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NUMERICAL SIMULATION AND WIND TUNNEL TESTING OF FLUTTER ABOUT AN ALL- MOVABLE HORIZONTAL TAIL AT TRANSONIC SPEEDS

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Abstract

In order to obtain the characteristic of flutter for a high maneuver aircraft all-movable horizontal tail, scaled structure dynamic similar models were manufactured and transonic flutter wind tunnel test was accomplished in FL-26 wind tunnel. In the mean time, CFD simulation using Navier-Stokes equation was accomplished. The horizontal tail flutter model has a rigid fuselage and a rigid wing to investigate aerodynamic influence to horizontal tail flutter boundary. Two flutter horizontal tail models were manufactured with different mass overload factor. Comparing the result of CFD simulation and wind tunnel test, a flutter design method was made for all-movable horizontal tail.

1 General Introduction

To a high maneuver aircraft all-movable horizontal tail, characteristic of flutter is an important constrain for structure design. The design parameters include the distribution of horizontal tail stiffness and mass, the stiffness of control loop, and the position of additional mass that can prevent flutter. Normally in order to obtain a lighter structure weight, it is impossible to a all-movable horizontal tail whose flutter boundary is very high. So the investigation of transonic flutter characteristic is very important. There are two ways to investigate transonic flutter characteristic for the all-movable horizontal tail: simulation and transonic wind tunnel test.

In simulations, double lattice method (DLM) is a normal flutter calculation method. There is big difference between the true flutter boundary and result of DLM in all-movable horizontal tail flutter analysis at transonic speeds. But DLM is still widely used because of easy and fast. In this paper, CFD simulation using Navier-Stokes equation was accomplished to investigate characteristic of flutter for the all-movable horizontal tail at transonic speeds.

FL-26 is a transonic pressurized wind tunnel whose size of test section is 2.4m x 2.4 m and a wind tunnel, which is ejection-driven, semi-circuit, and intermittent. It is located in Mianyang, Sichuan province, china.

The conditions of wind tunnel are limited. Density of airflow and Mach number cannot be changed freely. So scaled structure dynamic similar models were manufactured to investigate characteristic of flutter at transonic speeds.

In aircraft flutter analysis, mass parameter π ($\pi = m/\rho L^3$, m is aircraft mass, ρ is air density, L is characteristic length) is significant to flutter boundary prediction. It is called Newton number [1-3]. In high-speed flutter wind tunnel test, it is practically impossible to obtain the structure of model with similarity of mass-inertia properties because of the wind tunnel test condition. The mass of the model structure (or some parts of the structure) becomes more than mass required according to similarity of mass-inertia properties. Therefore, it is necessary to find the mass distribution with common mass overload factor $\overline{m}$ ($\overline{m} = m/m_S$, m is mass of flutter model, m_S is mass of required ideal model). Apparently $\overline{m}$ and π is proportional, and $\overline{m}$ has big influence to flutter boundary of the model. [4]

In this paper, we should investigate the influence of $\overline{m}$ to all-movable horizontal tail flutter boundary. For this purpose, two all-movable horizontal tail flutter models were designed and manufactured. One model's mass overload factor $\overline{m}$ is 1.0. Another model's mass overload factor $\overline{m}$ is 2.0.

In order to investigate the aerodynamic influence to horizontal tail flutter boundary, the horizontal tail model has two wind tunnel test configurations: with or without wing. In the mean time, CFD simulation using Navier-Stokes equation also has this two configurations.

Comparing the result of CFD simulation and wind tunnel test, a flutter design method was made for all-movable horizontal tail.

2 Flutter Model Design and Manufacture

The flutter model is a semi-aircraft model (see in Fig1). The fuselage and the wing is rigid which only simulate the shape for aerodynamic. The horizontal tail is elastic structure similar. There is a elastic panel inside rear fuselage to simulate the support stiffness to horizontal tail and the connection part is elastic to simulate the stiffness of control loop. The elastic horizontal tail, elastic rear fuselage panel and the elastic connection are combined as a vibration part to simulate frequencies and modes of horizontal tail. The vibration part is independent and can't touch rigid fuselage while vibrating. The horizontal tail model has two wind tunnel test configurations: with or without wing.

First to regard the horizontal tail's detailed structure as standard of flutter model design, and then based on the similarity criterion, to establish scaled and simplified structural dynamic similar wind tunnel model (see in Fig2). The horizontal tail model remains main components of structure including skins, spars, ribs and axis. There must be an error in frequency and mode between the scaled and simplified model (SSM) and original standard horizontal tail, and the main source of the error is from the physical parameter's error in the process of stiffness equation. For maximum elimination of this error, use a technology of dynamic finite element model's flexibility-mode collaborative correction, to meet the design requirements by optimizing the process.

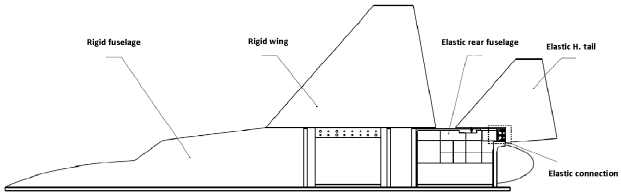


Fig1 Semi-aircraft flutter model

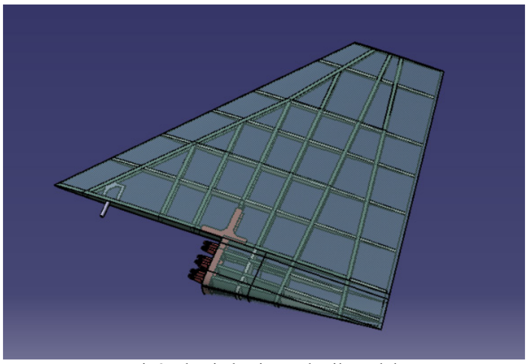


Fig2 Elastic horizontal tail model

One horizontal tail model was manufactured using mixed structure of glass fiber reinforced plastics, carbon fiber and polyfoam, whose mass overload factor $\overline{m}$ is 1.0 (tail1). Another model was manufactured using mixed structure of aluminum beam, glass fiber reinforced plastics skin and polyfoam, whose mass overload factor $\overline{m}$ is 2.0 (tail2). Local connections use aluminum, steel and other metal materials.

We mainly use mould to manufacture the model skin component of composite materials. The frame and the skin component were assembled into thin-walled structure that was filled PMI foam. All of the components were assembled mainly using glue. Some metal local connections use bolts. Manufacture of the model is shown in Fig3.

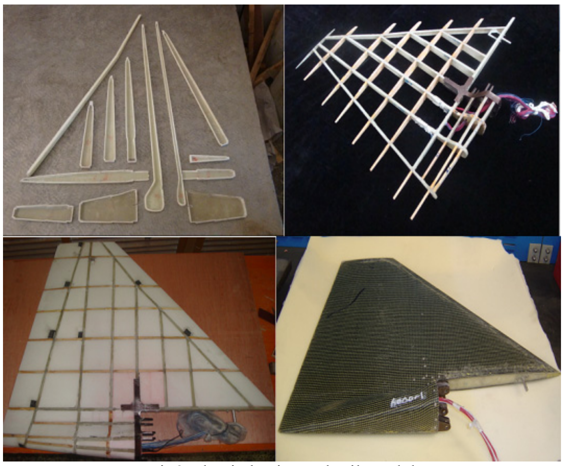
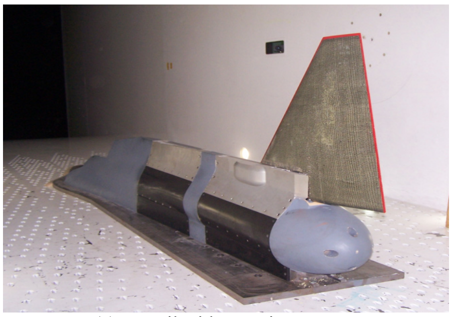


Fig3 Elastic horizontal tail model



(a) H. Tail without Wing

(b) H. Tail with Wing

Fig. 4 Transonic H. Tail Flutter Model Mounted in Wind Tunnel

3 Transonic Wind Tunnel Test

Flutter Model in the wind tunnel is shown in Fig4. There are two wind tunnel test configurations for the horizontal tail model: with or without wing. The angle of attack is 0.

Wind tunnel test adopts the way of fixing Mach number Ma variable dynamic pressure driving. Judge whether the flutter occurs or not according to dynamic response measurements using strain gage and acceleration sensor. The results of flutter wind tunnel test are shown in Fig5. Apparently there are big differences of flutter result between tail1 and tail2.

At mach number Ma=0.95, typical flutter responses are shown in Fig6. When flutter occurs, all sensors response a same frequency that is between H. tail 1st bend and 1st torsion. We call this as bend-torsion coupling flutter. At the same time, an instruction is given by a stop device system to shut down the wind tunnel and the flutter stop. Tail1's flutter response time history shows flutter occurs very quick and strong. Tail2's flutter is obvious slower. It is because tail2 has more weight and lower frequency.

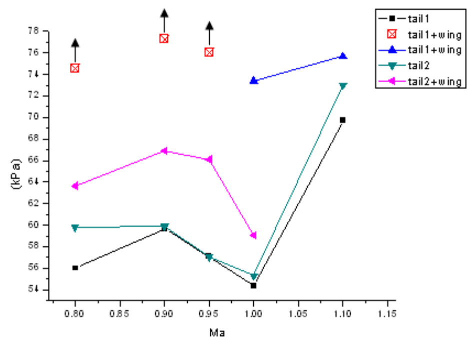


Fig5 Results of flutter wind tunnel test

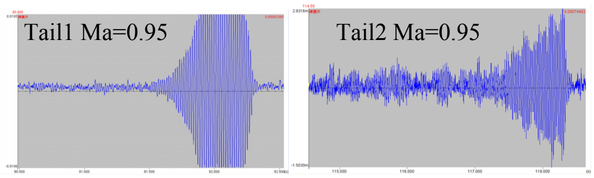


Fig6 Typical flutter responses in wind tunnel test

4 FEM Simulation and Flutter Calculation Using DLM

There are two parts of the flutter model, they are rigid and vibration part. The vibration part includes horizontal tail which is elastic structure similar, elastic panel inside rear fuselage and the elastic connection part (see in Fig7).

A FEM was built to calculate frequencies and modes of the vibration part including the elastic horizontal tail, elastic rear fuselage panel and the elastic connection (see in Fig8). Calculations of H. tail's first three modes are shown in Fig9. A ground vibration test (GVT) was done to measure frequencies and modes of the flutter model. Comparison of the results between GVT and FEM simulation is shown in table1. It shows that the FEM simulation has enough accuracy. The difference of frequency compared with the GVT experimental results is less then 3%.

Flutter calculation was done using doublet lattice method (DLM) and the results are shown in Fig10. The software we used is MSC/NASTRAN-Aeroelastic. V-g and V-f plot is shown in Fig10. The result of calculation is shown in Fig11. From the results these two models with different mass overload factor have almost same flutter boundary.

Fig11 shows that there is some difference between DLM simulation and wind tunnel test.

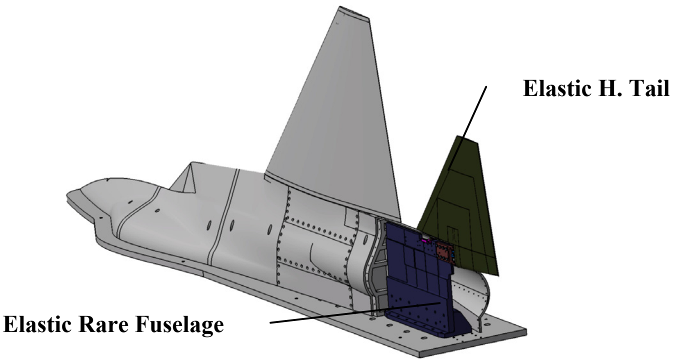


Fig7 FEM of vibration part

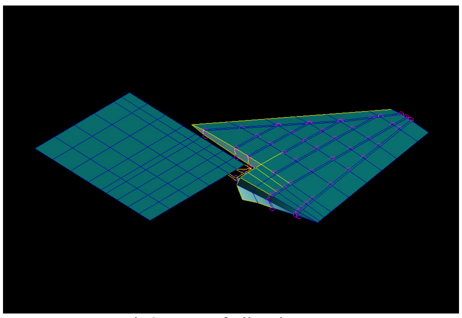


Fig8 FEM of vibration part

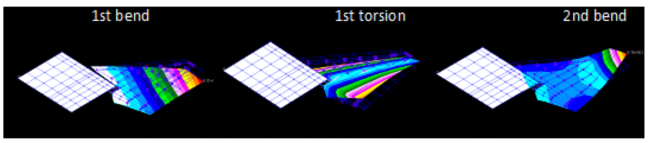


Fig9 Typical mode calculation of FEM model

Table1 Result of DLM calculation

	FEM (Hz)	GVT (Hz)
Tail1	1st bend 31.6	1st bend 30.77
	1st torsion 72.3	1st torsion 73.4
Tail2	1st bend 43.8	1st bend 43.76
	1st torsion 102.8	1st torsion 106.4

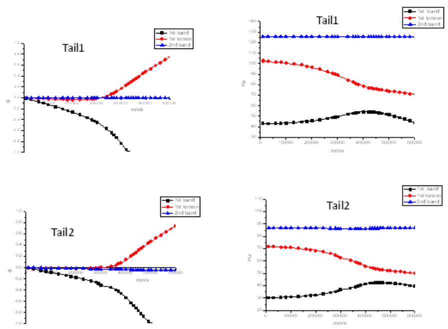


Fig10 V-g and V-f plot of DLM calculation

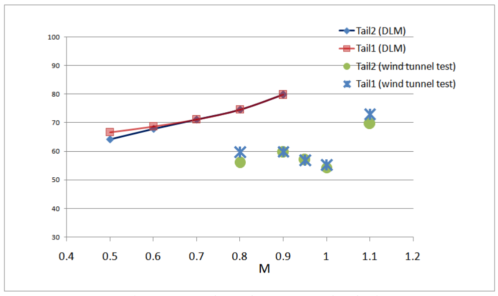


Fig11 Results of DLM calculation

5 CFD Simulation

We use the unsteady aerodynamic Navier-Stokes equations (hybrid mesh) code TRAN-FLUTTER developed by Chinese Academy of Sciences to do CFD simulation for the characteristic of flutter at transonic speeds. For the CFD/CSD coupling computation, the tightly coupled method was developed. If the sub-iteration is also used for the fluid solution, in each sub-iteration step, the flow and the structural deformation are solved contemporarily, which is a tightly coupled method. When the number of sub-iteration step tends to be infinite, the time accuracy of coupled calculation is second order[5].

In CFD flutter simulation, in order to predict the flutter boundary we need to change some parameters to make the vibration to diverge. Currently, the variable structural stiffness method, the variable flow density method are commonly used for the determination of flutter boundary. In the above methods, the Reynolds numbers are same, and equal to the experimental Reynolds number. In fact, it is easy to deduce that both the variable structural stiffness method and the variable flow velocity method are equivalent. In the paper, only variable flow velocity method is used.

In this case, the Mach number and the flow density were fixed, and the values of free-stream velocity were taken as different values. So the dynamics pressure of the airflow is changed to work out the flutter boundary. Unstructured meshes on surface of the plane and space used in the calculation are shown in Fig12. Typical result of CFD flutter simulation is shown in Fig13.

The results of CFD simulation for tail1 are shown in Fig14. Comparison between CFD simulation and wind tunnel test appears that CFD simulation and wind tunnel test has a consistent trend, but there is still some system difference.

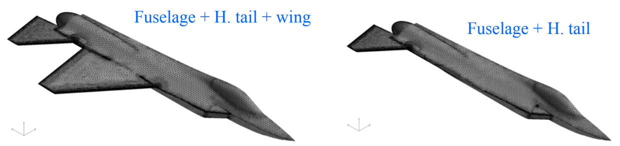


Fig12 CFD Meshes with and without wing

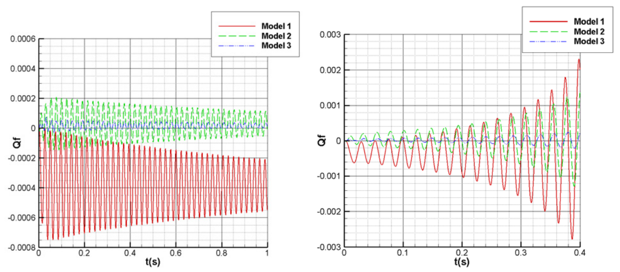


Fig13 Calculation of Typical Transonic Flutter

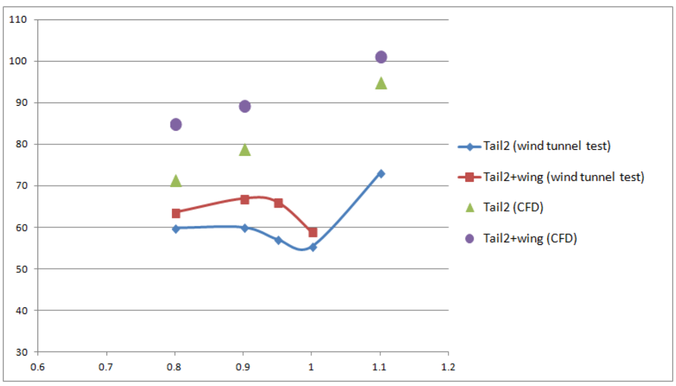


Fig14 Results of CFD simulation for ail1

6 Conclusion

Integrated above work, can come to the conclusion:

- An all-movable horizontal tail flutter was validated by CFD simulation and wind tunnel test;
- Although we get a low flutter boundary by DLM calculation, the flutter boundary still has safe margin at transonic speeds. So transonic flutter simulation and wind tunnel test is very important to this all-movable horizontal tail;
- The aerodynamic influence of wing to horizontal tail can increase flutter boundary;
- The horizontal tail flutter is sensitive to the model's mass, so Newton number ($\pi = m/\rho L^3$) has big influence to this flutter;
- There is some system difference between CFD simulation and wind tunnel test. It's hard to say the CFD code has enough accuracy. Transonic flutter wind tunnel test is still very important. Follow-up work should figure out the reason and improve the CFD simulation;
- The condition of transonic flutter wind tunnel test is limited. But combine flutter wind tunnel test with CFD simulation, we can build an all-movable horizontal tail flutter design system. Flutter design and evaluation could be done at different altitude and mach number in aircraft design.

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