

# EXPERIMENTAL AND NUMERICAL STUDIES OF FLUTTER CHARACTERISTICS OF AN ALL-MOVING CONTROL SURFACE AGAINST GAP EFFECTS

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## Abstract

*Gap effects are commonly existing for all-moving control surface used for high-speed aircraft. Such nonlinear system can significantly influence flutter characteristics of aircraft. A control surface model was designed and manufactured, which can consider gap effects. Initial FEM modeling investigated the different dynamic and flutter characteristic for different Mach numbers and gap sizes. GVT experiments and Wind tunnel tests were then presented to find physical results. An engineering method were both employed to study aeroelasticity, which can be verified by measurement and experimental results. Such work can present exemplary gap effects for all-moving control surface system from low Mach number to high Mach number. The present work can provide a significant basement for the future numerical simulations.*

## 1 Introduction

In recent twenty years, various techniques have been proposed by many investigators for predicting the transient response of aeroelastic systems that involves nonlinearities either in the structures or in the aerodynamics [1-3]. Gap effects on wing models can obviously bring harmful emissions which has risen among the main goals of the International Civil Aviation Organisation. The direct simulation approach assumes that the nonlinear system can be divided into several subdomains, and within each subdomain, the system, whose transient response can be computed by a straight forward time-integration procedure, is assumed to be linear [4].

But nonlinear procedure still needs deep experimental and numerical studies.

The present work wanted to study flutter characteristics of an all-moving control surface model with different gap arrangements which can bring nonlinearity effects. Both wind tunnel tests and numerical method were employed. Through the experimental phenomenon, a series of flutter characteristics were observed. Aeroelastic patterns can be analyzed with measurement and numerical simulations.

## 2 Structure and FEM modeling

Based on a typical all-moving control surface structure as shown in Fig.1, a scaled model was designed. Then a scales FEM (as shown in Fig.2 and Fig.3) was modelled and related modes was presented. This model can be used to confirm the flutter speeds in the wind tunnel.

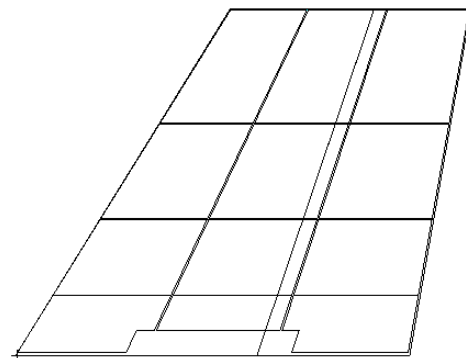


Fig.1 Structure Geometry.

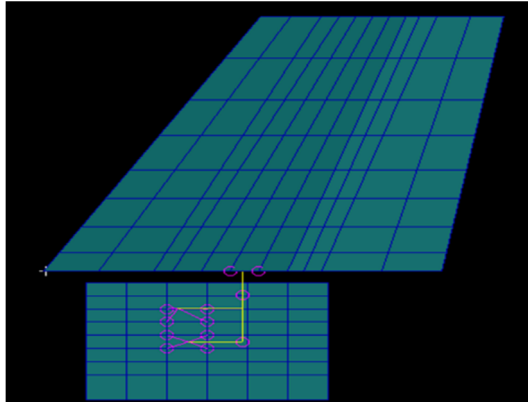


Fig.2 FEM with far hinge point.

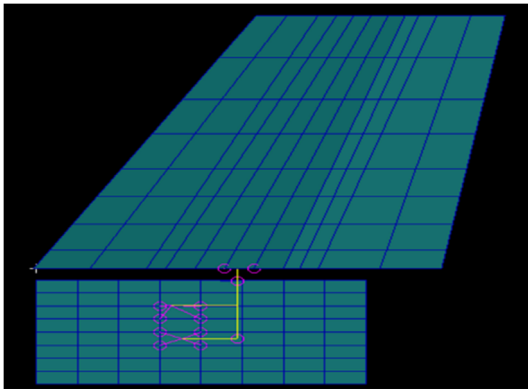


Fig.3 FEM with near hinge point.

In order to consider the influence of the position of the hinge point of the model on the mode of vibration, two FEM models are designed. One hinge point was far away from the root rib of the wing, and the other kind of hinge point was located near the root rib of the wing. The main natural vibration modes of the model were shown in Fig.4 and Fig.5. Flutter characteristics were also obtained, the results can be found in rear table 2.

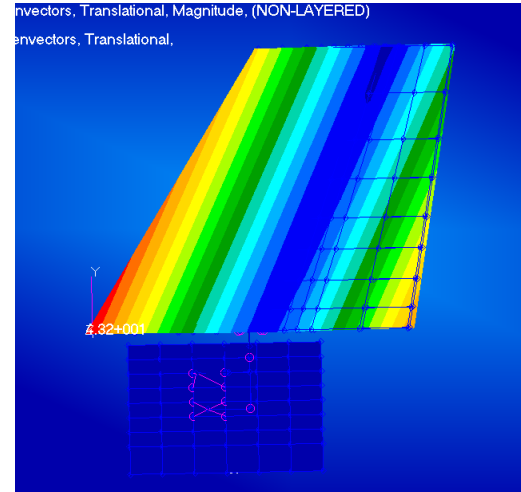
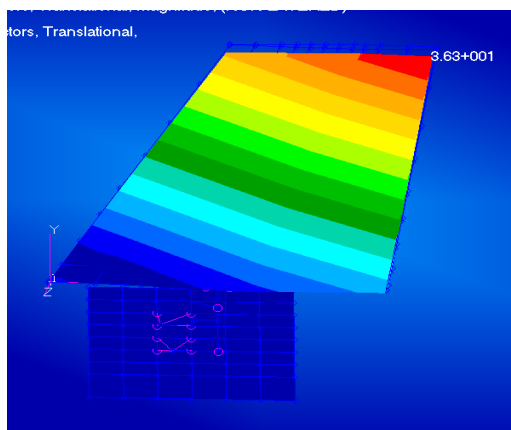


Fig.4 Modes of FEM with far hinge point.

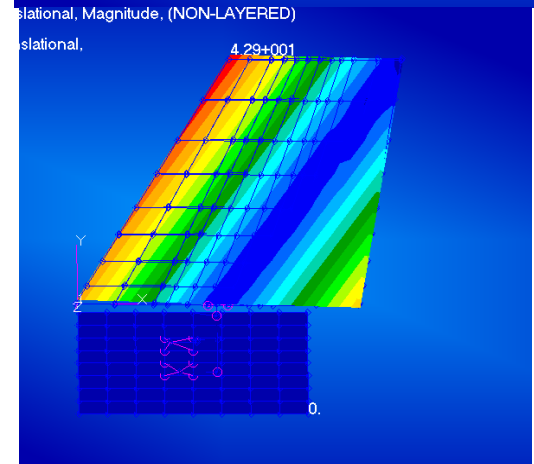
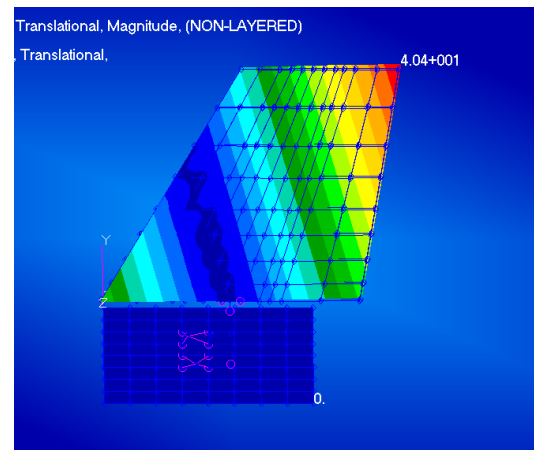


Fig.5 Modes of FEM with near hinge point.

### 3 Model manufacture

The design of the scaled model was presented in Fig.6 and manufacture of the model was shown in Fig.7. The ribbed material of the control surface was 5mm aeronautical laminates, the beam shape was a 2mm C type beam with

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material using glass steel; the C beam of the root rib shape was 2mm, the material was aluminum alloy; and the front edge and other parts were all glass steel. The beam element at the root of the control surface simulates the stiffness of the rudder shaft, and the torsion spring was used to simulate the torsional stiffness of the steering engine.

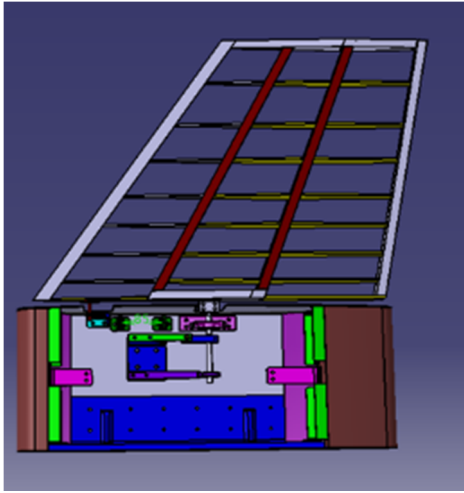


Fig.6 Design of the experimental model.



Fig.7 Manufacture of the experimental model.

Frequency experiment was finished by adopt a Siemens LMS Test.Lab system, as shown in Fig.8; the exciting force hammer used was produced by the Jiangsu Lianneng corporation in China, as shown in Fig.9; and the acceleration transducer used was ICP Piezoelectric acceleration transducer by PCB corporation. Experimental arrangement was shown in Fig.10. Experimental modes from LMS test system was shown in Fig.11 and Table 1. Different gap effects on GVT results was presented. It was seen that gap could influence GVT results of the present model.



Fig.8 Siemens LMS Test.lib system.



Fig.9 Exciting force hammer.

### 4 GVT experiments

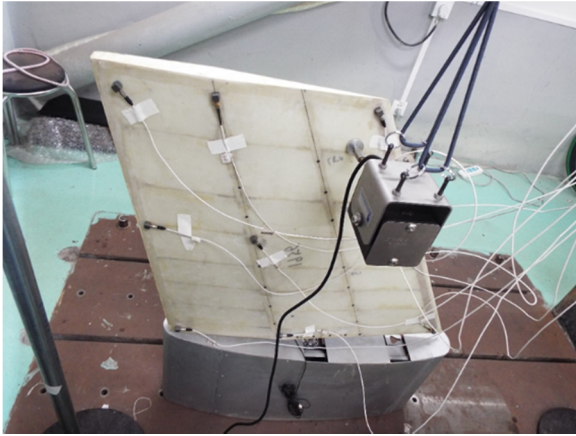


Fig.10 GVT experimental arrangement.

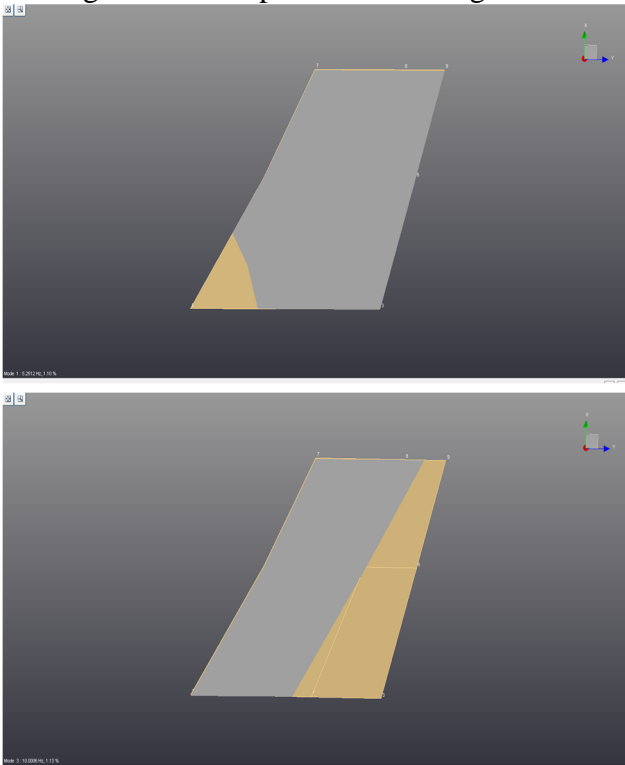


Fig.11 Modes from GVT experiments.

Table 1. GVT results with different gaps

Gap (mm)	Bending mode (Hz)	Torsion mode (Hz)
6.5	4.98	8.95
7.9	4.97	9.05

## 5 Wind tunnel tests

The experimental parameters were mainly chosen as: Mach numbers were 0.3. A half-model was chosen based on the parameters of subsonic wind tunnel in China, as shown in Fig.12. Flutter results can be found in rear table 2.



Fig.12 Wind tunnel arrangement.

## 6 Numerical simulations

### 6.1 Basic flutter computation

Basic computation of flutter of the present model was shown in Table 2. It was regret that the results were not fully managed until the deadline of the present paper.

Table 2 Flutter computation  
(a) Model with far hinge point

Bending (Hz)	Torsion (Hz)	Flutter velocity ( m/s )	Flutter frequency
4.23	8.33	55	5.7
4.37	8.40	47	6
5.42	9.34	30	7.8
5.90	10.45	28	9.2
6.11	11.38	28	10.2
6.21	12.05	28	11

(b) (b) Model with near hinge point

Bending (Hz)	Torsion (Hz)	Flutter velocity ( m/s )	Flutter frequency
6.04	8.62	15.5	8.14
6.04	10.08	19.8	9.46
6.04	11.04	21.2	10.2
6.05	11.64	24	10.9
6.05	12.02	24.5	11.22
6.04	8.62	15.5	8.14

### 6.2 Nonlinear computation

Numerical simulations of gap effects were solved with an effective method named fictitious mass



method [4]. Work flow of this method was shown in Fig.13 and the related symbol can be explained by Ref. [4].

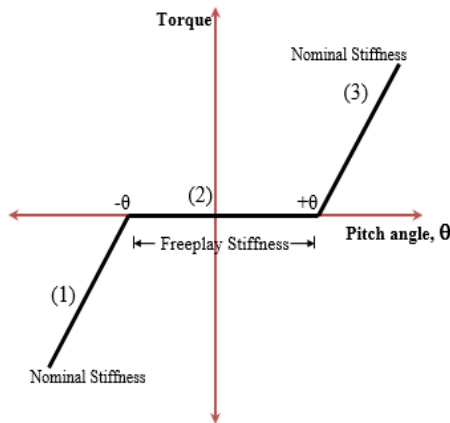
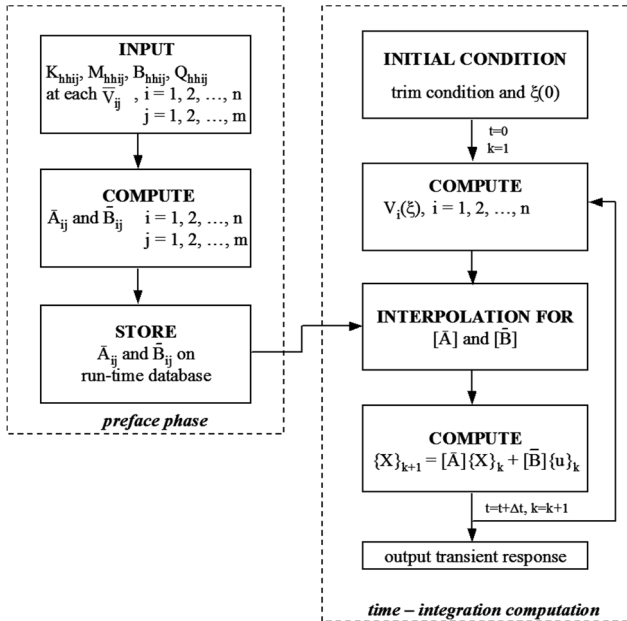


Fig13. Solution Procedure in ZAERO NLFLTR Module [4].

To simulate the wind tunnel turbulence, the configuration is subjected to a random gust. The computational results of the present wing was show in Fig.15.

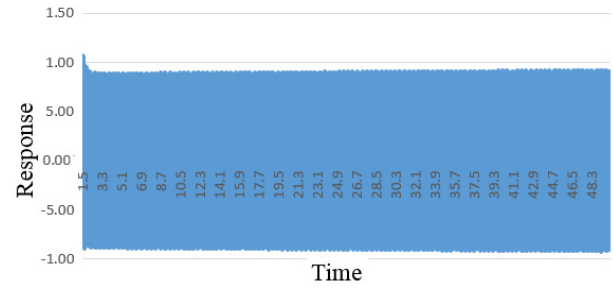


Fig.15 Time response.

## 7 Conclusion

The present work studied flutter characteristics of an all-moving control surface model with different gap arrangements which can bring nonlinearity effects. Both wind tunnel tests and numerical method were employed. Through the experimental phenomenon, a series of flutter characteristics were observed. Aeroelastic patterns can be analyzed with measurement and numerical simulations.

It was seen that gap effects can influence ground mode test results. Also the response against this effect should be evaluated.

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## References

- [1] Tang D, Kholodar D, Dowell EH. Nonlinear Response of Airfoil Section with ControlSurface Freeplay to Gust Loads. AIAA Journal, 2000, 38(9): 1543–1557.
- [2] Abbasi A A, Yin S, Qin Y, et al. Effect of Plasma Leading Edge Tubercles on Wing Performance. Aiaa Aerospace Sciences Meeting. 2018..
- [3] Beguet S, Perraud J, Forte M, et al. Modeling of Transverse Gaps Effects on Boundary-Layer Transition. Journal of Aircraft, 2016, 54(2):794-801.

- [4] Dong H L, Chen P C. Nonlinear Aeroelastic Studies on a Folding Wing Configuration with Free-Play Hinge Nonlinearity. Aiaa/asme/asce/ahs/asc Structures, Structural Dynamics, and Materials Conference, Aiaa/asme/ahs Adaptive Structures Conference. 2005.

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