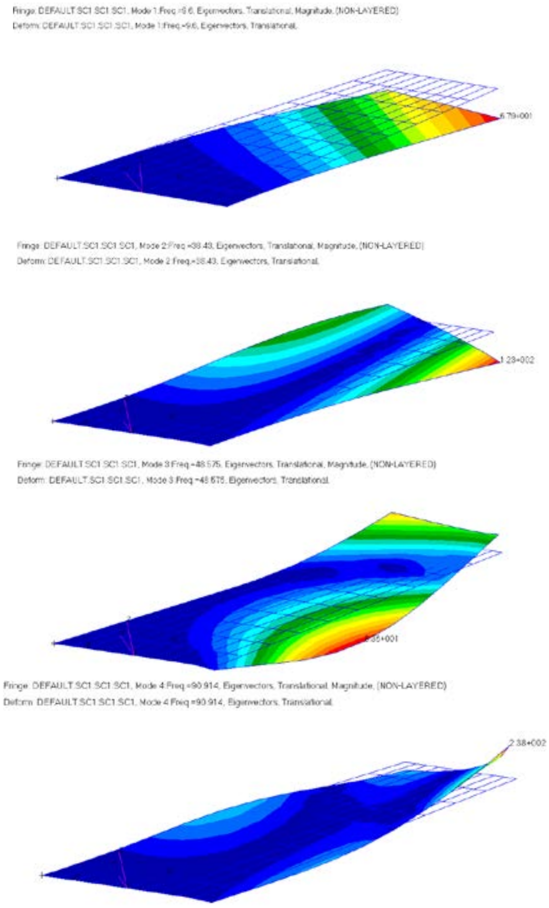

Fig.5 Computational results of modes

Table 1 presented comparison between the results of the model in this paper and that of NASA Langley research center, it can be found that FEM simulation can fully represent No.3 weakened stiffness model of AGARD WING 445.6 model, so it can be used for the rear design of the flutter model in this paper.

Table 1 Comparison of modes

Mode	FEM	AGARD 445.6	MAC
1st bending	9.60	9.599	0.9999
1st torsion	38.43	38.165	0.9984
2nd bending	48.58	48.348	0.9973
2nd torsion	90.9	91.545	0.9937

Flutter computation was finished by adopted MSC/NASTRAN software based on the first four modes, Ma=0.5, and the computational results was shown in Table 2, V-g and V-f view was shown in Fig.6. It was found that computational results of dynamic pressure was consistent with the experimental values and the computational flutter frequency was higher than experimental value.

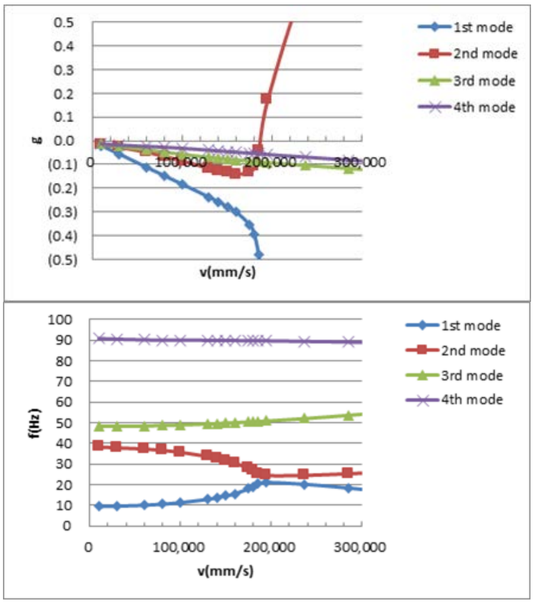

Fig.6 Computational results of flutter.

Table 2. Comparison between FEM and experiment

	Computed results by FEM (DLM)	AGARD445.6 experiment (Ma=0.5)
Dynamic pressure of flutter (kPa）	7.48	6.32
Flutter frequency (Hz）	25	20.7

2. Establishment of similarity scale

Based on the dynamic similarity principle and the demand of the pressurized intermittent wind tunnel, the related scale parameters are established:

Scale ratio K_l =1:1; dynamic pressure ratio K_q =18.9786; density ratio K_ρ =19.5957. Then stiffness ratio K_{EI} =18.9786; mass ratio K_m =19.5957; frequency ratio K_f =0.9841. It should be noticed that this mass ratio can induce too large mass, so the design mass was adjusted to 11Kg and the corresponding K_f was changed to 1.7935.

3. Design parameters of a flutter reference model of AGARD WING 445.6 with structure-similarity and their adjustment

Stiffness and mass distribution of the present AGARD WING 445.6 model was established based on the aboved scale. The model was manufactured by steel skeleton and carbon fiber skin. The principal direction of carbon fiber was still 45°. Structure parameters were computed through optimal process. A difficult problem should be resolved: after total weight 11kg of the model was established, no matter how much carbon fiber skin was increased, frequency ratio cannot be reached. In order to satisfy this demand, geometry shape change or wing thickness increase should be chosen. Finally, we decided to use the maximum frequency state related to airfoil shape and weight, so the designed model was not satisfy the demand of frequency ratio. FEM model was shown in Fig.7; the first four computational modes were shown in Fig.8; and comparison between basic model and designed model was shown in Table 3.

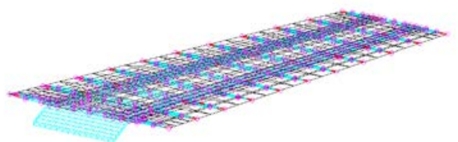

Fig7. FEM model of the bechmark model.

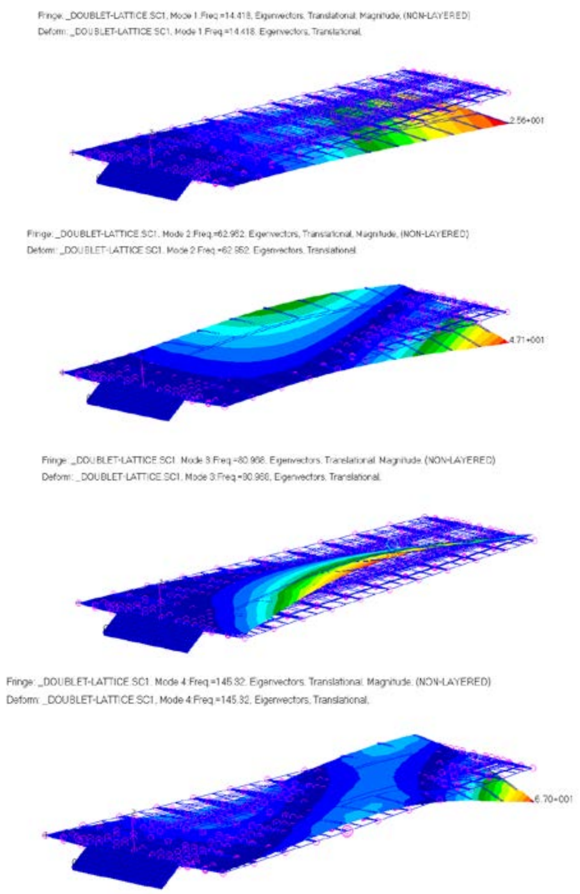

Fig.8 Computational modes

Table 3 Mode comparison

Model parameter	Initial model	Theoretical scale	Final design
Weight (g)	1864		11287
Barycenter X(mm)	567		560
Barycenter Y(mm)	330		320
1st order bending (Hz)	9.6	17.2	14.4
1st order torsion (Hz)	38.2	68.5	63.0
2nd order bending (Hz)	48.3	86.7	81.0
2nd order torsion (Hz)	91.5	164.2	145.6

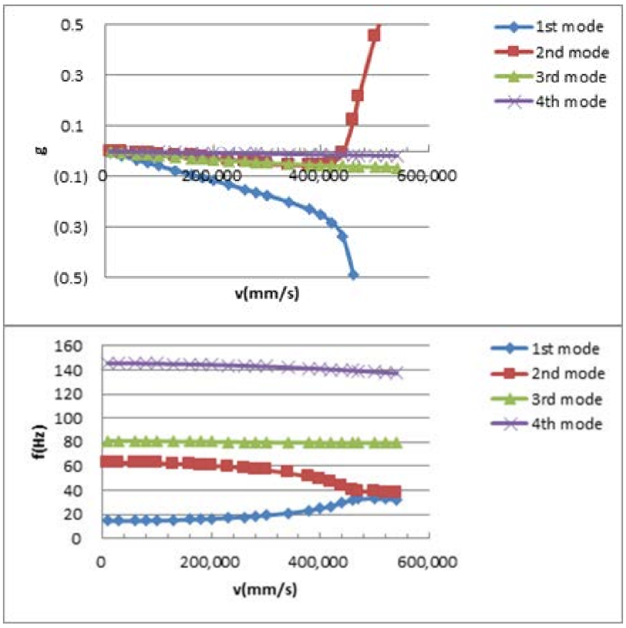

Fig.9 Flutter computational results of the designed model

Flutter computation was still implemented by MSC/NASTRAN. In Ma=0.5, dynamic pressure was 121.4Kpa, flutter frequency was 32Hz. The minimum of transonic flutter point was 55.1Kpa based on 45.4% transonic tip of the reference model. This results can satisfy the demand of dynamic pressure ratio design. The related V-g and V-f view were shown in Fig.9.

4. Manufacture of the reference model and the frequency experiment

After the design parameters were determined, final design of the present model was implemented. The material carbon fiber was adopted for the skin of the model and GB 45 (ASTM 1045) steel was adopted for the skeleton of the model, skin and skeleton were assembly molding with an accurate mould, as shown in Fig.10. Fig.11 shows the model arrangement for the frequency experiment.

Frequency experiment was finished by adopt a Siemens LMS Test.Lab system, as shown in Fig.12; the exciting force hammer used was produced by the Jiangsu Lianneng corporation in China, as shown in Fig.13; and the acceleration transducer used was ICP Piezoelectric acceleration transducer by PCB corporation. Test point arrangement was shown in Fig.14. Experimental modes from LMS test system was shown in Fig.15.

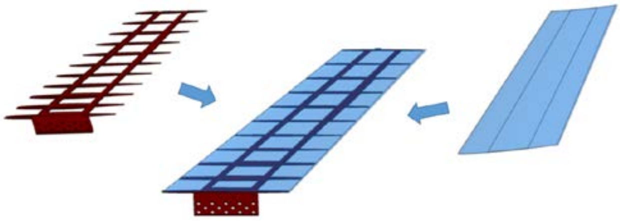

Fig 10. Assembly of the model.

Fig.11 Model arrangement for the frequency experiment.

Fig.12 Siemens LMS Test.lib system

Fig.13 Exciting force hammer

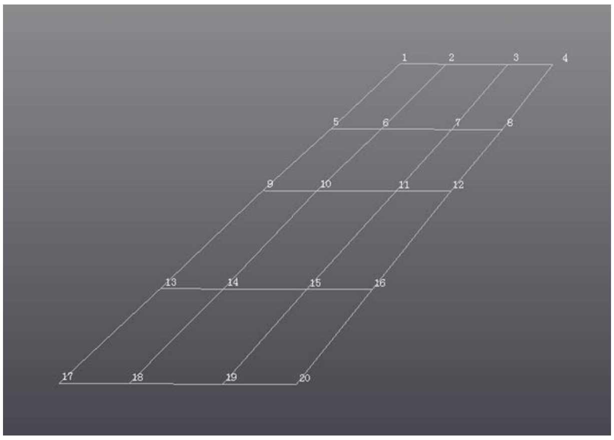

Fig.14 Test point arrangement.

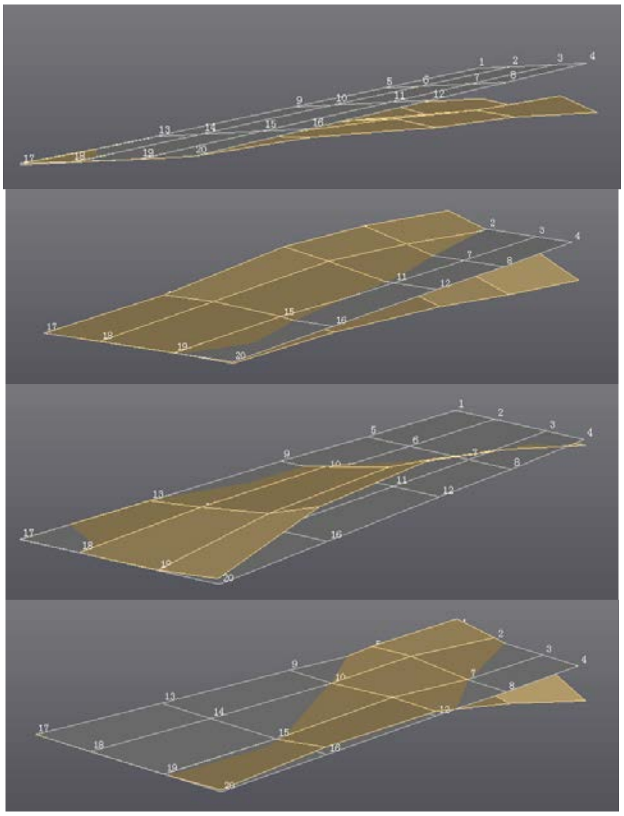

Fig.15 Experimental modes from LMS Test.lib system.

Table 4 gives comparison between the experimental and computed results of frequency of the wing model. Deviation was less than 5%. It can be found that the present design method can satisfy the design requirement.

Table 4 Comparison of the experimental and computed results of the wing model.

Mode	Results of GVT	Computed results
1^{st} bending (Hz)	14.2	14.4
1^{st} torsion (Hz)	62.3	63.0
2^{nd} bending (Hz)	78.5	81.0
2^{nd} torsion (Hz)	141.7	145.6

5. Conclusions

A reference structure-similarity model of AGARD WING 445.6 was presented in this paper. It generally provided consistent basic modes and flutter characteristic compared to the original structure. Such model can satisfy the demand of wind tunnel in China.

Through an encouraging GVT, flutter model entity was consistent with FEM simulation results. Both FEM model and physical model entity can satisfy the demand of design.

The present model can be used for related transonic flutter wind tunnel test, and the experimental results can be used to check CFD or other numerical simulation methods.

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Contact Author Email Address

Name: Mr. Wei Qian, Professor

Address: 2 Linggong Road, Ganjingzi District, School of Aeronautics and Astronautics, Dalian University of Technology Dalian 116023, China

E-mail: sy_qianwei@139.com

Tel: 86 (0) 13709889805 (mobile)

86 411 84709105 (office)